Localisation précise par moyens spatiaux

Global GNSS Processing at CODE

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Outline

- **Introduction**
  - IGS: International GNSS Service
  - CODE – one of the global IGS analysis centers
  - Introducing some formats: RINEX, SP3, SINEX

- **Orbit Determination (at CODE)**

- **Code Biases: DCB, ISB, IFB**
Outline

- Introduction

- Orbit Determination (at CODE)
  - Development of the IGS tracking station network
  - Orbit quality as a function of the tracking network and observation modeling (reprocessing)
  - Length of an orbital arc in the GNSS processing
  - Methods for orbit validation
  - Handling of GPS repositioning events

- Code Biases: DCB, ISB, IFB
Outline

- Introduction

- Orbit Determination (at CODE)

- Code Biases: DCB, ISB, IFB
  - GNSS observation equation as starting point
  - Dependencies of components in the observation equation from GNSS, frequency and observation type and resulting biases
  - DCBs in a GPS, GLONASS, GPS/GLONASS network solution
  - How DCBs can be computed?
  - Bonus: GLONASS-GPS translation bias
IGS: Motivation

- Repeatability (north, east, up) when processing 90 days of GPS observations at Graz (Austria) and Onsala (Sweden) (1200 km baseline) with broadcast orbits
- Towards the end of the 1980ties it was recognized that the error of the broadcast orbit was the accuracy limiting factor.
- As orbit determination for a satellite system is not a trivial business which can be done on a case-by-case basis, this was the motivation for the creation of a scientific orbit determination service.
Rule of thumb by Baueršíma

\[
\frac{\Delta_{\text{Baseline}}}{\Delta_{\text{Orbit}}} \approx \frac{\text{Length of the baseline}}{\text{Height of the orbit}}
\]

with \( \text{Height of the orbit} \approx 25000\text{km} \)

Errors in baseline components due to orbit errors (Baueršíma, 1982)

<table>
<thead>
<tr>
<th>Orbit error</th>
<th>Baseline length</th>
<th>Baseline error</th>
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</thead>
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<tr>
<td>2.50 m</td>
<td>1 km</td>
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<td>0.002 ppm</td>
</tr>
<tr>
<td>0.05 m</td>
<td>1000 km</td>
<td>0.002 ppm</td>
</tr>
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</table>
**IGS: History and first steps**

**August 1989**, IAG Scientific Assembly in Edinburgh
first ideas to establish a service to support users with highest requirements in the GPS data processing

**February 1991** Call for Participation with more than 100 responses

**August 1991–March 1992** IGS Campaign Oversight Committee
planned a two weeks test campaign in Summer 1992

**21. June 1992** test campaign started activities never stopped again

**November 1992** activities named now “IGS Pilot Service”

**01. January 1994** IGS starts as an official service of the IAG
IGS: What does it mean?

- International GPS Service for Geodesy and Geodynamics
  January 1994

- International GPS Service
  May 1998

- International GNSS Service
  March 2005
IGS: Main components

- **GNSS–Stations of the IGS–Tracking Network**
  basis for IGS activities; contributions from many different organizations

- **Regional and Global Data Centers**
  provide the data to the users and analysis centers

- **Analysis Centers**
  compute the products from the data of the IGS–stations

- **Analysis Center Coordinator**
  combines the contributions from the analysis centers to IGS–products

- **Product Databases**
  provide the IGS products to the users

- **IGS Central Bureau**
  day-to-day management of the IGS

- **IGS Governing Board**
  policy guidance of the IGS

- **IGS Working groups**
  for many different topics
**IGS: Product lines**

**Final series** – ORB, ERP, CLK (300/30 sec. sampling), CRD
- available about two weeks after the end of the week
- GPS and GLONASS in compatible but independent series

**Rapid series** – ORB, ERP, CLK
- available at the day after the measurements, 17:00 UTC
- quality very close to the final products

**Ultra–rapid series** – ORB, ERP, (CLK, 300 sec. sampling)
- four updates per day, latency 3 hours
- contains 24 hours estimated and 24 hours predicted orbits
- GLONASS series on an experimental stage
**IGS: Orbit combination**

1. An unweighted mean orbit between the Analysis Centers is computed.
2. The standard deviation of each contribution to this mean orbit is computed to assign a weight to each Analysis Center.
3. The combined IGS orbit consists of the satellite positions computed as the weighted mean of the positions contributed by the Analysis Centers.
4. The mean errors and the transformation parameters of the individual solutions with respect to the IGS orbit are made available every week for each day of the (preceding) week.

**Combined IGS orbit**
IGS: Consistency of the final GPS orbits

Final Orbits (AC solutions compared to IGS Final)
IGS: Consistency of the final GPS orbits

Final Orbits (AC solutions compared to IGS Final)

Weighted RMS [mm]

Time [GPS weeks]
## IGS: Product quality

Quality of the IGS core products at end of 2011
(see http://acc.igs.org/erp/egu12-igu-erps.pdf)

<table>
<thead>
<tr>
<th>Series</th>
<th>Product Type</th>
<th>Accuracy</th>
<th></th>
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</thead>
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<tr>
<td>Ultra-Rapid</td>
<td>GNSS Orbits</td>
<td>GPS: 5 cm (1D)</td>
<td>GLONASS: 10 cm (1D)</td>
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<tr>
<td>(predicted)</td>
<td>GPS satellite clocks</td>
<td>RMS: 3 ns</td>
<td>SDev: 1.5 ns</td>
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<tr>
<td></td>
<td>EOPs</td>
<td>PM: 250 µas</td>
<td>dLOD: 50 µs</td>
</tr>
<tr>
<td>Ultra-Rapid</td>
<td>GNSS Orbits</td>
<td>GPS: 3 cm (1D)</td>
<td>GLONASS: 10 cm (1D)</td>
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<tr>
<td>(observed)</td>
<td>GPS satellite clocks</td>
<td>RMS: 150 ps</td>
<td>SDev: 50 ps</td>
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<tr>
<td></td>
<td>EOPs</td>
<td>PM: &lt;150 µas</td>
<td>dLOD: 10 µs</td>
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<td>GNSS Orbits</td>
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<td></td>
<td>GPS sat. &amp; rec. clocks</td>
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<td>SDev: 25 ps</td>
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<td>GLONASS: &lt;5 cm (1D)</td>
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<td></td>
<td>GPS sat. &amp; rec. clocks</td>
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<td></td>
<td>Terrestrial Frame</td>
<td>N&amp;E: 2 mm</td>
<td>U: 5 mm</td>
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CODE: What does it mean?

CODE, Center for Orbit Determination in Europe, is one of at present ten Analysis Centers of the IGS.

CODE is formed as a joint venture of
- the Astronomical Institute of the University of Bern (AIUB),
- the Swiss Federal Office of Topography (swisstopo),
- the Institut für Kartographie und Geodäsie (BKG), and
- the Institut für Astronomische und Physikalische Geodäsie of TU München (IAPG, TUM).
CODE: Analysis Center of the IGS

- CODE is located at the AIUB in Bern.
- Initially about 20, today about 250 stations are processed daily.
- All results are generated using the Bernese GNSS Software.
- CODE provides products for the final, rapid, and ultra-rapid IGS products. All of them (except clocks) are based on a fully combined GPS/GLONASS data analysis.
- CODE started with this approach in May 2003. Meanwhile also other analysis centers join this a strategy.
International exchange formats

Within the IGS lots of data, products and meta information need to be exchange:

- Meta data (equipment at the stations)
- Observations data and navigation data from the stations
- Orbit products
- Solutions with full covariance information
- Clock products
- Miscellaneous information: e.g., antenna phase center corrections

Format

- RINEX
- SP3c
- SINEX
- Clock RINEX
- ANTEX
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<table>
<thead>
<tr>
<th>Format</th>
<th>RINEX</th>
<th>SP3c</th>
<th>SINEX</th>
<th>Clock RINEX</th>
<th>ANTEX</th>
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</thead>
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International exchange formats
**RINEX: observations**

RINEX = Receiver INdependent EXchange format

GNSS observation data in text format, independent from any internal receiver/manufacturer format

Contains (among others):
- Meta information (GNSS: equipment, antenna phase center offsets)
- List of observation types

Maintained by RINEX working group of IGS and RTCM-SC 104 (Chair: K. MacLeod, NRCan)
### Header part

<table>
<thead>
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<th>Field</th>
<th>Value</th>
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### Data part

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<td>130144380.32603</td>
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</tr>
</tbody>
</table>

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*Note: The table continues with similar entries.*
### Meta information

- **station**
- **receiver**
- **antenna**
- **position**
- **observation types**

### Epoch

**List of satellites**

<table>
<thead>
<tr>
<th>G: GPS</th>
<th>R: GLONASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G: GPS</td>
<td>R: GLONASS</td>
</tr>
</tbody>
</table>

**Observation record per satellite**

(Empty field: no obs.)
RINEX: observations

RINEX = Receiver INdependent EXchange format

Deficiencies of the currently used RINEX 2 format:

- For all satellites of all GNSS the full list of observations is expected. (if, e.g., Galileo is added much more empty fields in GPS and GLONASS fill appear)
- Not all necessary tracking information can be provided. (How the code on the 2nd frequency for GPS has really been constructed?)

A new format for multi-GNSS purposes has been developed: RINEX 3.
### Header part

<table>
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<th>Field</th>
<th>Value</th>
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<td>RINEX: observations</td>
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<td>RINEX VERSION / TYPE</td>
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<td>MARKER TYPE</td>
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<td>AGNES SWISSTOPO</td>
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<td>REC # / TYPE / VERS</td>
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### Data part

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</tr>
</tbody>
</table>
Observation records
- one line per satellite
- observation types are GNSS-specific
RINEX: navigations

RINEX = Receiver INdependent EXchange format

GNSS navigation data in text format, independent from any internal receiver/manufacturer format

Contains:
- GPS broadcast ephemerides
- GLONASS broadcast records

Maintained by RINEX working group of IGS and RTCM-SC 104 (Chair: K. MacLeod, NRCan)
**SP3c: orbit products**

- Positions (and velocities) for a list of satellites in a given sampling
- Given in the Earth fixed frame
- IGS provides positions of the GNSS satellites every 15 minutes
- Additional information:
  - Satellite clock corrections
  - Accuracy information
- Maintained by S. Hilla, NGS in cooperation with the services
## SP3c: orbit products

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<th>Precision</th>
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</table>
**Definitions and sampling**

**List of satellites**

**Four comment lines**

**Epoch**

**Satellites**

G: GPS / R: GLONASS

**Satellite positions (km)**

**Satellite clock corrections (μs)**
**SINEX: solutions**

**SINEX = Solution INdependent EXchange format**

Software- and technique independent

Contains:
- List of stations (Abbreviation, full name, description)
- Meta information (GNSS: equipment, antenna phase center offsets)
- List of parameters (description, time interval)
- Different options to deliver the solution
  - normal equation, observation vector, apriori values
  - solution vector, solution covariance matrix, apriori constraints

Maintained by IERS working group (Chair: D. Thaller, AIUB)
Outline

- Introduction

- Orbit Determination (at CODE)
  - Development of the IGS tracking station network
  - Orbit quality as a function of the tracking network and observation modeling (reprocessing)
  - Length of an orbital arc in the GNSS processing
  - Methods for orbit validation
  - Handling of GPS repositioning events

- Code Biases: DCB, ISB, IFB
Number of active GPS satellites

Statistics from Fritzsche et al. (2012)
Number of active GPS satellites

Statistics from Fritzsche et al. (2012)
Number of active GLONASS satellites

Statistics from Fritzsche et al. (2012)

Start of processing GLONASS data within the project
Number of active GNSS satellites

Statistics from Fritzsche et al. (2012)
Number of active IGS tracking stations

Statistics from May 2011
Distribution of active IGS tracking stations

January 1994

Statistics from May 2011
Distribution of active IGS tracking stations

Statistics from May 2011

January 1995

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 1996

Statistics from May 2011

GPS–only
GPS+GLONASS
Distribution of active IGS tracking stations

January 1997

Statistics from May 2011

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

Statistics from May 2011

January 1998

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 1999

Statistics from May 2011
Distribution of active IGS tracking stations

January 2000

Statistics from May 2011
Distribution of active IGS tracking stations

January 2001

Statistics from May 2011
Distribution of active IGS tracking stations

January 2002

Statistics from May 2011

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 2003

Statistics from May 2011
Distribution of active IGS tracking stations

January 2004

Statistics from May 2011

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 2005

Statistics from May 2011
Distribution of active IGS tracking stations

January 2006

Statistics from May 2011

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 2007

Statistics from May 2011
Distribution of active IGS tracking stations

Statistics from May 2011

January 2008

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 2010

Statistics from May 2011

GPS-only
GPS+GLONASS
Distribution of active IGS tracking stations

January 2011

Statistics from May 2011

GPS-only

GPS+GLONASS
The tracking network of the IGS consists of 370 (out of 440)\(^1\) active stations contributed by many organizations on a voluntary basis.

The continuous densification of the IGS network allowed an impressive improvement of the quality of the IGS orbits and other products.

Currently the IGS network is in a transition phase from a GPS-only to a combined GPS/GLONASS(/Galileo/…) tracking network. In this context two contradictory requirements need to be balanced:

- to have quickly as many new receivers/antennas in place as possible as
- to keep an installed antenna as long as possible without any changes to support a good long-term stability for reference frame establishment.

Nevertheless, we have to notice that many of these stations primary serve other goals than been an IGS station. The maintenance of such a network is difficult and the data have to be used with care.

\(^1\)Status: 27. August 2012
Coordinate time series for Ankara

Operational series from CODE, weekly solutions
Coordinate time series for Ankara

Operational series from CODE, weekly solutions
# Coordinate time series for Ankara

<table>
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Operational series from CODE, weekly solutions
Coordinate time series for Reykjavik

Operational series from CODE, weekly solutions
Coordinate time series for Reykjavik

Operational series from CODE, weekly solutions
Coordinate time series for Reykjavik

Operational series from CODE, weekly solutions
Coordinate time series for Reykjavik

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Reprocessing

Reprocessing of the IGS series by CODE was performed at
Institut für Astronomische und Physikalische Geodäsie
Technische Universität München

Time interval: 1996-2010

Includes GPS and GLONASS since May 2003

Statistics: 392 Stations
           5,753 Daily solutions
           1,278,571 Observation files
           4,190,689,049 Original observations
           63,066,190 Parameters
           ≈5 years CPU-time
## Reprocessing

<table>
<thead>
<tr>
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<tbody>
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Reprocessing

Parameters types

- Station coordinates: 50%
- Site-specific troposphere parameters: 27%
- Scaling factor for APL model: 5%
- Orbital elements: 5%
- Stochastic orbit parameters: 5%
- Earth rotation parameters: 5%
- Geocenter coordinates: 5%
- Satellite antenna offset parameters: 5%
- Satellite antenna pattern: 5%
- Scaling factor for higher-order ionosphere: 5%
- Ambiguity parameters: 5%
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Reduction due to the different boundaries for the piece-wise linear representation
## Reprocessing

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*Ecole d'Été 2012*
Coordinate time series for Zimmerwald

Operational series from CODE, weekly solutions
Coordinate time series for Zimmerwald

Reprocessed series from CODE, weekly solutions
Coordinate time series for Ankara

Reprocessed series from CODE, weekly solutions
Coordinate time series for Ankara

Reprocessed series from CODE, weekly solutions
Coordinate time series for Reykjavik

Reprocessed series from CODE, weekly solutions
Coordinate time series for Reykjavik

Reprocessed series from CODE, weekly solutions
A certain set of parameters need to be estimated in a GNSS-data analysis independent from the real purpose of the solution:

- Mandatory:
  - station coordinates, troposphere parameters (25%), ambiguities (50%)
- Optional for GNSS orbit determination:
  - GNSS orbit and Earth rotation parameters, geocenter coordinates

GNSS-derived times series (e.g., station coordinates) reflect:
1. data analysis model and their changes, reference frame updates,
2. equipment changes (antennas, receivers or even firmware), and
3. real geophysical events or processes.

A consistent reprocessing of the complete GNSS time series helps to eliminate (1st group) or reduce (2nd group) the influence from the GNSS data processing on the resulting time series.

We have looked at station coordinate series so far. What about the orbits?
Better orbit due to reprocessing

GLONASS satellites (oper.)

Operational/reprocessed series from CODE
Better orbit due to reprocessing

Operational/reprocessed series from CODE
Number of GLONASS tracking stations

Operational/reprocessed series from CODE
Better orbit due to reprocessing

GPS satellites (oper.)

Operational/reprocessed series from CODE
Better orbit due to reprocessing

Operational/reprocessed series from CODE
CODE processing changes in 2011

Operational series from CODE
A successful ambiguity resolution is absolutely needed for a precise GNSS orbit determination.

Operational series from CODE
IGS-MGEX campaign

IGS-MGEX: IGS Multi-GNSS Experiment

- August 2011: Call for Participation:
  This Call for Participation for the IGS Multi-GNSS Experiment – IGS-MGEX – recognizes the availability of new additional GNSS signals and new constellations on the horizon. The IGS is preparing for this next phase in the evolution of the IGS to eventually generate products for all GNSS available.
- October 2011: Proposal deadline
- December 2011/January 2012: Evaluation of the proposals by the IGS’ GNSS working group
- IGS-MGEX runs from 01-February until 31-August 2012 extended to the end of 2013
- First results have been presented at the IGS workshop in Olsztyn, Poland (end of July 2012).
CODE has contributed a **triple-GNSS solution** (the only?):

GPS+GLONASS+Galileo

(Presented at the IGS workshop by Dr. Lars Prange)

- The solution has been derived from the IGS rapid procedure at CODE considering in addition available Galileo-tracking data (insufficient COMPASS and QZSS tracking data in May 2012).

- Technical details (for completeness):
  - Specific cluster containing all Galileo data has been processed to consider all correlations for the Galileo measurements in a optimal way.
  - No ambiguity resolution for Galileo observations has been done so far.
  - Orbit solutions for four weeks have been presented at the IGS workshop.

- A lot of data format problems have been sorted out together with IGS database and station managers before the IGS MGEX data could be processed.
Number and distribution of tracking stations contributing to the CODE-MGEX solution

Number of stations:
- GPS: 147
- GLONASS: 120
- Galileo: 35

Observations per sat. and day:
- GPS: 20,000-24,000
- GLONASS: 16,000-19,000
- Galileo: 1,000-3,500
Number of stations that could theoretically track the satellites of the Galileo constellation; sampling 15 min; DOY 150

=> only parts of a daily orbit arc are covered with observations
CODE-MGEX: „trackability“

Number of stations that could theoretically track the satellites of the Galileo constellation; sampling 15 min; DOY 151

=> Optimal observation scenario (many European stations)
Number of stations that could theoretically track the satellites of the Galileo constellation; sampling 15 min; DOY 152
Multi-day arcs

Advantage of the „Extracted orbit for day n“ with respect to the direct „Orbit solution day n“:

- no (or at least less) degradation of the orbit at the end of the boundary.
- smoothed day boundary discontinuities (in particular if the satellite was only weakly observed)
CODE-MGEX: „trackability“

Number of stations that could theoretically track the satellites of the **Galileo** constellation; sampling 15 min; **DOYs 150-152**

=> long-arc: several passes over reasonable number of stations
Methods for orbit validation

1. Orbit overlaps

Orbit solution day n-1  Orbit solution day n  Orbit solution day n+1
CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 1 day arcs
(mean: G01: 7.6 cm; R24: 10.1 cm; Galileo: 90 – 220 cm)
CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 3 day arcs (last; RAPID-mode)

(mean: G01: 5.2 cm; R24: 5.3 cm; Galileo: 25 – 46 cm)
**CODE-MGEX solution: orbit overlaps**

GPS, GLONASS, Galileo: 3 day arcs (mid)

(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8.5 – 17 cm)
CODE-MGEX solution: orbit overlaps

GPS, GLONASS, Galileo: 5 day arcs (mid)

(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8 – 14 cm)
**CODE-MGEX solution: orbit overlaps**

GPS, GLONASS, Galileo: 5 day arcs (mid)

(mean: G01: 3.5 cm; R24: 3.5 cm; Galileo: 8 – 14 cm)
**Orbit overlaps for multi-day arcs**

Disadvantage of the „Extracted orbit for day n“ with respect to the direct „Orbit solution day n“:

- The orbits extracted from the three-day arc are not independent anymore.
- Day boundary discontinuities cannot be used as a real quality indicator anymore.
Methods for orbit validation

1. Orbit overlaps

   Orbit solution day n-1  Orbit solution day n  Orbit solution day n+1

2. Fitting long-arcs

   Orbit solution day n-1  Orbit solution day n  Orbit solution day n+1
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 1 day arcs
(mean: G01: 1.5 cm; R24: 2.4 cm; Galileo: 25 – 42 cm)
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 3 day arcs (last; RAPID-mode)

(mean: G01: 1.2 cm; R24: 1.8 cm; Galileo: 4.8 – 10.4 cm)
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 3 day arcs (mid)
(mean: G01: 1.0 cm; R24: 1.6 cm; Galileo: 2.7 – 5.1 cm)
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 5 day arcs (mid)

(mean: G01: 0.9 cm; R24: 1.5 cm; Galileo: 2.0 – 3.4 cm)
CODE-MGEX solution: 3-day orbit fit

GPS, GLONASS, Galileo: 5 day arcs (mid)
(mean: G01: 0.9 cm; R24: 1.5 cm; Galileo: 2.0 – 3.4 cm)
Disadvantage of the "Extracted orbit for day n" with respect to the direct "Orbit solution day n":

- The orbits extracted from the three-day arc are not independent anymore.
- An orbit fit over several days cannot be used as a real quality indicator anymore.
Methods for orbit validation

1. Orbit overlaps

   Orbit solution day n-1  Orbit solution day n  Orbit solution day n+1

2. Fitting long-arcs

   Orbit solution day n-1  Orbit solution day n  Orbit solution day n+1

3. Comparison with independent measurements (e.g., SLR)
   - Consistency of the station coordinates between GNSS and SLR is required.
   - Biases of both techniques need to be known.
   - In case of problems an identification must be implemented to define which technique has caused the problem.
CODE-MGEX solution: SLR residuals

Galileo, arclength 1 day

(bias: -5.4 cm; standard deviation: 20.0 cm)
CODE-MGEX solution: SLR residuals

Galileo, last day of 3-day long-arc (RAPID-mode)
(bias: -5.0 cm; standard deviation: 6.4 cm)
CODE-MGEX solution: SLR residuals

Galileo, mid day of 3-day long-arc
(bias: -5.0 cm; standard deviation: 5.8 cm)
Code-MGEX solution: SLR residuals

Galileo, mid day of 5-day long-arc

(bias: -5.4 cm; standard deviation: 7.9 cm)
CODE-MGEX solution: SLR residuals

Comparison of satellite systems

(GPS / GLO / GAL: bias: -3.1 / -2.5 / -5.0 cm; STD: 2.5 / 2.5 / 5.8 cm)
Length of orbital arcs

GNSS data are typically provided in observation files of one day. A one-day orbit solution is, therefore, native.

Why longer orbital arcs?

- With longer satellite arcs deficiencies in the tracking network can be compensated. The solution becomes more robust for poorly observed satellites.
- The orbit model must be good enough to represent the satellite trajectory during the longer satellite arc.

Why not longer orbital arcs?

- The consecutive days are not independent anymore.
  - need to be considered when validating the orbits
  - problems in the analysis from one day may degrade also the orbits from other days.
  - the measurements are used more than once.
**Length of orbital arcs**

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.

An orbit arc is affected by poorly determined ambiguities at its boundaries.

This can be compensated

- extracting the orbit for day \( n \) from a long arc over three (or more) days.
- increase the length of the processing batch.
**Length of orbital arcs**

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.

An orbit arc is affected by poorly determined ambiguities at its boundaries.

This can be compensated

- extracting the orbit for day $n$ from a long arc over three (or more) days.
- increase the length of the processing batch.
Length of orbital arcs

The receiver are continuously measuring but the ambiguities from one satellite pass are artificially cut due to processing batches.

An orbit arc is affected by poorly determined ambiguities at its boundaries.

This can be compensated

- extracting the orbit for day \( n \) from a long arc over three (or more) days.
  - Each observation is used exact three times.
  - Can easily be generated on normal equation level.
    (each observation needs only be processed once)

- increase the length of the processing batch.
  - Orbital arcs are shorter – less smoothing.
  - Observation files need to be re-organized (from daily files).
  - The processing for each arc starts from the original observation what increases the processing load.
CODE determines the repositioning events for the GPS satellites.

- Two independent satellite arcs are assumed (before and after the event)
- The smallest distance between both arcs gives the epoch and magnitude of the event.
GPS satellite repositioning events

As computed by CODE
GPS satellite repositioning events

As computed by CODE
GPS satellite repositioning events

As computed by CODE
Outline

- Introduction

- Orbit Determination (at CODE)

- Code Biases: DCB, ISB, IFB
  - GNSS observation equation as starting point
  - Dependencies of components in the observation equation from GNSS, frequency and observation type and resulting biases
  - DCBs in a GPS, GLONASS, GPS/GLONASS network solution
  - How DCBs can be computed?
  - Bonus: GLONASS-GPS translation bias
**GNSS observation equation**

\[
P_i^k = \left| \left( \overrightarrow{x}^k + \overrightarrow{\Delta x}^k \right) - \left( \overrightarrow{x}_i + \overrightarrow{\Delta x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
L_i^k = \left| \left( \overrightarrow{x}^k + \overrightarrow{\Delta x}^k \right) - \left( \overrightarrow{x}_i + \overrightarrow{\Delta x}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
\quad + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k
\]
**GNSS observation equation**

\[
P_i^k = \left| \left( \mathbf{x}^k + \Delta \mathbf{x}^k \right) - \left( \mathbf{x}_i + \Delta \mathbf{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \\
L_i^k = \left| \left( \mathbf{x}^k + \Delta \mathbf{x}^k \right) - \left( \mathbf{x}_i + \Delta \mathbf{x}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \\
+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k
\]

\(\mathbf{x}^k\) position vector of satellite \(k\) related to its center of mass
**GNSS observation equation**

\[
P_i^k = \left[ (\vec{x}^k + \Delta \vec{x}^k) - (\vec{x}_i + \Delta \vec{x}_i) \right] + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k) \\
L_i^k = \left[ (\vec{x}^k + \Delta \vec{x}^k) - (\vec{x}_i + \Delta \vec{x}_i) \right] + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k) \\
\quad + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k
\]

- \(\vec{x}^k\): position vector of satellite \(k\) related to its center of mass
- \(\Delta \vec{x}^k, \Delta \vec{x}^k\): vector from the center of mass of the satellite \(k\) to the antenna signal emission point for code and phase observations
**GNSS observation equation**

\[
P_i^k = |(\overrightarrow{x^k} + \Delta\overrightarrow{x^k}) - (\overrightarrow{x_i} + \Delta\overrightarrow{x_i})| + T_i^k + I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \\
L_i^k = |(\overrightarrow{x^k} + \Delta\overrightarrow{\chi^k}) - (\overrightarrow{x_i} + \Delta\overrightarrow{\chi_i})| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \\
+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta\varphi_i^k
\]

- \(\overrightarrow{x^k}\) position vector of satellite \(k\) related to its center of mass
- \(\Delta\overrightarrow{x^k}, \Delta\overrightarrow{\chi^k}\) vector from the center of mass of the satellite \(k\) to the antenna signal emission point for code and phase observations
- \(\delta^k\) clock correction of the satellite \(k\) with respect to GPS time
**GNSS observation equation**

\[
P_i^k = \left| \left( \overrightarrow{x^k} + \Delta \overrightarrow{x^k} \right) - \left( \overrightarrow{x_i} + \Delta \overrightarrow{x_i} \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
L_i^k = \left| \left( \overrightarrow{x^k} + \Delta \overrightarrow{\chi^k} \right) - \left( \overrightarrow{x_i} + \Delta \overrightarrow{\chi_i} \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]  
\[+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

- \(\overrightarrow{x^k}\) position vector of satellite \(k\) related to its center of mass
- \(\Delta \overrightarrow{x^k}, \Delta \overrightarrow{\chi^k}\) vector from the center of mass of the satellite \(k\) to the antenna signal emission point for code and phase observations
- \(\delta^k\) clock correction of the satellite \(k\) with respect to GPS time
- \(\alpha^k, \alpha^k\) hardware delay in the satellite \(k\) for code and phase measurements
GNSS observation equation

\[
P_i^k = \left| \left( \overrightarrow{x}^k + \Delta \overrightarrow{x}^k \right) - \left( \overrightarrow{x}_i + \Delta \overrightarrow{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[
L_i^k = \left| \left( \overrightarrow{x}^k + \Delta \overrightarrow{\chi}^k \right) - \left( \overrightarrow{x}_i + \Delta \overrightarrow{\chi}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k\]

\[
I_i^k \quad \text{signal delay in the ionosphere}
\]

\[
T_i^k \quad \text{signal delay in the troposphere}
\]
\[ p^k_i = \left| \left( \hat{x}^k + \Delta x^k \right) - \left( \bar{x}_i + \Delta \bar{x}_i \right) \right| + T^k_i + I^k_i + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ L^k_i = \left| \left( \hat{x}^k + \Delta \chi^k \right) - \left( \bar{x}_i + \Delta \chi_i \right) \right| + T^k_i - I^k_i + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]
\[ p^k_i + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]

- \( I^k_i \): signal delay in the ionosphere
- \( T^k_i \): signal delay in the troposphere
GNSS observation equation

\[ P_i^k = \left| \left( \bar{x}^k + \Delta x^k \right) - \left( \bar{x}_i + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \bar{x}^k + \Delta \chi^k \right) - \left( \bar{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]
GNSS observation equation

\[ p_i^k = \left| \left( \overrightarrow{x^k} + \Delta \overrightarrow{x^k} \right) - \left( \overrightarrow{x_i} + \Delta \overrightarrow{x_i} \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ l_i^k = \left| \left( \overrightarrow{x^k} + \Delta \overrightarrow{x^k} \right) - \left( \overrightarrow{x_i} + \Delta \overrightarrow{x_i} \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]
GNSS observation equation

\[
P_i^k = \left| \left( \vec{x}^k + \Delta \vec{x}^k \right) - \left( \vec{x}_i + \Delta \vec{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
L_i^k = \left| \left( \vec{x}^k + \Delta \vec{\chi}^k \right) - \left( \vec{x}_i + \Delta \vec{\chi}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k\]

\[a_i, \alpha_i\] hardware delay in the receiver at the station \(i\) for code and phase measurements
\[ P_i^k = \left| \left( \vec{x}^k + \Delta \vec{x}^k \right) - \left( \vec{x}_i + \Delta \vec{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ L_i^k = \left| \left( \vec{x}^k + \Delta \vec{\chi}^k \right) - \left( \vec{x}_i + \Delta \vec{\chi}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

\( a_i, a_i \)  

hardware delay in the receiver at the station \( i \) for code and phase measurements

\( \delta_i \)  

clock correction of the receiver at the station \( i \) with respect to GPS time
GNSS observation equation

\[ P_i^k = \left| \left( \overrightarrow{x_i^k} + \Delta x_i^k \right) - \left( \overrightarrow{x_i} + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \overrightarrow{x_i^k} + \Delta \chi_i^k \right) - \left( \overrightarrow{x_i} + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k

\[ \overrightarrow{x_i} \]

\[ a_i, \alpha_i \]

hardware delay in the receiver at the station \( i \) for code and phase measurements

\[ \delta_i \]

clock correction of the receiver at the station \( i \) with respect to GPS time

\[ \overrightarrow{x_i} \]

position vector of marker at station \( i \)
**GNSS observation equation**

\[
P_i^k = \left| \left( \hat{x}^k + \Delta x^k \right) - (\hat{x}_i + \Delta x_i) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[
L_i^k = \left| \left( \hat{x}^k + \Delta \chi^k \right) - (\hat{x}_i + \Delta \chi_i) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[\lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k\]

- \(a_i, \alpha_i\) hardware delay in the receiver at the station \(i\) for code and phase measurements
- \(\delta_i\) clock correction of the receiver at the station \(i\) with respect to GPS time
- \(\hat{x}_i\) position vector of marker at station \(i\)
- \(\Delta x_i, \Delta \chi_i\) vector from the marker of the station \(i\) to the antenna signal reception point for code and phase observations
GNSS observation equation

\[ p_i^k = \left| \left( \bar{x}^k + \Delta x^k \right) - \left( \bar{x}_i^k + \Delta \bar{x}_i^k \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta_i^k + \alpha_i^k) \]

\[ l_i^k = \left| \left( \bar{x}^k + \Delta \bar{x}^k \right) - \left( \bar{x}_i^k + \Delta \bar{x}_i^k \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i^k + \alpha_i^k) - c \cdot (\delta_i^k + \alpha_i^k) \]

\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]
**GNSS observation equation**

\[
P_i^k = \left| \left( \vec{x}^k + \Delta \vec{x}^k \right) - \left( \vec{x}_i + \Delta \vec{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
L_i^k = \left| \left( \vec{x}^k + \Delta \chi^k \right) - \left( \vec{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k
\]

phase ambiguity (one and the same for one pass)
$$p_i^k = \left| \left( \overrightarrow{x_i^k + \Delta x_i^k} - \overrightarrow{x_i + \Delta x_i} \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k)$$

$$l_i^k = \left| \left( \overrightarrow{x_i^k + \Delta x_i^k} - \overrightarrow{x_i + \Delta x_i} \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k$$

- $N_i^k$: phase ambiguity (one and the same for one pass)
- $\Delta \varphi_i^k$: initial phase shift between the oscillators at station $i$ and satellite $k$
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GNSS observation equation

\[ P_i^k = \left| \left( \mathbf{x}_i^k + \Delta \mathbf{x}_i^k \right) - \left( \mathbf{x}_i + \Delta \mathbf{x}_i \right) \right| + T_i^k + L_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \mathbf{x}_i^k + \Delta \chi_i^k \right) - \left( \mathbf{x}_i + \Delta \chi_i \right) \right| + T_i^k - L_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]

\( P_i^k, L_i^k \) code/phase observation of station \( i \) to satellite \( k \)

\( \mathbf{x}_i^k, \mathbf{x}_i \) position vector of station \( i \) and satellite \( k \), respectively

\( \Delta \mathbf{x}_i^k, \Delta \mathbf{x}_i \) vector from the center of mass of the satellite \( k \) to the antenna signal emission point for code and phase observations

\( \Delta \mathbf{x}_i, \Delta \chi_i \) vector from the marker of the station \( i \) to the antenna signal reception point for code and phase observations

\( T_i^k, L_i^k \) signal delay in the troposphere and ionosphere

**Warning:**

There are many further terms like multi-path, relativistic corrections, etc. that are not relevant in this context. They will be introduced tomorrow.

\( c \) speed of light

\( N_i^k \) phase ambiguity (one and the same for one pass)

\( \Delta \varphi_i^k \) initial phase shift between the oscillators at station \( i \) and satellite \( k \)

\( \lambda^k \) wavelength of the carrier phase (satellite \( k \))
Dependency of the terms

\[ P_i^k = \left| \left( \hat{x}_i^k + \Delta x_i^k \right) - \left( \hat{x}_i + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k) \]

\[ L_i^k = \left| \left( \hat{x}_i^k + \Delta \chi_i^k \right) - \left( \hat{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
Dependency of the terms

\[ P_i^k = \left| \left( \vec{x}^k + \Delta \vec{x}^k \right) - \left( \vec{x}_i + \Delta \vec{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \vec{x}^k + \Delta \vec{\chi}^k \right) - \left( \vec{x}_i + \Delta \vec{\chi}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
- **Code**: \( \Delta \vec{x}_i \)
- **Phase**: \( \Delta \vec{\chi}_i \)
Dependency of the terms

The following parameters depend on:

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \Delta x_i \), \( a_i \)
  - Phase: \( \Delta \chi_i \), \( a_i \)
Dependency of the terms

\[ P_i^k = \left| (\overrightarrow{x_i^k} + \Delta x_i^k) - (\overrightarrow{x_i} + \Delta x_i) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ L_i^k = \left| (\overrightarrow{x_i^k} + \Delta \chi_i^k) - (\overrightarrow{x_i} + \Delta \chi_i) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]
\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \Delta x_i \) \( a_i \) \( \delta^k \)
  - Phase: \( \Delta \chi_i \) \( \alpha_i \) \( \delta^k \)
Dependency of the terms

\[ p_i^k = \left| \left( x_i^k + \Delta x_i^k \right) - \left( \overrightarrow{x}_i + \overrightarrow{\Delta x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

\[ l_i^k = \left| \left( x_i^k + \Delta x_i^k \right) - \left( \overrightarrow{x}_i + \overrightarrow{\Delta x}_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k \]

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  
  **Code**: \[\Delta x_i\] \[\alpha_i\] \[\delta^k\]  
  **Phase**: \[\Delta \chi_i\] \[\alpha_i\] \[\delta^k\]  
  ISB: Inter-system bias
Dependency of the terms

\[ P_i^k = \left| \left( \overrightarrow{x}_i^k + \Delta x_i^k \right) - \left( \overrightarrow{x}_i + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \overrightarrow{x}_i^k + \Delta \chi_i^k \right) - \left( \overrightarrow{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \overrightarrow{\Delta x}_i \), \( a_i \), \( \delta^k \)
  - Phase: \( \overrightarrow{\Delta \chi}_i \), \( a_i \), \( \delta^k \)
  - ISB: Inter-system bias

- **Frequency**: (\( f_1 \) or \( f_2 \) or \( f_n \) for GLONASS or ...)

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The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  
  **Code:** \(\Delta \chi_i\) \(a_i\) \(\delta^k\)  
  **Phase:** \(\Delta \chi_i\) \(a_i\) \(\delta^k\)  
  ISB: Inter-system bias

- **Frequency**: (f₁ or f₂ or fₙ for GLONASS or ...)
  
  **Code:** \(\Delta \chi^k\) \(\Delta \chi_i\)  
  **Phase:** \(\Delta \chi^k\) \(\Delta \chi_i\)
Dependency of the terms

\[ P_i^k = \left| \left( \hat{x}^k + \Delta x_i^k \right) - \left( \hat{x}_i + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ L_i^k = \left| \left( \hat{x}^k + \Delta \chi_i^k \right) - \left( \hat{\chi}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

The following parameters depend on

- **GNSS:** (GPS or GLONASS or ...)
  
  Code: \( \Delta x_i \quad \alpha_i \quad \delta^k \)
  
  Phase: \( \Delta \chi_i \quad \alpha_i \quad \delta^k \)

- **Frequency:** (f_1 or f_2 or f_n for GLONASS or ...)
  
  Code: \( \Delta x_i^k \quad \Delta x_i \quad \alpha_i \quad a^k \)

  Phase: \( \Delta \chi_i^k \quad \Delta \chi_i \quad \alpha_i \quad a^k \)

ISB: Inter-system bias
**Dependency of the terms**

\[
P_i^k = \left| \left( \hat{x}_i^k + \Delta x_i^k \right) - \left( \hat{x}_i + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[
L_i^k = \left| \left( \hat{x}_i^k + \Delta \chi_i^k \right) - \left( \hat{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[
+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \varphi_i^k
\]

The following parameters depend on:

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \Delta x_i \quad a_i \quad \delta^k \)  
  - Phase: \( \Delta \chi_i \quad a_i \quad \delta^k \)  
  - ISB: Inter-system bias

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  - Code: \( \Delta x^k \quad \Delta x_i \quad a_i \quad a^k \)  
  - Phase: \( \Delta \chi^k \quad \Delta \chi_i \quad a_i \quad \alpha^k \)  
  - \( I_i^k \)
Dependency of the terms

\[
P_i^k = \left| \left( \mathbf{x}_i^k + \Delta \mathbf{x}_i^k \right) - \left( \mathbf{x}_i + \Delta \mathbf{x}_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k)
\]

\[
L_i^k = \left| \left( \mathbf{x}_i^k + \Delta \chi_i^k \right) - \left( \mathbf{x}_i + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k)
\]

+ \lambda_i^k \cdot N_i^k + \lambda_i^k \cdot \Delta \phi_i^k

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \Delta x_i \)
  - Phase: \( \Delta \chi_i \)
  - Code: \( a_i \)
  - Phase: \( \alpha_i \)
  - ISB: Inter-system bias

- **Frequency**: (f₁ or f₂ or fₙ for GLONASS or ...)
  - Code: \( \Delta x_i^k \)
  - Phase: \( \Delta \chi_i^k \)
  - Code: \( a_i \)
  - Phase: \( \alpha_i \)
  - IFB: Inter-frequency bias


**Dependency of the terms**

\[ P_i^k = \left| \left( \overrightarrow{x^k} + \Delta x^k \right) - \left( \overrightarrow{x_i} + \Delta x_i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ L_i^k = \left| \left( \overrightarrow{x^k} + \Delta \chi^k \right) - \left( \overrightarrow{x_i} + \Delta \chi_i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]

\[ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

The following parameters depend on:

- **GNSS**: (GPS or GLONASS or ...)
  
  - **Code**: \( \overrightarrow{\Delta x_i} \)
  
  - **Phase**: \( \Delta \chi_i \)

  - \( a_i \)
  
  - \( \delta^k \)  

    - ISB: Inter-system bias

- **Frequency**: (\( f_1 \) or \( f_2 \) or \( f_n \) for GLONASS or ...)

  - **Code**: \( \overrightarrow{\Delta x^k} \)
  
  - **Phase**: \( \Delta \chi^k \)

  - \( a_i \)
  
  - \( a^k \)

  - \( \delta^k \)

    - IFB: Inter-frequency bias

- **Signal type**: (C1P/C or C2P/C or ...)
Dependency of the terms

\[ P^k_i = \left| \overrightarrow{\Delta x^k_i} - \overrightarrow{x^k_i} \right| + T^k_i + I^k_i + c \cdot (\delta^k_i + a^k_i) - c \cdot (\delta^k + a^k) \]

\[ L^k_i = \left| \overrightarrow{\Delta \chi^k_i} - \overrightarrow{\Delta \chi_i} \right| + T^k_i - I^k_i + c \cdot (\delta^k_i + a^k_i) - c \cdot (\delta^k + a^k) \]

\[ + \lambda^k \cdot N^k_i + \lambda^k \cdot \Delta \phi^k_i \]

The following parameters depend on:

- **GNSS**: (GPS or GLONASS or ...)
  - **Code**: \( \overrightarrow{\Delta x^k_i} \) \( a^k_i \) \( \delta^k \) \( \text{ISB: Inter-system bias} \)
  - **Phase**: \( \overrightarrow{\Delta \chi^k_i} \) \( a^k_i \) \( \delta^k \)

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  - **Code**: \( \overrightarrow{\Delta x^k_i} \) \( \overrightarrow{\Delta x_i} \) \( a^k_i \) \( a^k \) \( \text{IFB: Inter-frequency bias} \)
  - **Phase**: \( \overrightarrow{\Delta \chi^k_i} \) \( \overrightarrow{\Delta \chi_i} \) \( a^k_i \) \( a^k \)

- **Signal type**: (C1P/C or C2P/C or ...)
  - **Code**: \( a^k_i \) \( a^k \)
Dependency of the terms

\[ p_i^k = \left| (\vec{x}_i^k + \Delta \vec{x}_i^k) - (\vec{x}_i + \Delta \vec{x}_i) \right| + T_i^k + I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

\[ l_i^k = \left| (\vec{x}_i^k + \Delta \chi_i^k) - (\vec{x}_i + \Delta \chi_i) \right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \]

\[ + \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k \]

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...)
  - Code: \( \Delta \vec{x}_i \)
  - Phase: \( \Delta \chi_i \)
  - Code: \( \alpha_i \)
  - Phase: \( \alpha_i \)
  - ISB: Inter-system bias \( \delta^k \)

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...)
  - Code: \( \Delta \vec{x}_i^k \)
  - Phase: \( \Delta \chi_i^k \)
  - Code: \( a_i \)
  - Phase: \( a_i \)
  - IFB: Inter-frequency bias \( \delta^k \)

- **Signal type**: (C1P/C or C2P/C or ...)
  - Code: \( a_i \)
  - Phase: \( a_i \)
  - DCB: Differential code bias
Dependency of the terms

$$\begin{align*}
P_i^k &= \left|\left(\mathbf{x}_i^k + \Delta x_i^k\right) - \left(\mathbf{x}_i + \Delta x_i\right)\right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + \alpha^k) \\
L_i^k &= \left|\left(\mathbf{x}_i^k + \Delta x_i^k\right) - \left(\mathbf{x}_i + \Delta x_i\right)\right| + T_i^k - I_i^k + c \cdot (\delta_i + \alpha_i) - c \cdot (\delta^k + \alpha^k) \\
&\quad + \lambda_i^k \cdot N_i^k + \lambda_i^k \cdot \Delta \varphi_i^k
\end{align*}$$

The following parameters depend on

- **GNSS**: (GPS or GLONASS or ...

  - Code: \(\Delta x_i\) \(a_i\) \(\delta^k\) **ISB**: Inter-system bias
  - Phase: \(\Delta \chi_i\) \(\alpha_i\) \(\delta^k\)

- **Frequency**: (f_1 or f_2 or f_n for GLONASS or ...

  - Code: \(\Delta x_i^k\) \(\Delta x_i\) \(a_i\) \(a^k\) **IFB**: Inter-frequency bias
  - Phase: \(\Delta \chi_i^k\) \(\Delta \chi_i\) \(\alpha_i\) \(\alpha^k\)

- **Signal type**: (C1P/C or C2P/C or L2P/C or ...

  - Code: \(a_i\) \(a^k\) **DCB**: Differential code bias
  - Phase: \(\alpha_i\) \(\alpha^k\) (Quarter cycle problem)
Dependency of the terms

The following parameters depend on:

- **GNSS:**
  - Code: \( \Delta x_i \) \( a_i \) \( \delta^k \) ISB: Inter-system bias
  - Phase: \( \Delta \chi_i \) \( a_i \) \( \delta^k \)

- **Frequency:**
  - Code: \( \Delta x^k \) \( \Delta x_i \) \( a_i \) \( a^k \) IFB: Inter-frequency bias
  - Phase: \( \Delta \chi^k \) \( \Delta \chi_i \) \( a_i \) \( a^k \)

- **Signal type:**
  - Code: \( a_i \) \( a^k \) DCB: Differential code bias
Dependency of the terms

\[ p_i^k = \left| \left( \frac{x_i^k}{x_i^k} + \Delta x_i^k \right) - \left( \frac{x_i^k}{x_i^k} + \Delta x_i^k \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) \]
\[ l_i^k = \left| \left( \frac{x_i^k}{x_i^k} + \Delta x_i^k \right) - \left( \frac{x_i^k}{x_i^k} + \Delta x_i^k \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k) + \lambda^k \cdot N_i + \lambda^k \cdot \Delta \varphi_i^k \]

- **GNSS:**
  - Code: \( \Delta x_i \)
  - Phase: \( \Delta \chi_i \)

- **Frequency:**
  - Code: \( \Delta x_i^k \)
  - Phase: \( \Delta \chi_i^k \)

- **Signal type:**
  - Code: \( a_i \)

ISB: Inter-system bias

IFB: Inter-frequency bias

DCB: Differential code bias
Biases when processing code data

If we focus on processing code measurements we have to consider:

- **DCB: differential code bias**
  different hardware delays for P– and C–Code bias at the *receiver and satellite*

- **ISB: inter–system bias**
  different hardware delays for measurements of different GNSS bias only at the *receiver*

- **IFB: inter–frequency bias**
  frequency–dependent hardware delays for the different GLONASS–signals bias at the *receiver*
  (also at the satellite when frequency is changed)
We can only extract the sum of delays from a GPS/GLONASS data processing.

Relation between receiver code biases

Inter-frequency bias, IFB(P)
Inter-frequency bias, IFB(C/A)
Inter-system bias, ISB

GLONASS
P-Code
f_n: 6
f_n: 0
f_n: -7

C/A-Code
f_n: 6
f_n: 0
f_n: -7

GPS
P-Code
Differential code bias, DCB(GPS)

C/A-Code
Differential code bias, DCB(GLO)
Why do we need these biases?

GPS sat. $k$

GPS rec. (C1P-Code)

GPS-sat. clock: $\delta^k + a^k(C1P)$

GPS rec. (C1P-Code)

GPS-sat. clock: $\delta^k + a^k(C1P)$

GPS rec. (C1C-Code)

GPS-sat. clock: $\delta^k + a^k(C1C)$
Why do we need these biases?

**GPS sat. \( k \)**

**GPS rec. (C1P-Code)**

\[
\text{GPS-sat. clock: } \delta^k + a^k(C1P)
\]

**GPS rec. (C1P-Code)**

\[
\text{GPS-sat. clock: } \delta^k + a^k(C1P)
\]

**GPS rec. (C1C-Code)**

\[
\text{GPS-sat. clock: } \delta^k + a^k(C1C) + DCB^k(C1P - C1C)
\]

Resulting satellite clock correction refers to C1P.
Why do we need these biases?

Whether choosing C1P or C1C as reference is fully equivalent. Choosing C1C or C1P for the satellite clock is purely cententional. The IGS follows the convention that the satellite clocks refer to the P-Code.
Why do we need these biases?

GPS sat. $k$

GPS rec. $k$: C2P-Code
$\delta^k + a^k(C2P)$

GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2P)$

GPS rec. $l$: C2C-Code
$\delta^l + a^l(C2C)$

GPS sat. $l$

GPS rec. $k$: C2P-Code
$\delta^k + a^k(C2P)$

GPS-sat. clock:
$k: \delta^k + a^k(C2P)$
$l: \delta^l + a^l(C2C)$

GPS rec. $l$: C2C-Code
$\delta^l + a^l(C2C)$
Why do we need these biases?

GPS sat. $k$

GPS rec. $k$: C2P-Code

GPS-sat. clock: $k: \delta^k + a^k(C2P)$

GPS rec. $l$: C2P-Code

GPS-sat. clock: $l: \delta^l + a^l(C2P)$

GPS sat. $l$

GPS rec. $k$: C2P-Code

GPS-sat. clock: $k: \delta^k + a^k(C2P)$

GPS rec. $l$: C2C-Code

GPS-sat. clock: $l: \delta^l + a^l(C2C)$

$+ DCB^l (C2P - C2C)$
Why do we need these biases?

GPS sat. $k$
- GPS rec. $k$: C2P-Code
- GPS rec. clock: $k: \delta_1 + a_1(C2P)$

GPS sat. $l$
- GPS rec. $l$: C2P-Code
- GPS rec. clock: $l: \delta_2 + a_2(C2P)$

GPS sat. $k$
- GPS rec. $k$: C2P-Code
- GPS rec. clock: $k: \delta_3 + a_3(C2P)$

GPS sat. $l$
- GPS rec. $l$: C2C-Code
- GPS rec. clock: $l: \delta_3 + a_3(C2C)$
Why do we need these biases?

- GPS sat. $k$
  - GPS rec. $k$: C2P-Code
  - GPS-rec. clock: $k: \delta_1 + a_1(C2P)$
  - $l: \delta_1 + a_1(C2P)$

- GPS sat. $l$
  - GPS rec. $k$: C2P-Code
  - GPS-rec. clock: $k: \delta_2 + a_2(C2P)$
  - $l: \delta_2 + a_2(C2P)$

  $+ DCB_2 (C2P - C2C)$

  - GPS rec. $l$: C2C-Code
  - GPS-rec. clock: $k: \delta_3 + a_3(C2P)$
  - $l: \delta_3 + a_3(C2C)$

  $+ DCB_3 (C2P - C2C)$
**DCBs in a GPS network solution**

Depending on the code measurements of the individual receivers we can get:

- C1P-C1C or P1-C1 DCBs for all GPS satellites,
- C2P-C2C or P2-C2 DCBs for Block IIR-M (or later) satellites,
- C2P-C2C or P2-C2 DCBs for receivers if it tracks GPS satellites with P- and C-code on the second frequency at the same time.

As soon as we get a mixture between all these observation types in one network solution we need

- either to correct the DCBs in the data processing
- or to estimate DCB parameters
  - **P1-C1**: Your reference clock only belongs to either the P- or C/A-code class – you need an additional reference for the satellite related biases.
  - **P2-C2**: You have these DCBs at the satellites and receivers at the same time – you need additional references for the satellite and receiver related biases.
Why do we need these biases?

GLO sat. $k$

GLO rec. $k$: C1P-Code
$l$: C1P-Code
GLO-sat. clock:
$k: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$

GLO sat. $l$

GLO rec. $k$: C1P-Code
$l$: C1P-Code
GLO-sat. clock:
$k: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$

GLO rec. $k$: C1P-Code
$l$: C1P-Code
GLO-sat. clock:
$k: \delta^k + a^k(C1P)$
$l: \delta^l + a^l(C1P)$
Why do we need these biases?

GLO sat. $k$
- $k$: C1P-Code
- $k$: C1C-Code
- $k$: C1C-Code

GLO-sat. clock:
- $k$: $\delta^k + a^k(C1P)$
- $k$: $\delta^k + a^k(C1C)$
- $k$: $\delta^k + a^k(C1C)$

GLO sat. $l$
- $l$: C1P-Code
- $l$: C1C-Code
- $l$: C1C-Code

GLO-sat. clock:
- $l$: $\delta^l + a^l(C1P)$
- $l$: $\delta^l + a^l(C1C)$
- $l$: $\delta^l + a^l(C1C)$
Why do we need these biases?

GLO rec.  
\( k: \) C1P-Code  
\( l: \) C1P-Code

GLO-sat. clock:  
\( k: \delta^k + a^k(C1P) \)
\( l: \delta^l + a^l(C1P) \)

GLO rec.  
\( k: \) C1C-Code  
\( l: \) C1C-Code

GLO-sat. clock:  
\( k: \delta^k + a^k(C1C) \)
\( l: \delta^l + a^l(C1C) \)
\( +DCB^k(C1P - C1C) \)
\( +DCB^l(C1P - C1C) \)
Why do we need these biases?

GLO sat. $k$

GLO rec. $k$: C1P-Code

GLO-rec. clock:

$k: \delta_1 + a_1(C1P)$

$l: \delta_1 + a_1(C1P)$

GLO sat. $I$

GLO rec. $k$: C1C-Code

GLO-rec. clock:

$k: \delta_2 + a_2(C1C)$

$l: \delta_2 + a_2(C1C)$

GLO rec. $k$: C1C-Code

GLO-rec. clock:

$k: \delta_3 + a_3(C1C)$

$l: \delta_3 + a_3(C1C)$
Why do we need these biases?

Because each GLONASS satellite emits the signal on its own frequency, the receiver hardware delays become (satellite-)frequency-dependent.
**DCBs in a GLONASS network solution**

Depending on the code measurements of the individual receivers we can get:
- C1P-C1C or P1-C1 DCBs for all GLONASS satellites,
- C2P-C2C or P2-C2 DCBs for all GLONASS satellites.

As soon as we get a mixture between all these observation types in one network solution we need
- either to correct the DCBs in the data processing
- or to estimate DCB parameters
  - P1-C1 and P2-C2: Your reference clock only belongs to either the P- or C-code class – you need an additional reference for the satellite related biases.

Note that we need to consider in addition an inter-frequency bias (IFB) because each GLONASS satellite emits the signal on another frequency.
Why do we need these biases?

GPS sat. $k$

GPS rec. $k$: C1P-Code

GNSS-sat. clock:
$k: \delta^k + a^k(C1P)$

GNSS rec. $k$: C1P-Code

GNSS-sat. clock:
$k: \delta^k + a^k(C1P)$

GLO sat. $l$

GNSS rec. $l$: C1C-Code

GNSS-sat. clock:
$k: \delta^k + a^k(C1C)$

GNSS rec. $l$: C1C-Code

GNSS-sat. clock:
$l: \delta^l + a^l(C1C)$
Why do we need these biases?

GPS sat. \( k \)

GPS rec.

\( k \): C1P-Code

GNSS-sat. clock:

\( k: \delta^k + a^k(C1P) \)

GNSS rec.

\( k \): C1P-Code

\( l: \delta^l + a^l(C1P) \)

GLO sat. \( l \)

GNSS rec.

\( k \): C1C-Code

\( l \): C1C-Code

GNSS-sat. clock:

\( k: \delta^k + a^k(C1C) \)

\( l: \delta^l + a^l(C1C) \)

\( +DCB^k(C1P - C1C) \)

\( +DCB^l(C1P - C1C) \)
Why do we need these biases?

GPS sat. \( k \)

\[ \text{GPS rec. } k: \text{C1P-Code} \]

\[ \text{GNSS-rec. clock: } k: \delta_1 + a_1(C1P) \]

GLO sat. \( l \)

\[ \text{GNSS rec. } k: \text{C1P-Code} \]

\[ \text{GNSS-rec. clock: } k: \delta_2 + a_2(C1P)^{GPS} \]

\[ l: \delta_2 + a_2(C1P)^{GLO} \]

\[ \text{GNSS rec. } l: \text{C1C-Code} \]

\[ \text{GNSS-rec. clock: } k: \delta_3 + a_3(C1C)^{GPS} \]

\[ l: \delta_3 + a_3(C1C)^{GLO} \]
Why do we need these biases?

GPS sat. \( k \):

- GNSS-rec. clock:
  - \( k : \delta_1 + a_1(C1P) \)

GPS rec. \( k \):

- C1P-Code

GLO sat. \( l \):

- GNSS-rec. clock:
  - \( l : \delta_1 + a_2(C1P)^{GPS} \)
  - \( l : \delta_2 + a_2(C1P)^{GPS} + ISB_2(C1P) \)

GNSS rec. \( k \):

- C1P-Code

GNSS rec. \( l \):

- C1C-Code

GNSS-rec. clock:

- \( k : \delta_3 + a_3(C1C)^{GPS} \)
- \( l : \delta_3 + a_3(C1C)^{GPS} + ISB_3(C1C) \)
Bias in a GPS/GLONASS network solution

We can see all DCBs from a GPS and GLONASS network solution and the GLONASS IFB in a combined GPS/GLONASS network solution.

Note that we need to consider in addition an inter-system bias (ISB) at each combined GPS/GLONASS receiver.

All these biases are hardware related (with respect to the satellites or receivers). Consequently, we can only assess them as one single parameter $a_i = DCB + IFB + ISB$.

- References are needed for
  - P1-C1 DCB for GPS satellites,
  - P2-C2 DCB for GPS satellites and GPS receivers tracking C2C,
  - ISB for combined GPS/GLONASS tracking receivers,
  - IFB for GLONASS tracking receivers.
Bias in a GPS/GLONASS network solution

In consequence the estimated biases depend on the realization of the reference (e.g., selection of a reference or list of stations in case of zero-mean conditions).

These biases need to be considered (estimated or corrected) at any time when different types of code measurements are involved.

Typical examples are:
- Receiver/satellite clock estimation in a zero-difference network solution.
- Melbourne-Wübben linear combination for ambiguity resolution (even in the double-difference analysis).

An alternative approach to obtain the DCBs is to inspect RINEX observation files containing the full list of observations.
Direct access from RINEX files

If RINEX observation files contain all possible code measurements

**GPS:** C1P  C1C  C2P  C2C

**GLONASS:** C1P  C1C  C2P  C2C

the following differences can be evaluated to derive the DCBs:

\[
\begin{align*}
(C1P)^{GPS} - (C1C)^{GPS} &= DCB^{GPS}(P1-C1) - DCB^{GPS}(P1-C1) \\
(C2P)^{GPS} - (C2C)^{GPS} &= DCB^{GPS}(P2-C2) - DCB^{GPS}(P2-C2) \\
(C1P)^{GLO} - (C1C)^{GLO} &= DCB^{GLO}(P1-C1) - DCB^{GLO}(P1-C1) \\
(C2P)^{GLO} - (C2C)^{GLO} &= DCB^{GLO}(P2-C2) - DCB^{GLO}(P2-C2)
\end{align*}
\]

Because each observation contains the DCBs for the receiver and satellite we need again a convention regarding the reference (e.g., zero-mean condition for all satellites).

This direct DCB determination approach is the only way to get access to the GLONASS DCB values independent from the inter-system bias.
DCBs from RINEX files

CODE’s GNSS P1-C1 DCB monthly solution, computed for December 2011 (directly from RINEX)
DCBs from RINEX files

Table:
- ASHTECH UZ-12
- JAVAD TRE_G3T_DELTA
- JPS E_GGD
- TPS EGGDT
- TPS LEGACY
- TRIMBLE NETR5
- AOA BENCHMARK ACT
- ASHTECH Z-XII3
- JAVAD TRE_G3T_DELTA
- JPS LEGACY
- TPS EUROCARD
- TPS NET-G3A
- TRIMBLE NETR8
- AOA SNR-12 ACT
- ASHTECH Z-XII3T
- JPS EGGDT
- SEPT POLARX2
- TPS E_GGD
- TPS NETG3
- TRIMBLE NETR9
- AOA SNR-8000 ACT
- BLACKJACK
- JPS EUROCARD
- SEPT POLARX3ETR
- TPS GB-1000
- TPS ODYSSEY_E

Graph:
- DCBs (p1c1) in ns
- Stations
- GPS
DCBs from RINEX files

GLONASS

Stations
CODE’s GNSS P2-C2 DCB monthly solution, computed for December 2011 (directly from RINEX)
DCBs from RINEX files

![Graph showing DCB(p2c2) in ns for different GPS stations.](Image)
DCBs from RINEX files

The graph shows the DCB(p2c2) in ns for GLONASS satellites and stations. The stations are represented along the x-axis, while the DCB values are plotted on the y-axis. Different colors and symbols represent different satellite and receiver combinations.

GLONASS

Stations:
- WITZ
- HERS
- SCH2
- WHIT
- GOPE
- UNBT
- UNB3
- GMSD

Satellite and Receiver Combinations:
- JAVAD TRE_G3TH DELTA
- TPS NETG3
- TRIMBLE NETRS
- LEICA GRX1200+GNSS
- TRIMBLE NETR5
- SEPT POLARX3ETR
- TRIMBLE NETR6
- TPS NET-G3G
- TRIMBLE NETR9
ISB/IFB from a GPS/GLONASS solution

<table>
<thead>
<tr>
<th>Instrument</th>
<th>ISB/IFB from CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHTECH Z18</td>
<td>JPS_E_GGD</td>
</tr>
<tr>
<td>JPS E_GGD</td>
<td>TPS E_GGD</td>
</tr>
<tr>
<td>NOV OEMV3</td>
<td>TPS NETG3</td>
</tr>
<tr>
<td>TPS NET-G3A</td>
<td>TRIMBLE NETR8</td>
</tr>
<tr>
<td>TRIMBLE NETR9</td>
<td>JAVAD TRE_G3T DELTA</td>
</tr>
<tr>
<td>JPS LEGACY</td>
<td>JPS E_GGD</td>
</tr>
<tr>
<td>TPS E_GGD</td>
<td>TPS ODYSSEY_E</td>
</tr>
<tr>
<td>TPS NETG3</td>
<td>TRIMBLE NETR9</td>
</tr>
<tr>
<td>TPS GB-1000</td>
<td>JAVAD TRE_G3TH DELTA</td>
</tr>
<tr>
<td>LEICA GRX1200+GNSS</td>
<td>JPS EGGDT</td>
</tr>
<tr>
<td>TPS LEGACY</td>
<td>LEICA GRX1200GGPRO</td>
</tr>
<tr>
<td>TPS ODYSSEY_E</td>
<td>TRIMBLE NETR5</td>
</tr>
</tbody>
</table>

ISB/IFB from CODE

test solution submitted to the IGS workshop on GNSS biases in January 2012
ISB/IFB from a GPS/GLONASS solution

ISB/IFB from ESA
test solution submitted to the IGS workshop on GNSS biases in January 2012
ISB/IFB from a GPS/GLONASS solution

ISB/IFB from GFZ

test solution submitted to the IGS workshop on GNSS biases in January 2012
ISB/IFB from a GPS/GLONASS solution

ISB/IFB: Differences CODE-ESA
test solution submitted to the IGS workshop on GNSS biases in January 2012
ISB/IFB from a GPS/GLONASS solution

ISB/IFB: Differences CODE-GFZ
test solution submitted to the IGS workshop on GNSS biases in January 2012
ISB/IFB from a GPS/GLONASS solution

<table>
<thead>
<tr>
<th>ASHTECH Z18</th>
<th>JAVAD TRE_G3T DELTA</th>
<th>JAVAD TRE_G3TH DELTA</th>
<th>JPS EGGDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPS E_GGD</td>
<td>JPS LEGACY</td>
<td>LEICA GRX200+GNSS</td>
<td>LEICA GRX1200GGPRO</td>
</tr>
<tr>
<td>NOV OEMV3</td>
<td>TPS E_GGD</td>
<td>TPS GB-1000</td>
<td>TPS LEGACY</td>
</tr>
<tr>
<td>TPS NETG3</td>
<td>TPS NETG3</td>
<td>TPS ODYSSEY_E</td>
<td>TRIMBLE NETR5</td>
</tr>
<tr>
<td>TRIMBLE NETR8</td>
<td>TRIMBLE NETR9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ISB/IFB: Differences GFZ-ESA
test solution submitted to the IGS workshop on GNSS biases in January 2012
## ISB/IFB from a GPS/GLONASS solution

Differences between ISB characteristic of the receivers

<table>
<thead>
<tr>
<th>Difference</th>
<th>Number of stations</th>
<th>Mean in ns</th>
<th>Median in ns</th>
<th>RMS in ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE GFZ</td>
<td>52</td>
<td>-210.6</td>
<td>-209.4</td>
<td>4.9</td>
</tr>
<tr>
<td>CODE ESA</td>
<td>39</td>
<td>-377.5</td>
<td>-377.6</td>
<td>5.1</td>
</tr>
<tr>
<td>GFZ ESA</td>
<td>36</td>
<td>-167.7</td>
<td>-168.2</td>
<td>6.1</td>
</tr>
<tr>
<td>CODE GRGS</td>
<td>50</td>
<td>-371.9</td>
<td>-372.1</td>
<td>18.7</td>
</tr>
<tr>
<td>GFZ GRGS</td>
<td>46</td>
<td>-162.1</td>
<td>-163.0</td>
<td>19.2</td>
</tr>
<tr>
<td>ESA GRGS</td>
<td>34</td>
<td>6.1</td>
<td>5.8</td>
<td>20.6</td>
</tr>
</tbody>
</table>

- High consistency (low RMS) with a proper IFB—handling (enough weight for the code measurements?)
- Test whether the ACs select the same type of code observations (CODE differs from ESA and GFZ)
Further biases

- When forming linear combinations from the $P_1$ and $P_2$ measurements
  \[ LC = k_1 \cdot P_1 + k_2 \cdot P_2 \]
  the original P1-C1, P2-C2 DCB values have to be applied with the corresponding coefficients:
  \[ DCB(LC) = k_1 \cdot DCB(P1C1) + k_2 \cdot DCB(P2C2) \]

- Alternative factors need to apply when $P_2$ or $C_2$ is not directly tracked (e.g., cross-correlation technique).

- When extracting the ionosphere information by a $P_1 - P_2$ linear combination, the differences between the hardware delays for $P_1$ and $P_2$ at the receiver and satellite need to be considered as an additional type of DCBs: $DCB(P1P2)$

- With more GNSS and their new signals more groups of DCBs will become relevant (e.g, third frequency for GPS and GLONASS).
### Dependency of the terms

\[
P_i^k = \left| \left( \vec{x}_i^k + \Delta \vec{x}_i^k \right) - \left( \vec{x}_i^i + \Delta \vec{x}_i^i \right) \right| + T_i^k + I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[
L_i^k = \left| \left( \vec{x}_i^k + \Delta \vec{x}_i^k \right) - \left( \vec{x}_i^i + \Delta \vec{x}_i^i \right) \right| + T_i^k - I_i^k + c \cdot (\delta_i + a_i) - c \cdot (\delta^k + a^k)
\]

\[+ \lambda^k \cdot N_i^k + \lambda^k \cdot \Delta \phi_i^k\]

---

**GNSS:**
- **Code:** \( \Delta x_i^k \)
- **Phase:** \( \Delta \chi_i^k \)
- **ISB:** Inter-system bias
  \( (\delta_i) \)

**Frequency:**
- **Code:** \( \Delta x_i^k \)
- **Phase:** \( \Delta \chi_i^k \)
- **IFB:** Inter-frequency bias
  \( c \cdot (\delta_i + a_i) \)

**Signal type:**
- **Code:** \( a_i \)
- **DCB:** Differential code bias
  \( \lambda^k \cdot \Delta \phi_i^k \)
GLONASS-GPS translation bias

A GNSS antenna should be individually calibrated for each GNSS to consider the system-dependency of the $\Delta \chi_i$ term.

The coordinate GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center offset.

- Station coordinate from GPS-only
- Station coordinate from GLONASS-only
- Vector between GPS- and GLONASS coordinates
- Two independent networks with independent datum definition
- Zero-mean condition over all GLONASS-GPS bias in XYZ
GPS/GLONASS-Bias

Differences between weekly coordinate solutions for GPS/GLONASS stations with and without estimating GLONASS-GPS translation biases

Receiver/satellite antenna model: IGS05
GPS/GLONASS-Bias

Differences between weekly coordinate solutions for GPS/GLONASS stations with and without estimating GLONASS-GPS translation biases

Receiver/satellite antenna model: IGS08
A GNSS antenna should be individually calibrated for each GNSS to consider the system-dependency of the $\Delta \chi_i$ term.

The troposphere GLONASS-GPS translation bias shall compensate for a potential deficiency in the GNSS-specific calibration of the antenna phase center variation.

- Troposphere estimates from GPS-only
- Troposphere estimates from GLONASS-only
- Difference between GLONASS- and GPS troposphere series
- No further condition is necessary.
GLONASS-GPS troposphere ZPD biases
(for up to 143 IGS GNSS stations)

Model switch from IGS05 to IGS08
CODE processing changes in 2011

Operational series from CODE

Ecole d'Eté 2012
Outline

- Introduction
- Orbit Determination (at CODE)
- Code Biases: DCB, ISB, IFB