Kinematic Orbit Positioning applying the Raw Observation Approach

Barbara Suesser-Rechberger, Torsten Mayer-Guerr and Sandro Krauss

Institute of Geodesy
Graz University of Technology

EGU General Assembly 2020, Vienna

05 May 2020

Overview

- **Introduction**
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

Introduction

- Low earth orbiting (LEO) satellites with onboard global navigation satellite system (GNSS) receiver offer good opportunities to use their position for different research branches like

  - gravity field observation or
  - analyzing solar event impacts on LEO satellites

- To achieve high accurate research results the position of the satellite has be determined as precisely as possible.

- The kinematic strategy for precise orbit determination (POD) of LEO satellites uses only geometric observations to estimate the satellite orbit and does not take any forces into account.

- This strategy requires a large amount of observation data for one epoch to determine the three-dimensional satellite position. One possibility to get this data is the usage of the spaceborne GNSS technology, which provides a high number of accurate observations.

Overview

- Introduction
- **Raw Observation Approach**
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

Raw Observation Approach - Basics

- Zehentner (2016) shown a method to determine the kinematic orbit based on raw and unchanged GNSS observations.
- This method use a least-square adjustment and systematic effects are corrected or will be estimated as parameter.
- Kinematic orbit positioning applying the raw observation approach by using a least-squares adjustment has shown promising results with a high accuracy.

Raw Observation Approach – Process Flow

Raw Observation Approach – Process Flow

Ground station-GNSS network processing

Raw Observation Approach – Process Flow

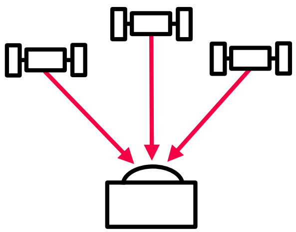
Ground station-GNSS network processing

Kinematic orbit processing

Raw Observation Approach – Process Flow

Ground station-GNSS network processing

Ground station-GNSS network



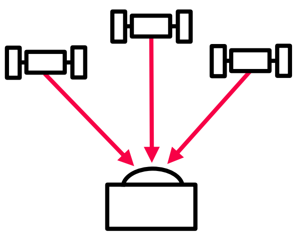
output:
- GNSS orbits, clocks
- Normal equations for GNSS antenna center variations (ACV)

Kinematic orbit processing

Raw Observation Approach – Process Flow

Ground station-GNSS network processing

Ground station-GNSS network



output:
- GNSS orbits, clocks
- Normal equations for GNSS antenna center variations (ACV)

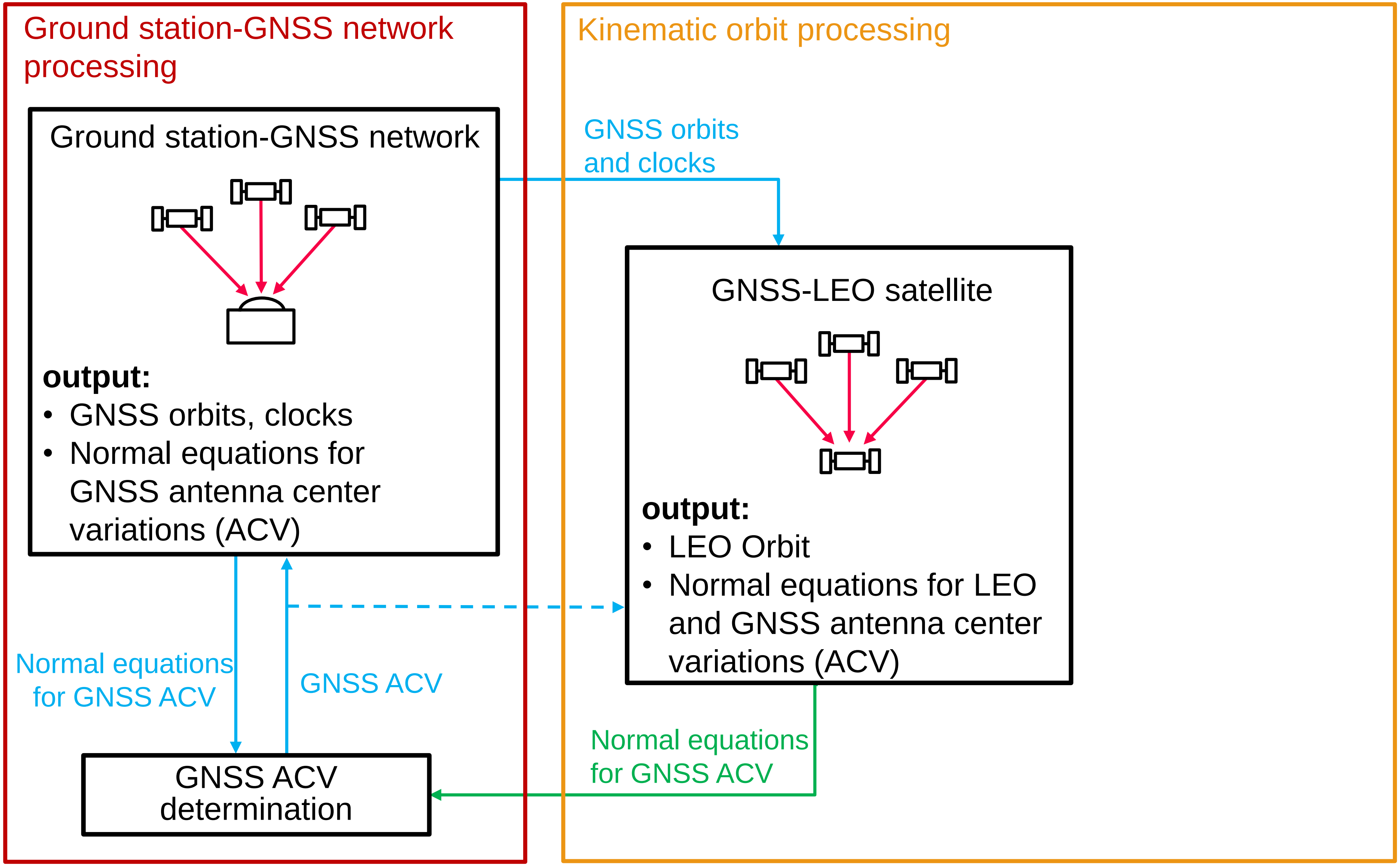
Normal equations for GNSS ACV

GNSS ACV

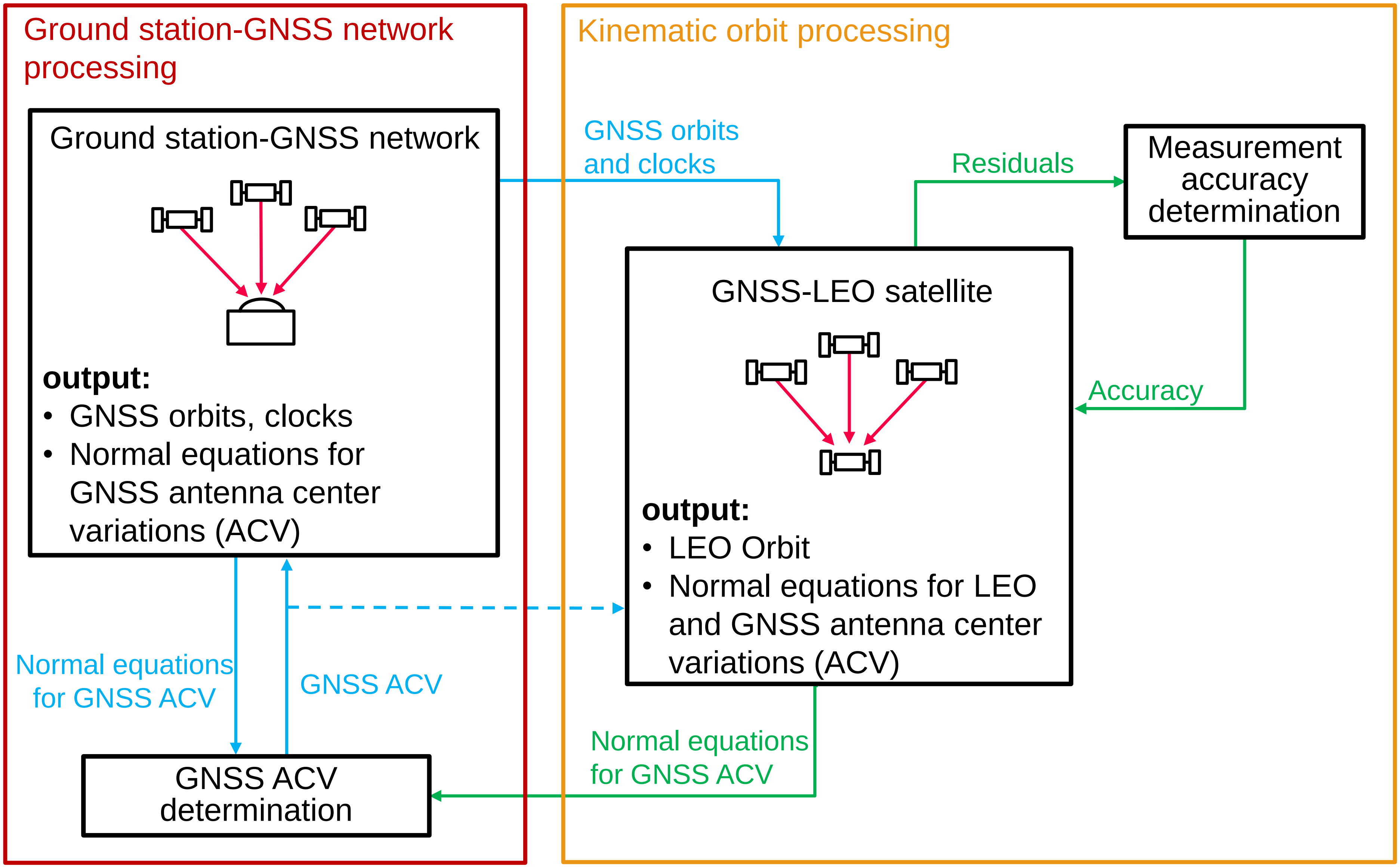
GNSS ACV determination

Kinematic orbit processing

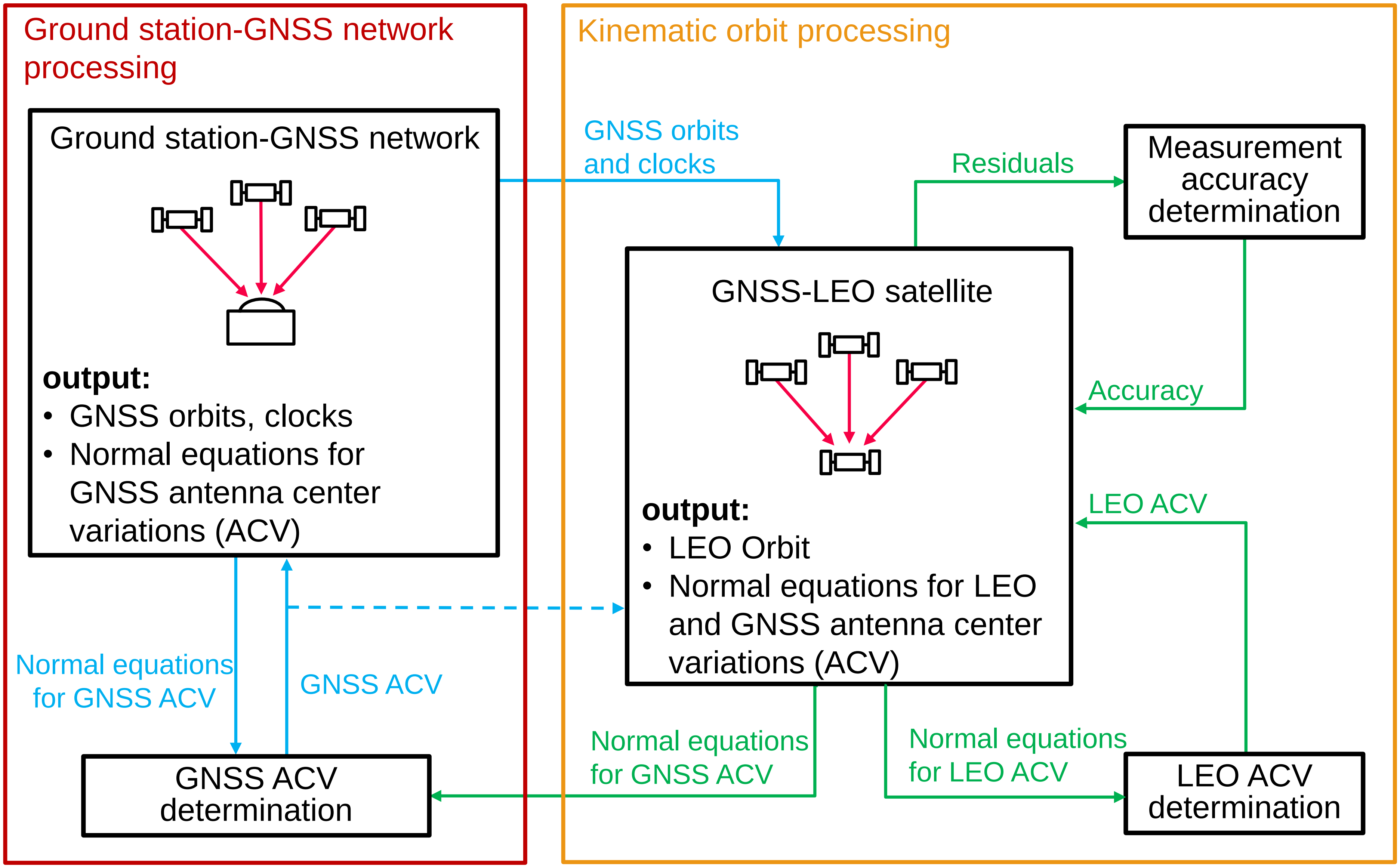
Raw Observation Approach – Process Flow



Raw Observation Approach – Process Flow



Raw Observation Approach – Process Flow

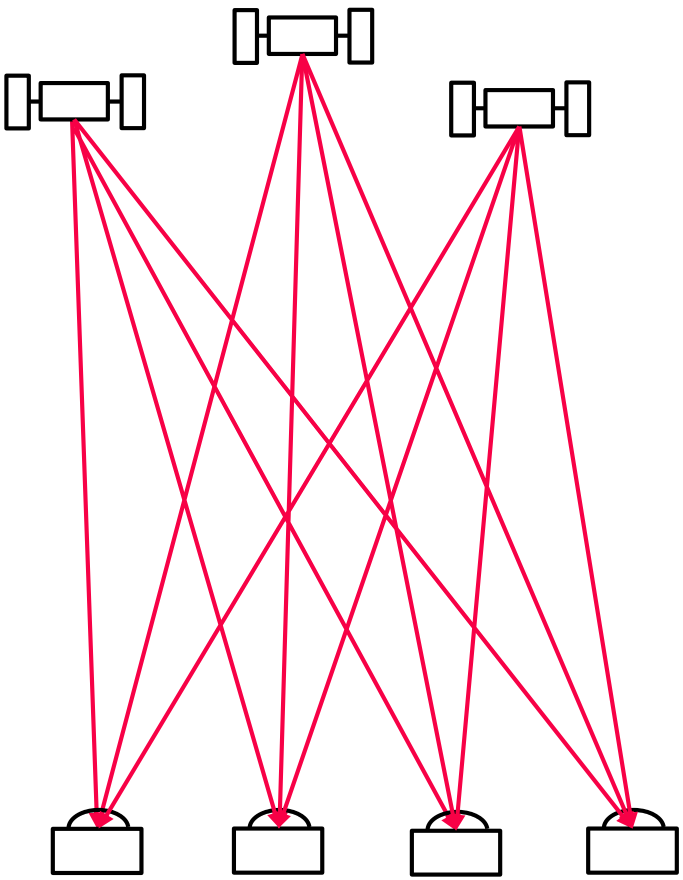


Overview

- Introduction
- Raw Observation Approach
- **Ground Station-GNSS Network Processing**
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

Ground station-GNSS network processing

Consistent reprocessing (2000 – up to now) → GPS orbit, clock and bias solutions



GPS satellites

- Update to date force modelling
  - Annual & trend gravity field (GOCO06s)
  - Atmosphere and Ocean variations (AOD1B)
- Estimated Antenna Center Variations
  - from previous iteration
  - Normals combination of stations, Jason 1/2/3, GRACE, GRACE-FO observations

Ground station network

- ~200 IGS stations daily
- Full 30 second sampling
- Atmosphere and Ocean Loading (AOD1B)

- 5 second clock densification using CODE final solution

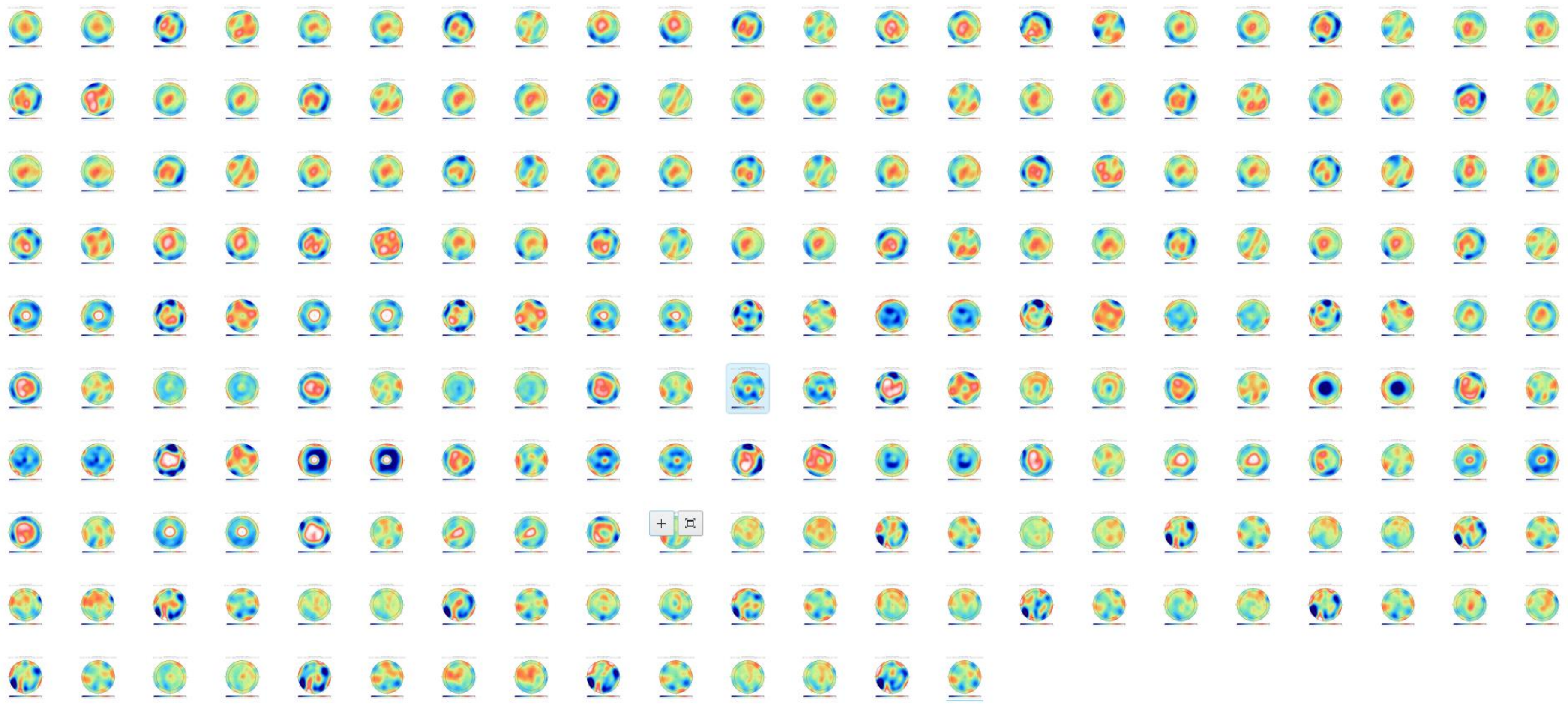
Barbara Suesser-Rechberger et al.

Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- **GPS Antenna Center Variations**
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

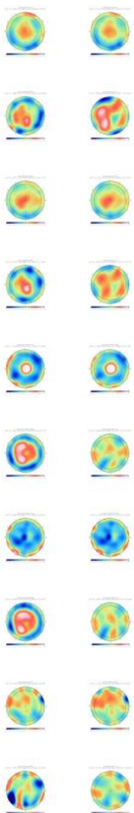
GPS Antenna Center Variations

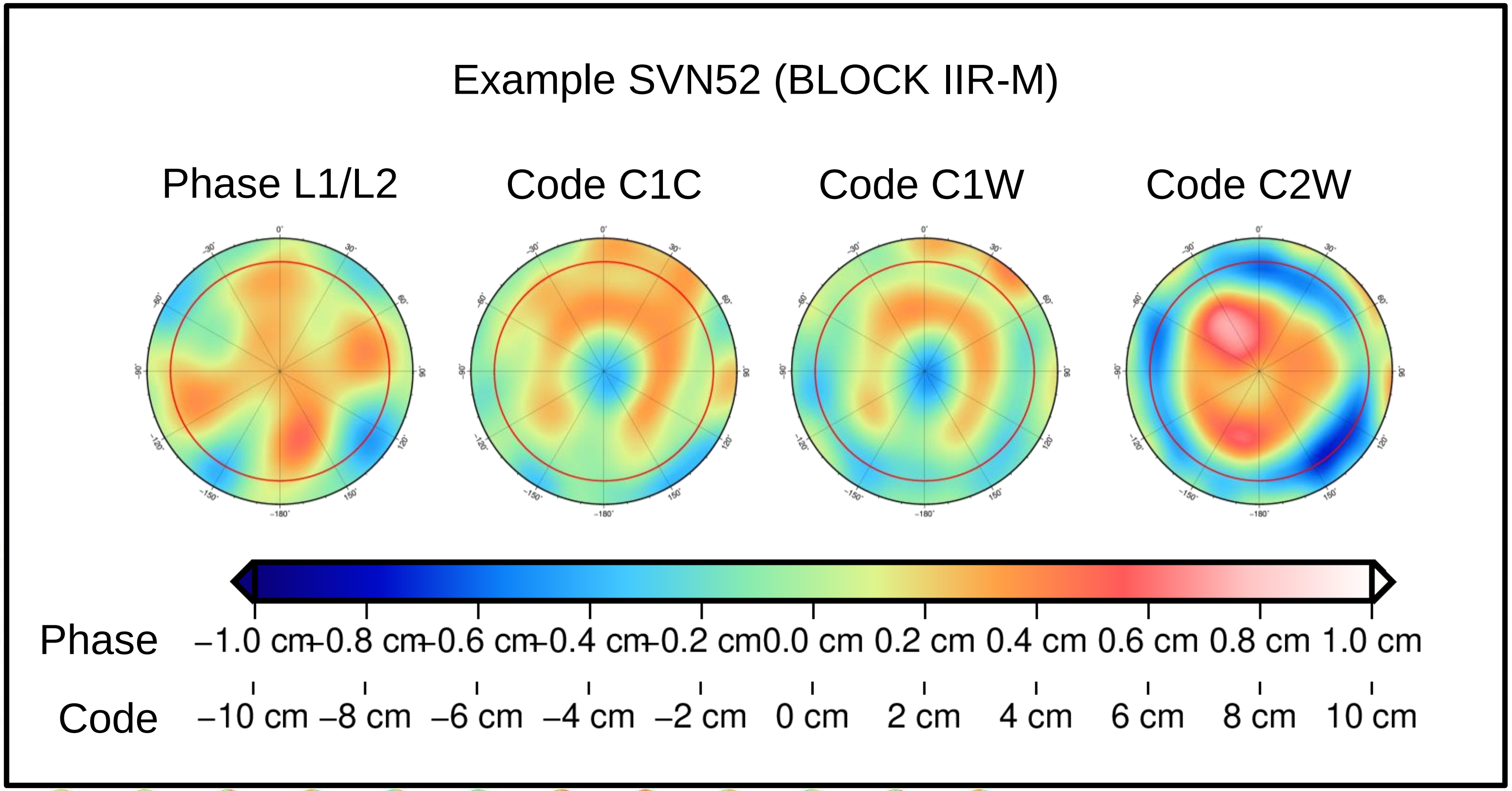
- Estimated for each SVN
- For each signal (Phase L1/L2, Code C1C, C1W, C2W)
- Azimuth, zenith dependency
- Based on ANTEX IGS R3

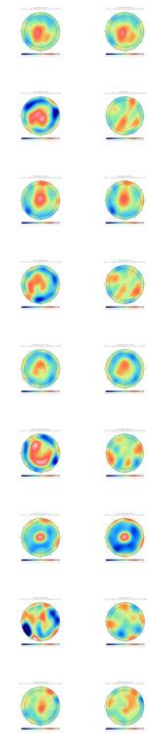


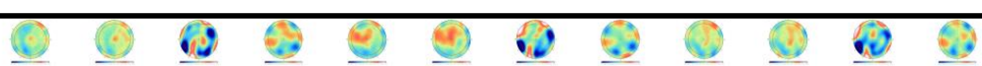
GPS Antenna Center Variations

- Estimated for each SVN
- For each signal (Phase L1/L2, Code C1C, C1W, C2W)
- Azimuth, zenith dependency
- Based on ANTEX IGS R3







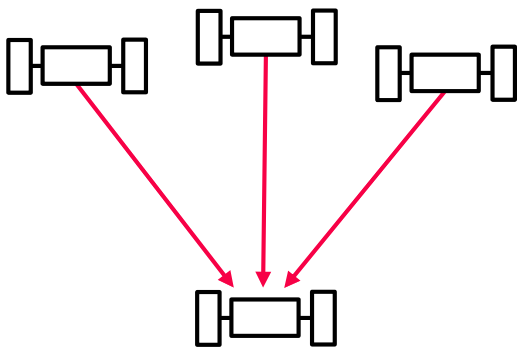


Barbara Suesser-Rechberger et al.

Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- **Kinematic Orbit Processing**
- LEO Antenna Center Variations
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

Kinematic Orbit Processing (1)



LEO satellite missions

- CHAMP
- GRACE
- Jason 1/2/3
- TerraSAR-X
- TanDEM-X
- …

GNSS-LEO satellite

- Determination of the orbit and set up the normal equations for LEO & GNSS antenna center variations (ACV) using least-squares adjustment.
- Ambiguities are fixed, this causes
  - more stable orbit and
  - clearly reduced long-wave variations
- Determination of the residuals $\hat{\boldsymbol{e}} = \Delta\boldsymbol{l} - \boldsymbol{A}\Delta\hat{\boldsymbol{x}}$

Measurement accuracy

- Analyzing the accuracy from the residuals $\hat{\boldsymbol{e}}$, is used for next estimation.

LEO antenna center variations determination

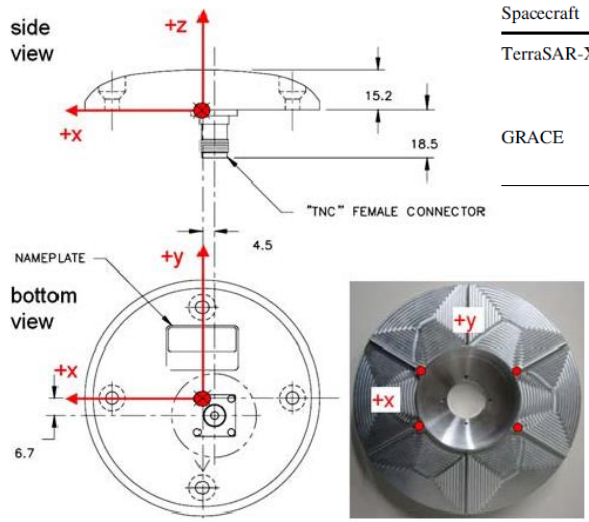
- Solving the LEO ACV normal equations, solution is used for next estimation.

GNSS antenna center variations determination

- Solution of the GNSS ACV normal equations is used for Ground station-GNSS network and kinematic orbit determination.

Kinematic Orbit Processing (2)

- Before the precise orbit can be determined following data of every used LEO satellite have to be collected
  - GNSS raw data, attitude data, coarse orbit (initial orbit)
  - Meta-data information of the satellite including informations about the satellite reference frame, antenna reference frame/point, center of mass, antenna phase center offsets …



Spacecraft	Point	X (mm)	Y (mm)	Z (mm)	Boresight (+z)	Azimuth(+y)
TerraSAR-X	POD main antenna (ARP)	+1604.3	−16.8	−1065.2	(0, 0, −1)	(0, −1, 0)
	POD aux antenna (ARP)	+1234.3	−16.8	−1065.2	(0, 0, −1)	(−1, 0, 0)
	SLR reflector	−1307.7	−212.1	+953.8		
GRACE	GPS main antenna (ARP)	0.0	0.0	−444.0	(0, 0, −1)	(0, −1, 0)
	SLR reflector	+600.0	−327.5	+217.8		

Frequency	N (+y) (mm)	E (+x) (mm)	U (+z) (mm)
L1	1.49 ± 0.09	0.60 ± 0.12	−7.01 ± 0.48
L2	0.96 ± 0.26	0.86 ± 0.20	22.29 ± 0.44

Examples of satellite meta-data [Source: Montenbruck, O., Garcia-Fernandez, M., Yoon, Y., Schön, S., and Jäggi, A. (Jan. 2009)."Antenna phase center calibration for precise positioning of LEO satellites." In: GPS Solutions 13.1, pp. 23–34.]

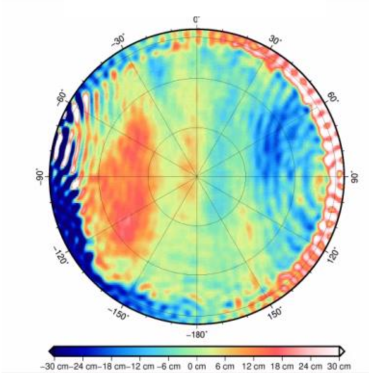
Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- **LEO Antenna Center Variations**
- Measurement Accuracy
- Kinematic Orbit Results
- Outlook

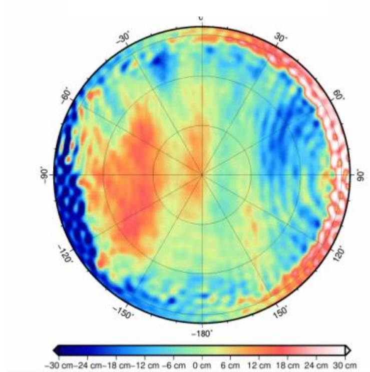
LEO Antenna Center Variations (1)

- Example: TerraSAR-X
  - Resulting ACV pattern for period 01-2015

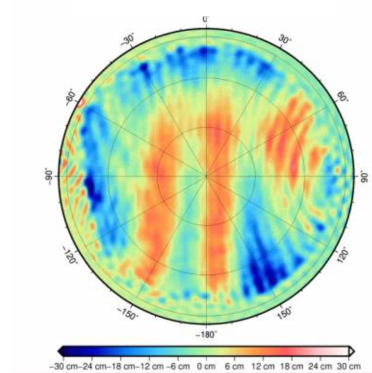
Code C1C



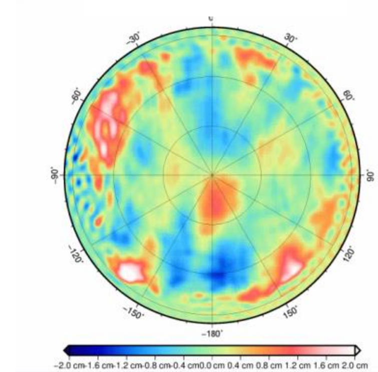
Code C1W



Code C2W

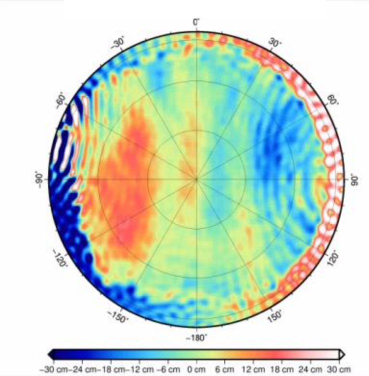


Phase L1/L2

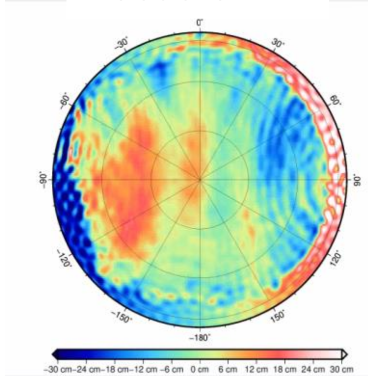


  - Resulting ACV pattern for period 01-2016

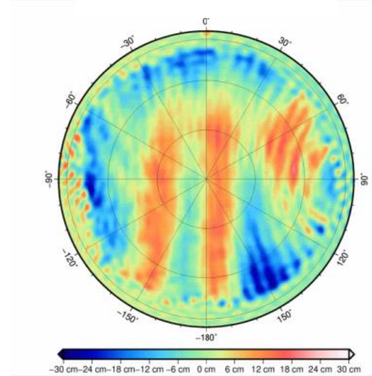
Code C1C



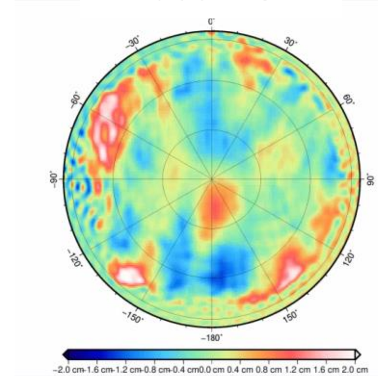
Code C1W



Code C2W



Phase L1/L2

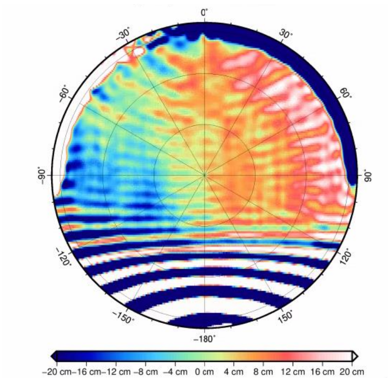


LEO Antenna Center Variations (2)

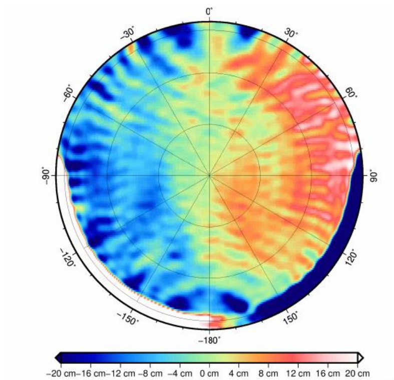
- Basically it is assumed that antenna center variations do not vary over time.
- But time-variant antenna center variations can be caused by e.g.
  - switches between main and redundant antenna
  - occultation antenna which affects the GNSS antenna
- For achieving high accuracy results the exact estimation of the antenna center variations are of paramount importance → investigation if the antenna center variations changes over time is absolutely necessary.
- Example: GRACE
  - Period 02-2014 to 06-2015

Code C1C

Occultation antenna on



Occultation antenna off



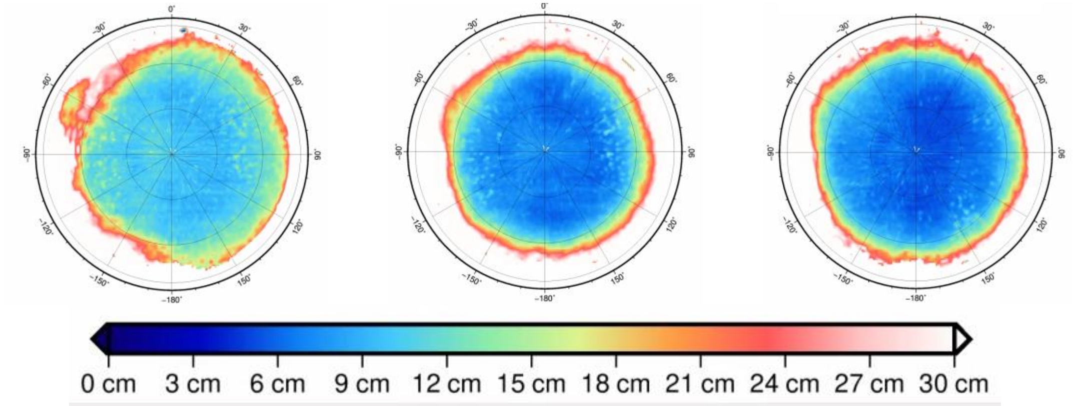
Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- **Measurement Accuracy**
- Kinematic Orbit Results
- Outlook

Measurement Accuracy

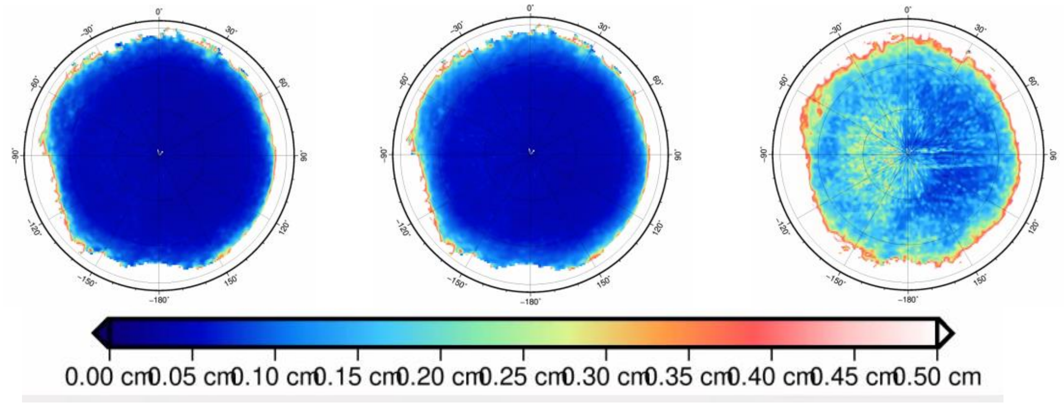
- Accuracy calculation is related to azimuth and elevation.
- Example: TerraSAR-X, using ACV solution from period 01-2016
  - Code Signals

C1C C1W C2W



  - Phase Signals

L1C L1W L2W

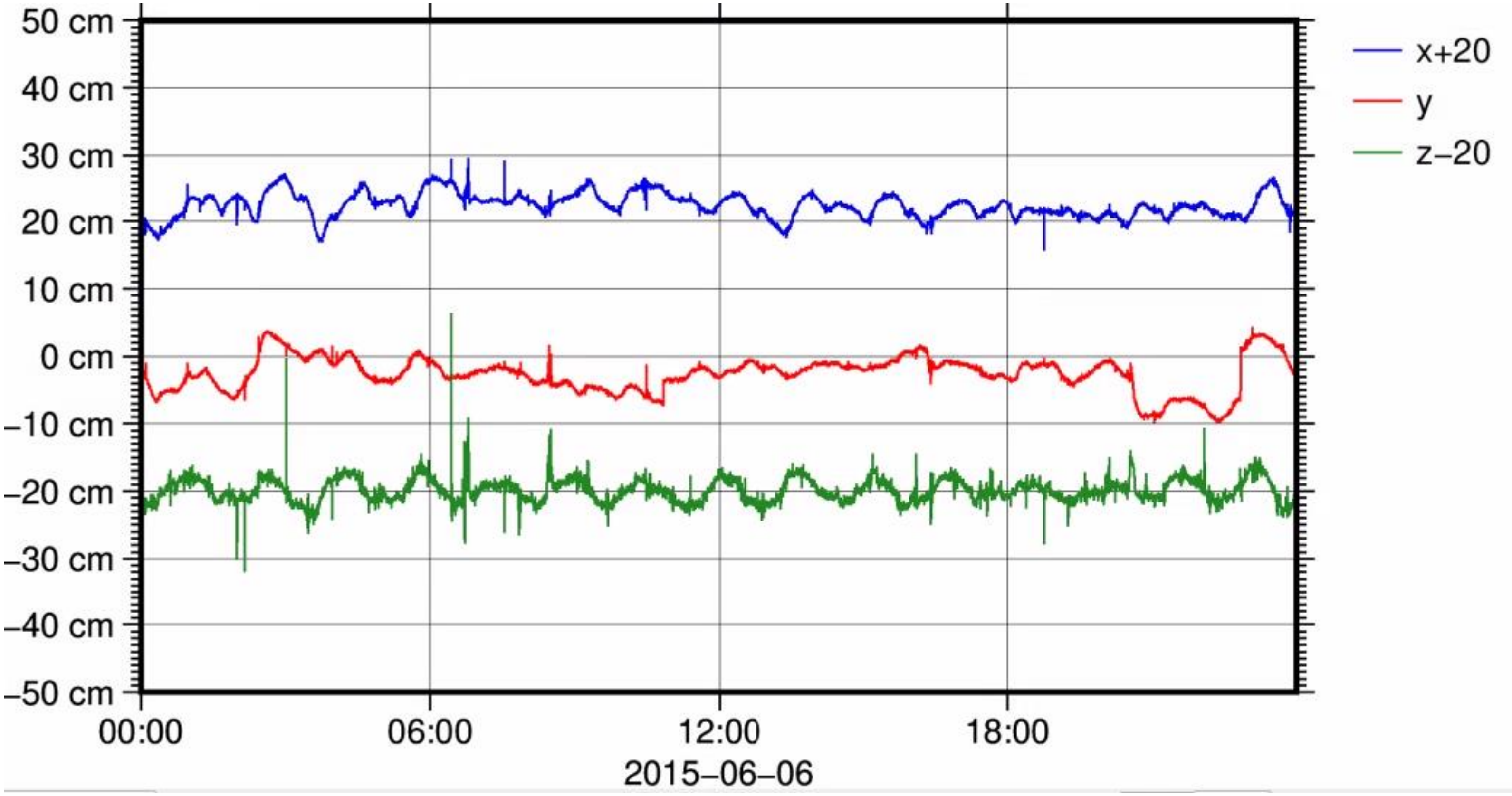


Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- **Kinematic Orbit Results**
- Outlook

Kinematic Orbit Results

- Example TerraSAR-X: Difference of kinematic orbit and rapid science orbit (RSO)



Overview

- Introduction
- Raw Observation Approach
- Ground Station-GNSS Network Processing
- GPS Antenna Center Variations
- Kinematic Orbit Processing
- LEO Antenna Center Variations
- Kinematic Orbit Results
- **Outlook**

Outlook

- Next to gravity observations, precise kinematic orbit determination can be used for investigation of space weather.
- Strong sun events like coronal mass ejections (CME) affects Earth-orbiting satellites in such a way that the drag force acting on the spacecraft is enhanced and subsequently leads to an additional storm induced orbit decay.
- Satellites equipped with accelerometers offer the possibility to deduce information on the current state of the atmospheric neutral mass density based on the measurements of non-gravitational forces acting on the spacecraft. Variations of the neutral density triggered by CME induced geomagnetic storms can be used to estimate the storm induced orbit decay of the satellite.
- Since satellite mission with on board accelerometers are extremely rare the information shall be gathered additionally from GNSS based kinematic orbits.
- The advantage of this approach is, that theoretically almost every LEO satellite mission which is tracked by GNSS can be used for the evaluation.
- Since all these satellites are orbiting at different altitudes between 300-800km, a tomography of the upper Earth's atmosphere is feasible and the impact of a solar event on a satellite can be estimated as a function of its orbital altitude.

Thank you