L1: FROM METER TO CENTIMETER

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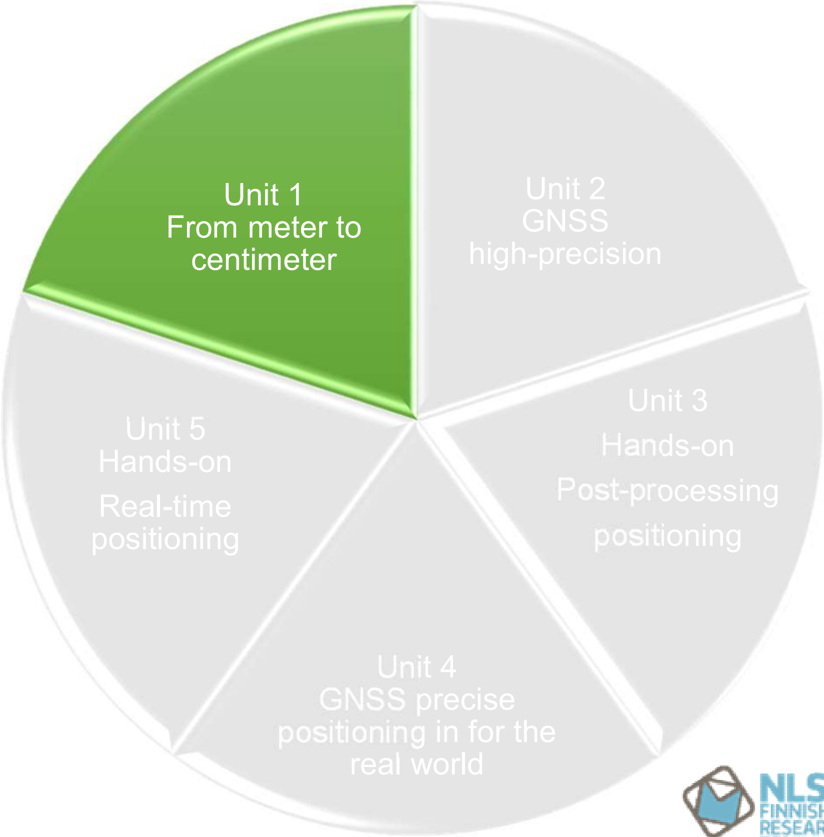
LECTURE STRUCTURE

- Video watch
- Poll questions
- Lecture slides
- Reflection questions

- Active student participation
- Questions on the chat
- Raise your hand

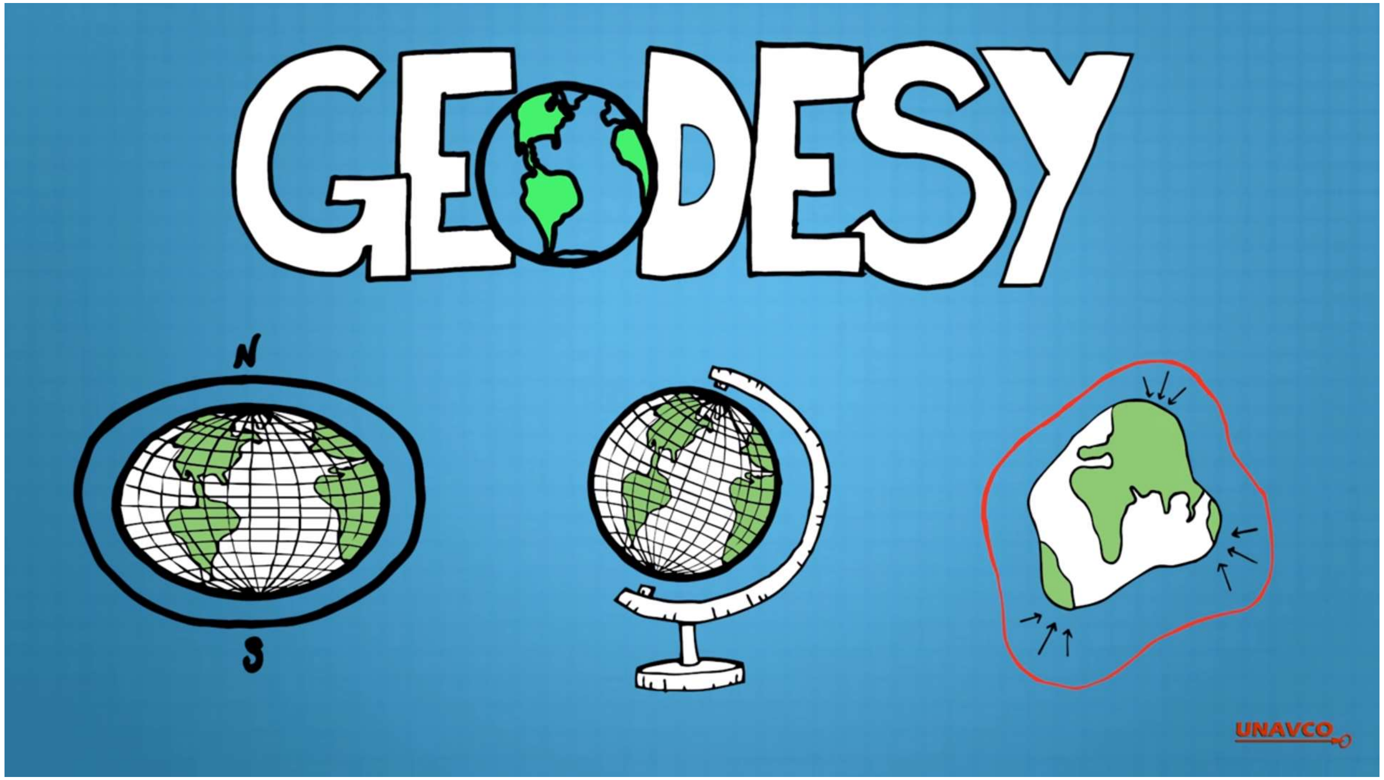


FROM METER TO SUB CENTIMETER

- **Content**
  - ➢ Various positioning modes and techniques to improve the precision level of positioning down to centimeter or even below.

- After this lecture, the participant should be able:
  - ✓ **to distinguish** between different positioning modes.
  - ✓ **to choose** a suitable positioning technique for your application.

WHY GEODESY?



https://www.youtube.com/watch?v=BCK5Zj--w7w

What? … watch video
How long? … 5-min
Who? ... everyone

Pay attention!
Take notes if preferred.
Questions afterwards

QUIZZ: QUESTION 1

The video mentioned several fields of application. How many are presented in the video? (give one single number)

https://app.sli.do/event/yi90jfe5

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QUIZZ: QUESTION 2

The video has mentioned several fields of application. Name as many as you can remember.

(multiple answers allowed, max. 50 characters per answer)

https://app.sli.do/event/yi90jfe5

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QUIZZ: QUESTION 3

What are the most common or key words used in the video?

(type as many as you recall, max. 25 characters per word)

https://app.sli.do/event/yi90jfe5

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WHAT DOES IT MEAN PRECISE?

10 m

1 cm

1 m

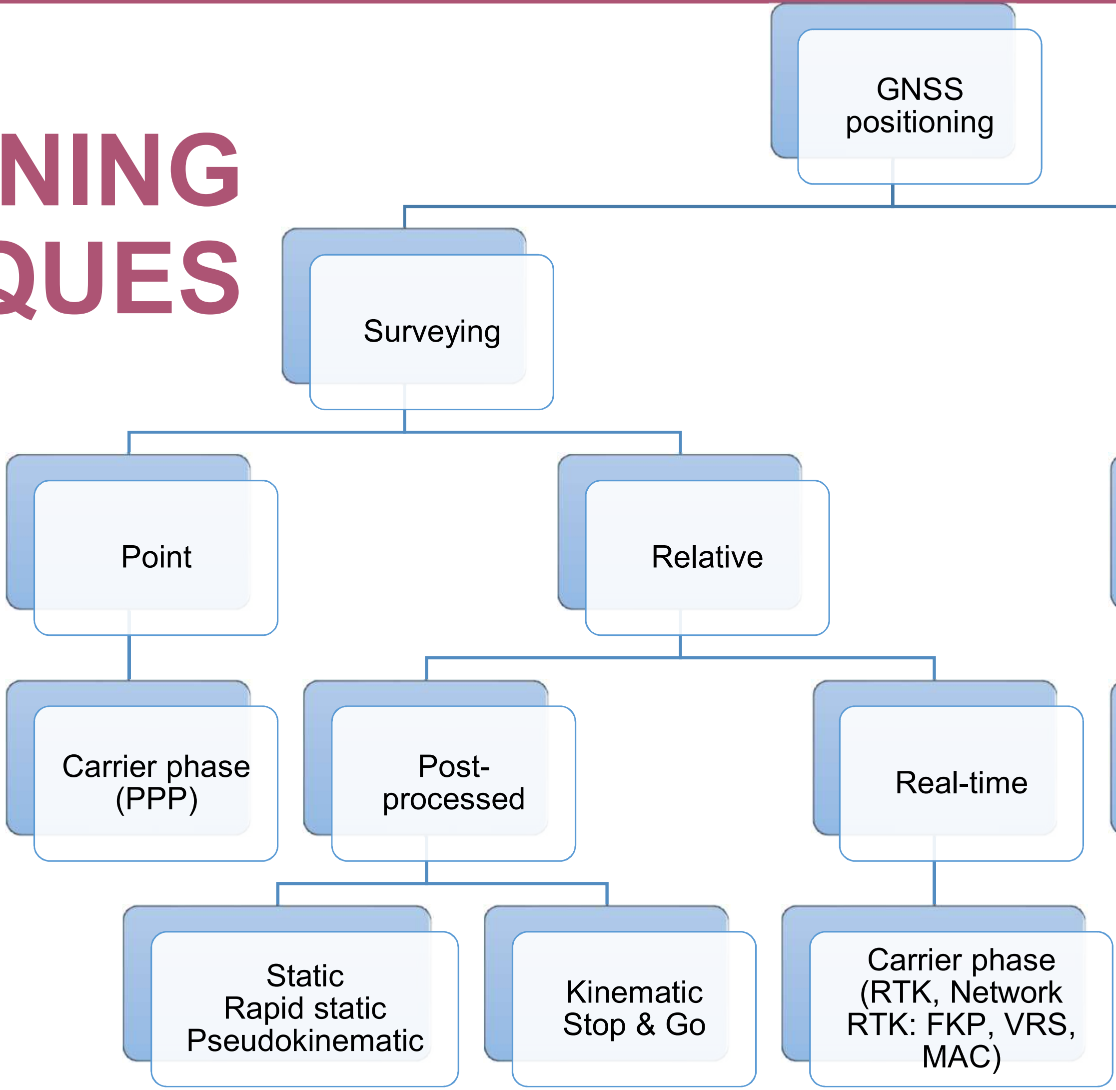
1 mm

GNSS POSITIONING MODES / MODELS

- **Positioning modes**
  - Point, differential, relative positioning

- **Positioning techniques / methods / models**
  - Single Point Positioning
  - Precise Point Positioning
  - Differential GNSS
  - Real Time Kinematic
  - Network RTK

GNSS POSITIONING TECHNIQUES



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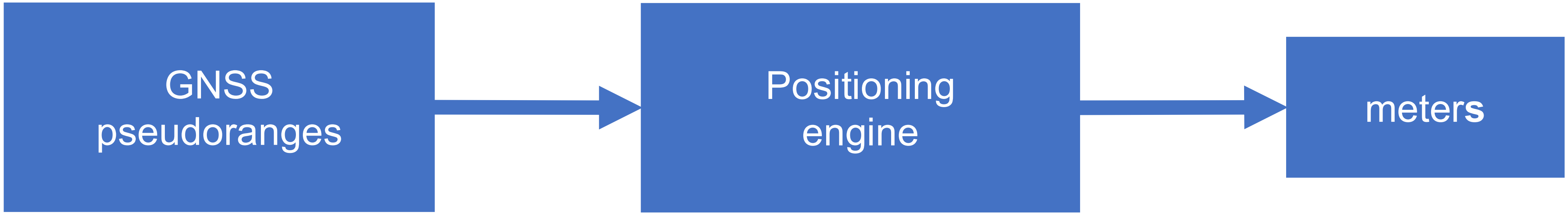
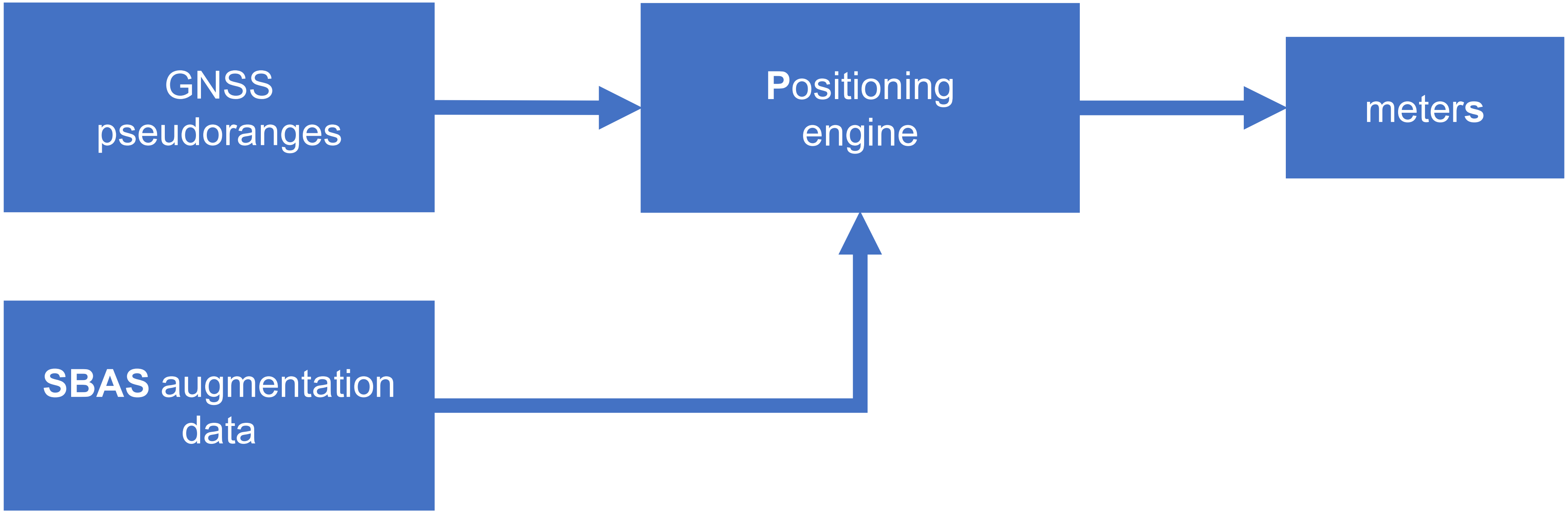
Feature	Code-based (Standard Positioning)
Observable	Pseudorange (code)
Computation	Relatively simple **d = c x t**
Mode	Absolute but not precise
Receiver noise	3 m / 30 cm
Multipath	30 cm – 30 m
Sensitivity	High (< 20 dBHz)
Discontinuity	No slip
Ambiguity	-
Receiver cost	Low (€100+)
Accuracy (RMS)	Single : 3 m (H), 5 m (V) DGNSS: 1 m (H), 2 m (V)
Applications	General navigation, Fleet management, Geocatching, Timining, SARm LBS, etc.

Feature	Code-based (Standard Positioning)	Carrier phase-based (Precise Positioning)
Observable	Pseudorange (code)	Carrier phase + pseudorange
Computation	Relatively simple **d = c x t**	Complicated **d = N x** λ
Mode	Absolute but not precise	Relative but not absolute
Receiver noise	3 m / 30 cm	3 cm
Multipath	30 cm – 30 m	1 – 3 cm
Sensitivity	High (< 20 dBHz)	Low (> 35 dBHz)
Discontinuity	No slip	Cycle-slip
Ambiguity	-	Estimated / Resolved
Receiver cost	Low (€100+)	Expensive (€10k+)
Accuracy (RMS)	Single : 3 m (H), 5 m (V) DGNSS: 1 m (H), 2 m (V)	Static: 5 mm (H), 1 cm (V) RTK : 1 cm (H), 2 cm (V)
Applications	General navigation, Fleet management, Geocatching, Timining, SARm LBS, etc.	Surveying (land, sea & air), Machine guidance, Precise engineering, Datum monitoring, Earth observations, etc.

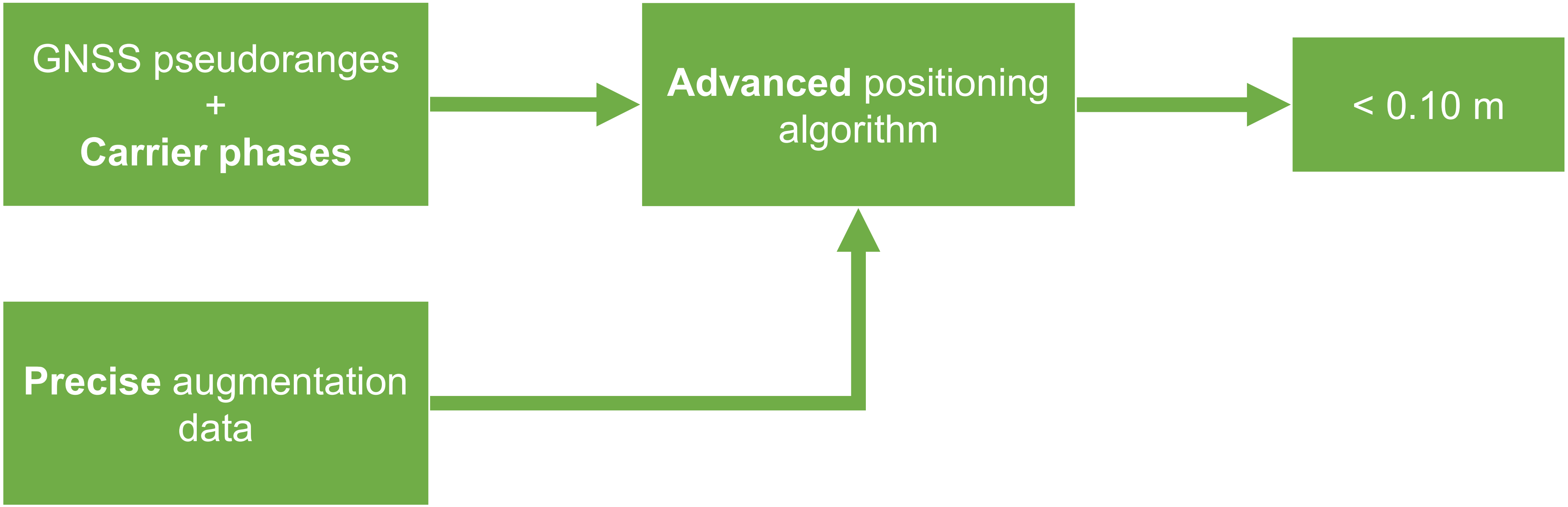
GNSS STANDALONE POSITIONING



GNSS STANDALONE POSITIONING



GNSS PRECISE POSITIONING



REDUCING GNSS ERRORS

Observation
Space
Representation
(OSR)

State
Space
Representation
(SSR)

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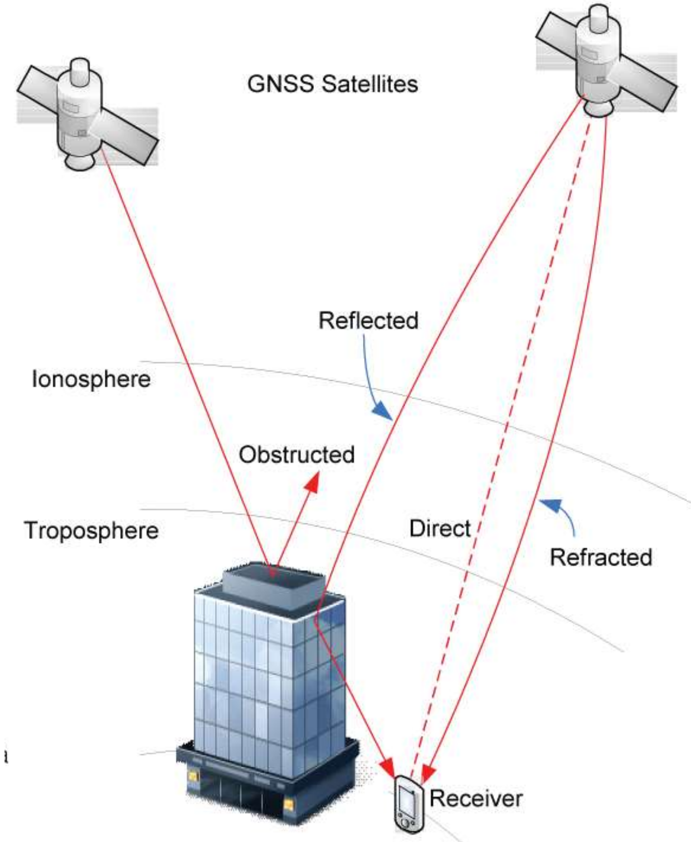
COMMON ERRORS

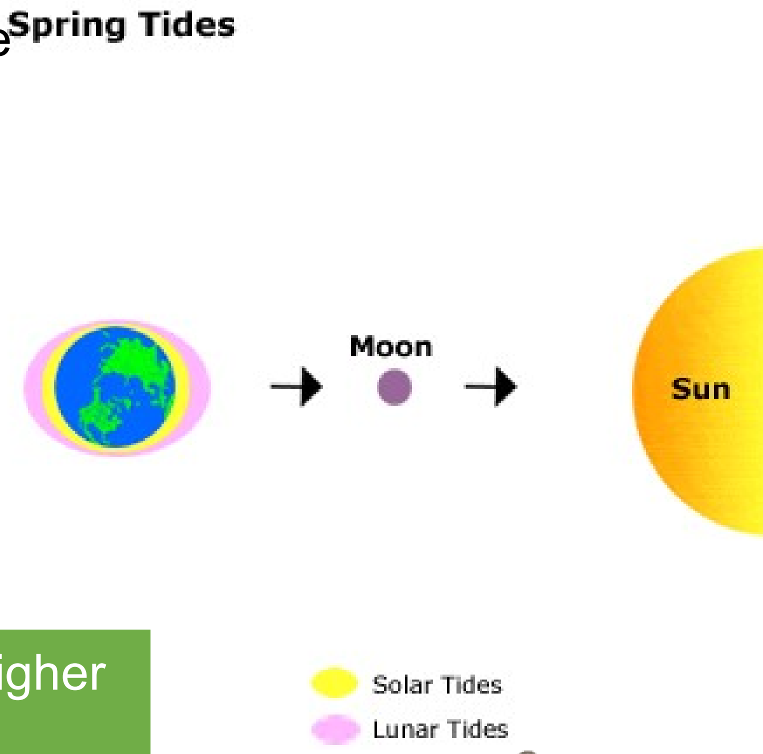
- **Satellite-dependent**
  - ➢ Satellite orbital errors
  - ➢ Satellite clock errors
  - ➢ Satellite antenna, geometry
- **Propagation-dependent**
  - Ionospheric & tropospheric delays
  - Multipath
  - Cycle slips
- **Receiver/site-dependent**
  - Receiver clock error, noise
  - Antennae



Source: http://www.novatel.com/

SPECIAL ERRORS

- Several other errors have to be considered to calculate very accurate point positioning solutions (e.g., PPP)
- Satellite antenna phase center offset & variations
- Phase wind-up
- Solid Earth tides
- Ocean loading
- Polar tides
- Code and phase biases



The more comprehensive the list the higher the positioning performance

WHAT ENABLES PRECISE POSITIONING?

- Centimeter level accuracy has been possible for many years!

- Easily accessible **correction / augmentation data**
- **Advanced** positioning algorithms

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CORRECTION DATA

Before

- Your own base receiver
- Radio link (limited to 3 km, affected by terrain, national legislation)
- Availability of radio channels
- Long delays for precise orbits and clocks

Now

- RT correction services development, broadcast over cellular frequencies
- Base station data available 24/7 via CORS networks
- Rapid precise orbits and clock corrections
- Increased quality of corrections delivered over L-band, MSM, SSR, LPP, CLAS, SPARTN

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ADVANCED POSITIONING ALGORITHMS

Real Time Kinematic (RTK)

- User determines the position of an unknown point (rover) with respect to a known point (base)
  - At least a **pair** of receivers
- Simultaneous observations
  - Time-tagged GNSS measure-ments are transmitted from the base
  - The differentiation process takes place at the rover
- Baseline and position at rover
- Faster fixes over longer baselines
- Single base or Network RTK

Precise Point Positioning (PPP)

- **Precise** satellite **clocks & orbits**
- **Carrier phase** observations
- **Single** (dual-frequency) receiver
- Iono-free data combinations
- Significant improvements in the last decade
- Post-processing (popular)
- Real-time (now)
- Cm-level accuracy in kinematic, real-time achievable (now)

DRIVERS FOR POSITIONING PERFORMANCE

- More signals: availability, complex, robust
- Antenna selection
- Antenna placement
- Receiver capabilities
- Multiple constellations
- Multiple frequencies
- Error modelling
- Algorithm design
- Correction services
- Positioning mode

REFLECTION QUESTION

Why precise positioning has expanded from the traditional surveying and geodesy to other markets & applications?

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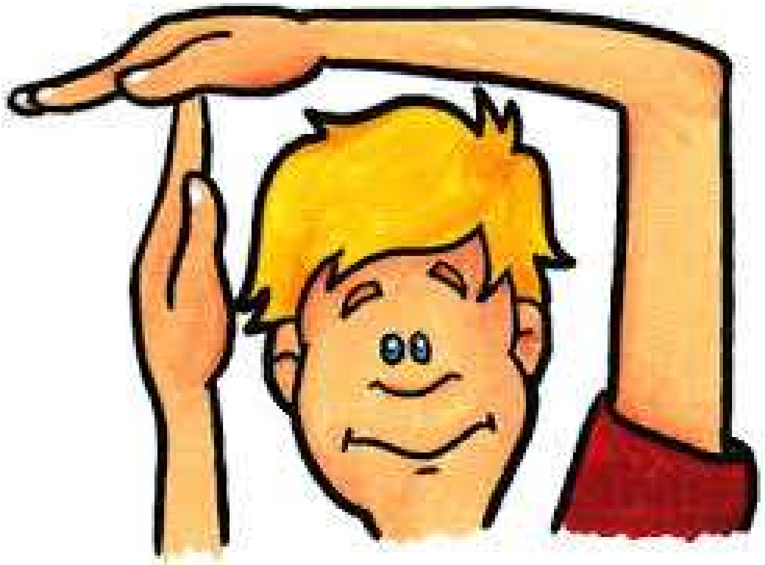
TIME FOR BREAK



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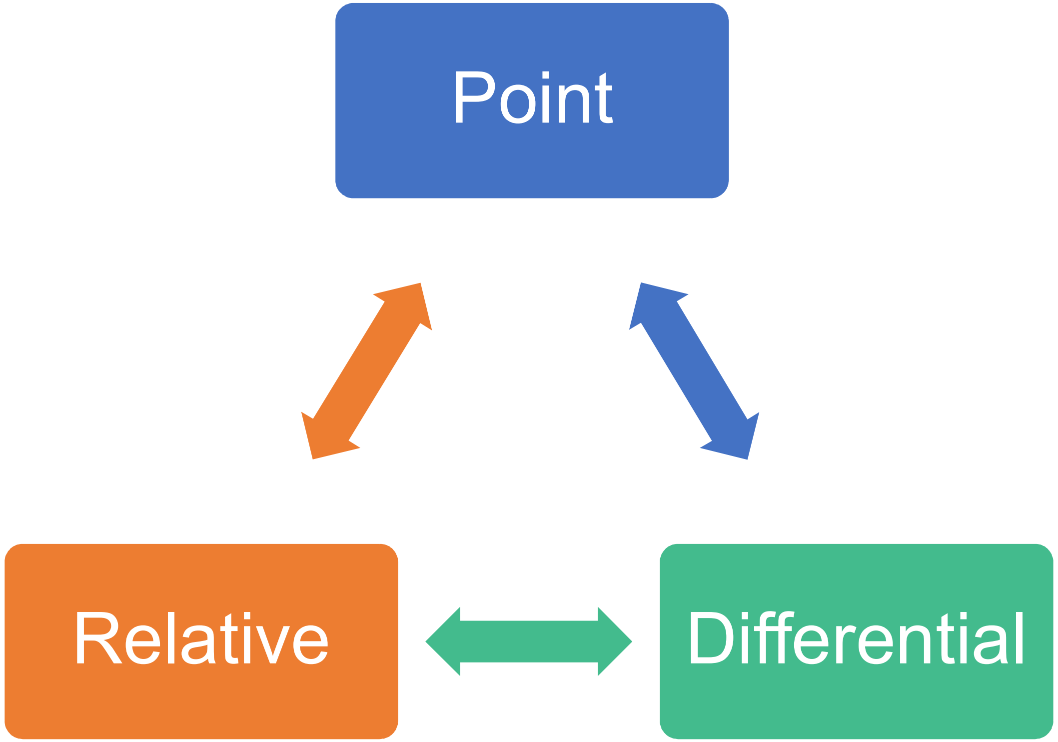
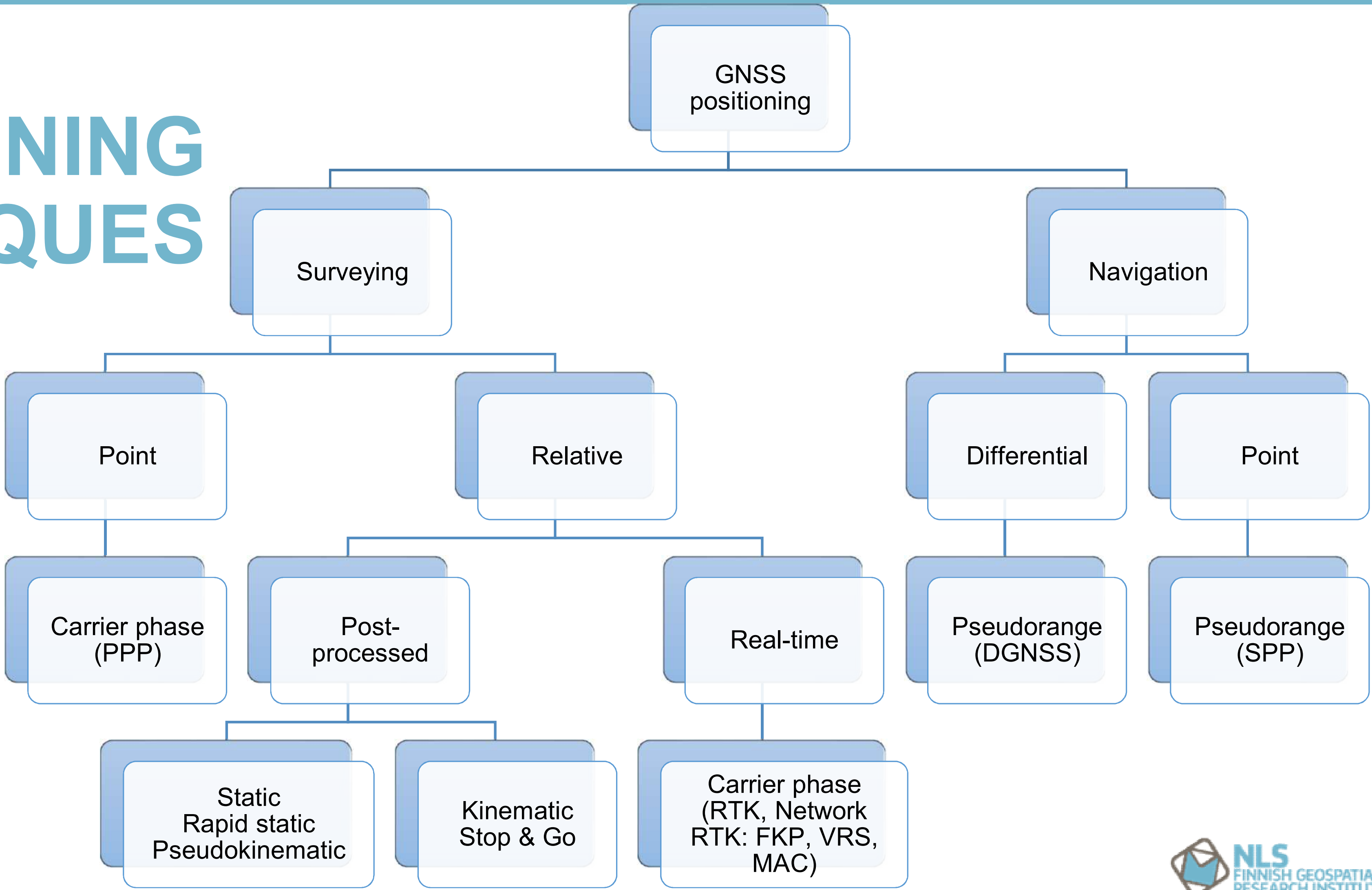
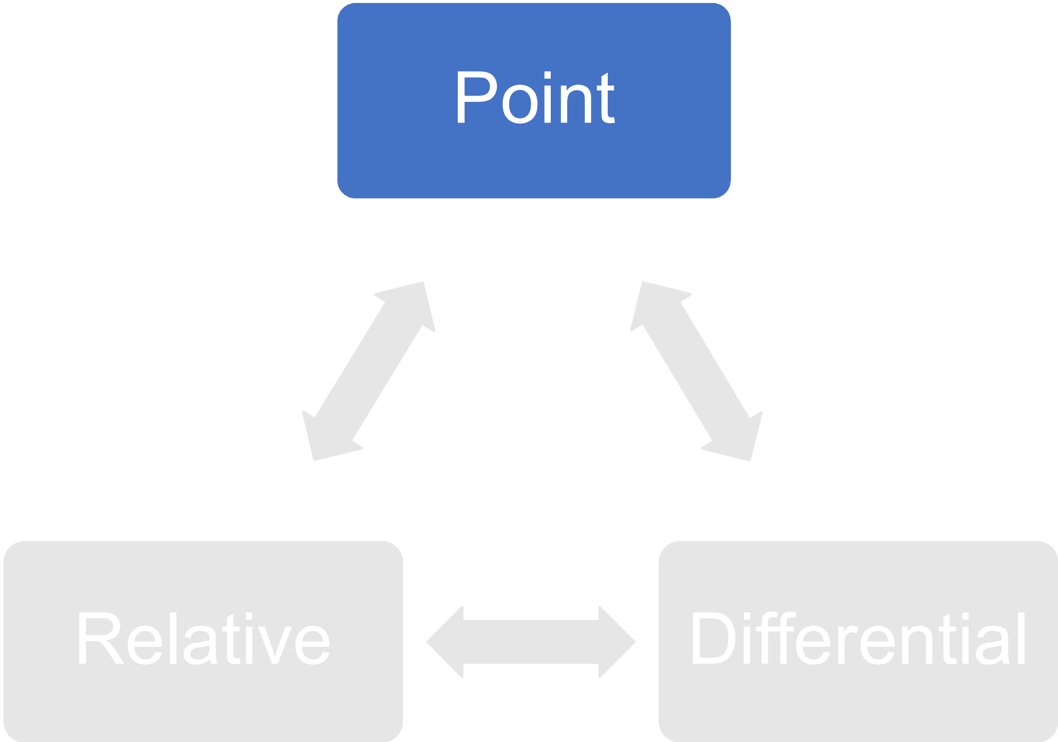
POSITIONING MODES



GNSS POSITIONING TECHNIQUES



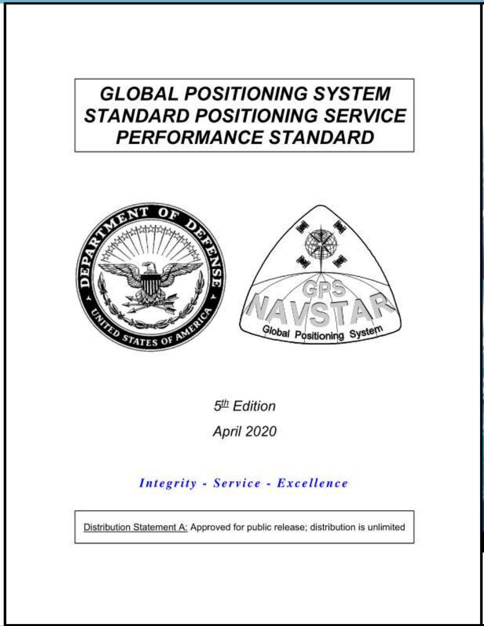
POSITIONING MODES

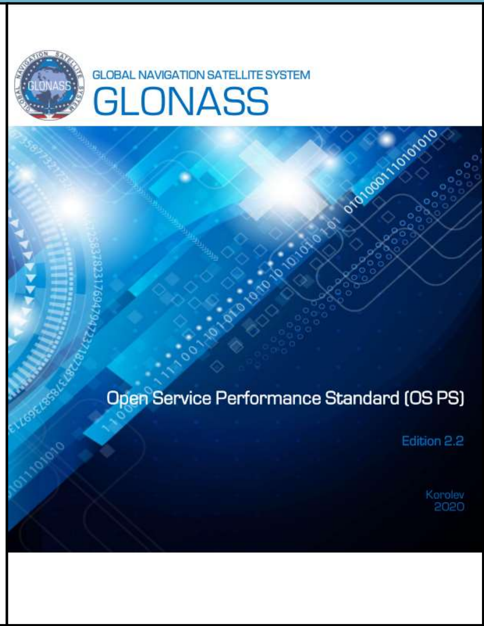


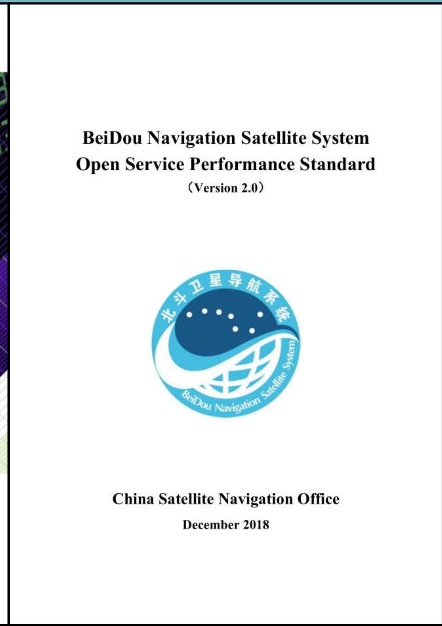
STANDARD POINT POSITIONING (SPP)

- Autonomous / standalone / absolute positioning
- Pseudoranges measured at **one receiver**
- GPS/GLONASS: two levels of performances
  - C/A-code: Standard Positioning Service (SPS) / Standard Precision Service (SP)
  - P-code: Precision Positioning Service (PPS) / High Precision Service (HP)
- Galileo / BeiDou
  - Open Service (OS)
  - Public Regulated Service (PRS) / Authorized Service
- 5 – 10 m (H), 10-20 m (V), 10-20 ns

The more you average over time the better the precision (~ 1 m)







	GPS	GLONASS	Galileo	BeiDou 2/3
Horizontal	8 / 15 m (95%)	5 / 12 m (95%)	7.5 m (95%)	5 -10 m (95%)
Vertical	13 / 33 m (95%)	9 / 25 m (95%)	15 m (95%)	5 -10 m (95%)
Velocity	< 0.2 m/sec (95%)	-	-	-
Timing	< 30 ns (95%)	< 40 ns (95%)	< 31 ns (95%)	< 10-20 ns
Document	5th Edition (2020)	v2.2 (2020)	SDD_v1.1 (2019)	v2.0 (2018)

PRECISE POINT POSITIONING (PPP)

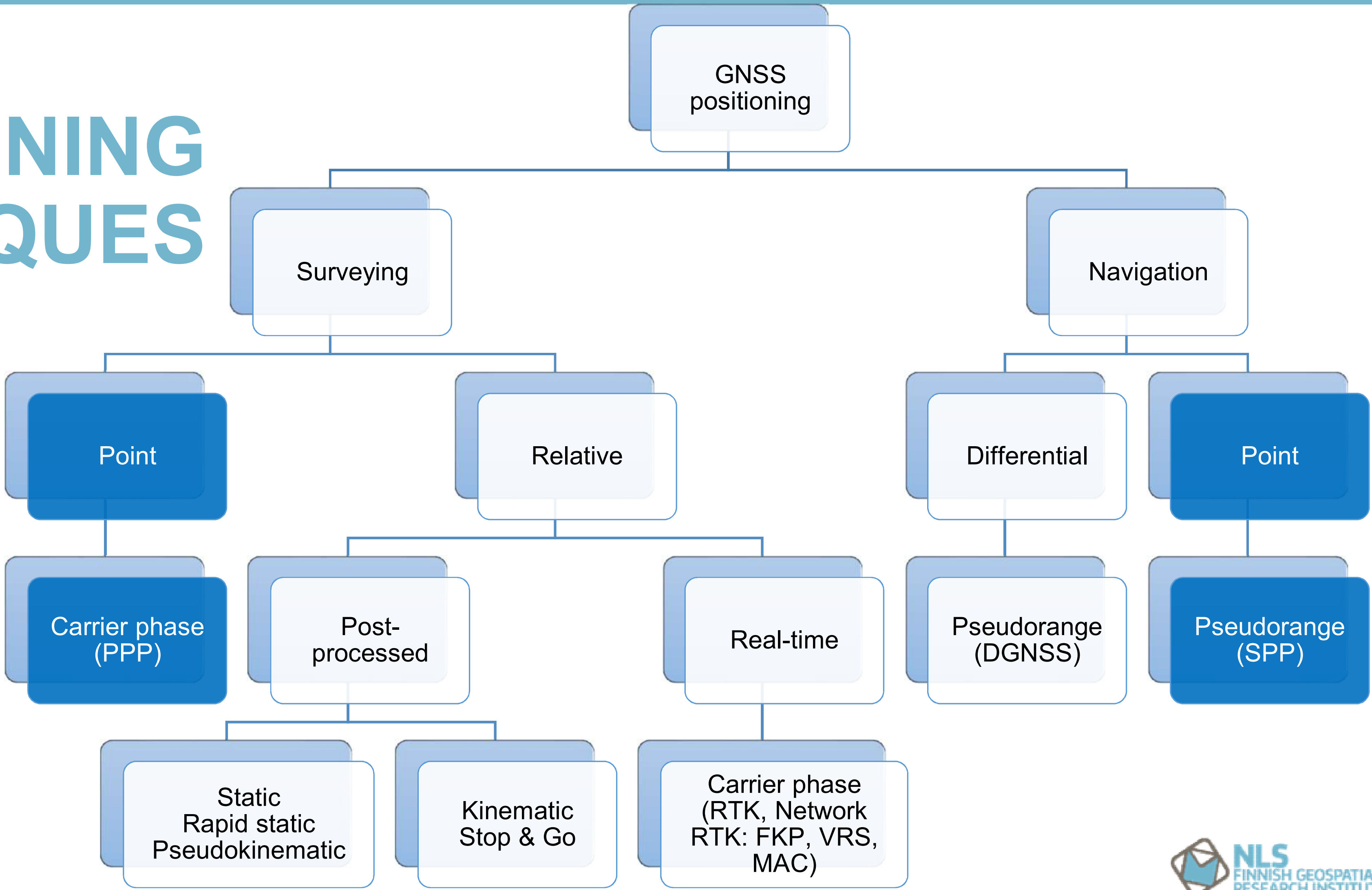
- **Precise** satellite **orbits** & **clocks**
- Pseudorange & **carrier phase** observations
- **Single** (Dual-Frequency) GNSS Receiver
- Iono-free data combinations (P3, L3)
- Traditional in post-processing, static, < 10 cm
- Convergence period (20-30 min)
- Real-time, kinematic require code/phase biases for AR, decimeter
- **Open**: OPUS, magicGNSS, RTS-IGS, etc.
- **Commercial:** CenterPoint RTX, Veripos APEX, Nexteq i-PPP, Fugro Starfix

Source: Andrei (2010)

POINT POSITIONING @METSÄHOVI

separate slides

GNSS POSITIONING TECHNIQUES



REFLECTION QUESTION

What are the characteristics differences between single point positioning (SPP) and precise point positioning (PPP)?

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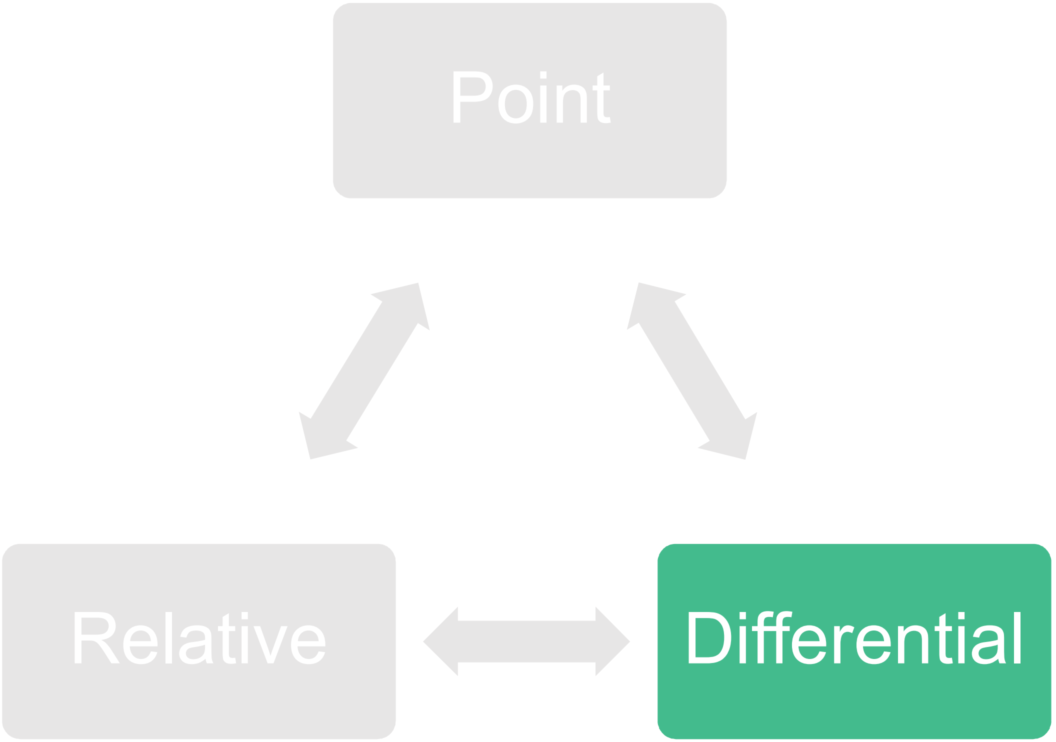
POSITIONING MODES



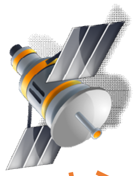
DIFFERENTIAL GNSS (CODE-BASED)

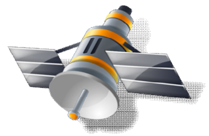
- Pseudo-ranges measured at **two receivers**
- Base station (reference receiver) at a **known location**
- **Real-time**
  - Base transmits *range errors* to remote (mobile) user
  - Maritime (RTCM), Aviation (RTCA)
- **Post-processing**
  - Single difference of pseudo-ranges
- Removes most ephemeris, atmospheric and satellite clock erros (including Selective Availability)

RTCM: Radio Technical Commission for Maritime Services
RTCA: Radio Technical Commission of Aeronautics

DIFFERENTIAL GNSS: PRINCIPLE

GNSS satellites





Two standards:
- RTCM (maritime)
- RTCA (aviation)

Base station

Base station at a known location.

Base station transmits **range corrections** to rovers (e.g., over a radio link).

Rover receiver

A rover receiver receives the GNSS signals, calculates pseudoranges, then **apply** the range corrections. Corrected ranges are used to determine **rover position.**

Base station receives GNSS signals, calculates pseudoranges to satellites, then determines **range errors.**

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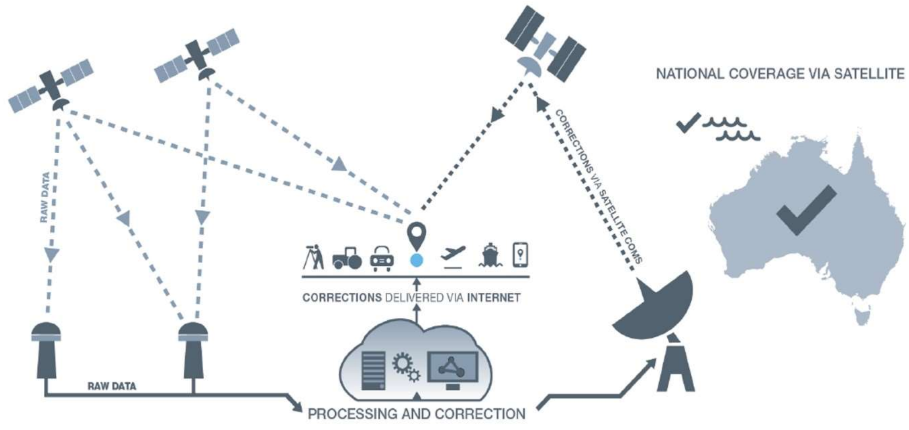
WIDE-AREA DGNSS

- Multiple base stations, master station, model local/regional corrections (orbit, clock, tropo, ionosphere as a grid)
- Several thousands km
- **Satellite-based augmentation (SBAS)**
    - **Non-commercial:**
        - WAAS (US), EGNOS (Europe), MSAS (Japan), GAGAN (India), SDCM (Russia),
        - BDSBAS (China), KASS (Korea),
    - **Commercial:**
        - OmniSTAR (Fugro, NLD), Starfire (NavCom, US), Veripos (Subsea7, UK)
- **Ground-based augmentation (GBAS)**
    - CDGPS (CAD), GRAS (AUS)

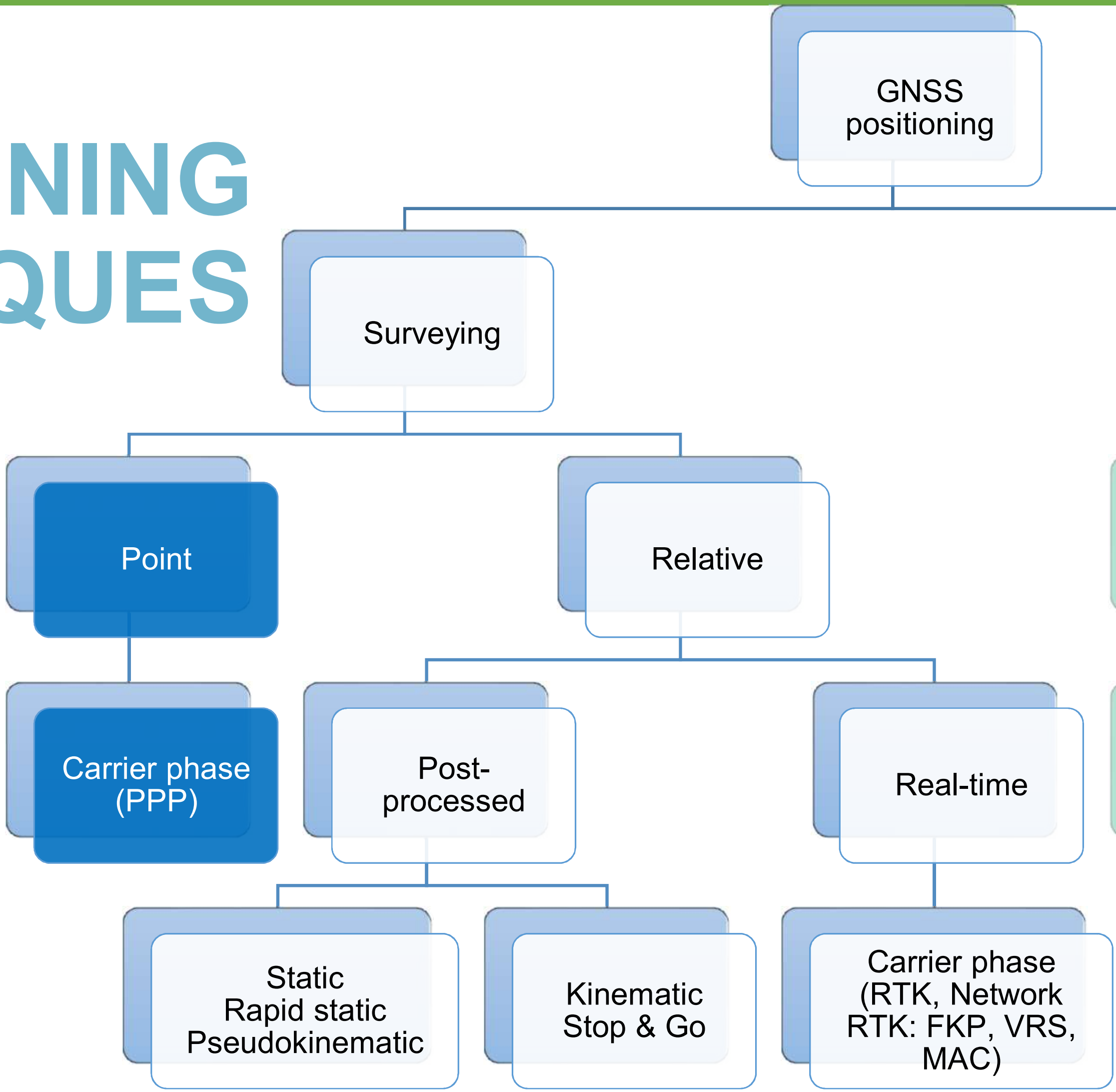


Source: Geoscience Australia

DGPS @METSÄHOVI

Results in separate slides

GNSS POSITIONING TECHNIQUES



REFLECTION QUESTION

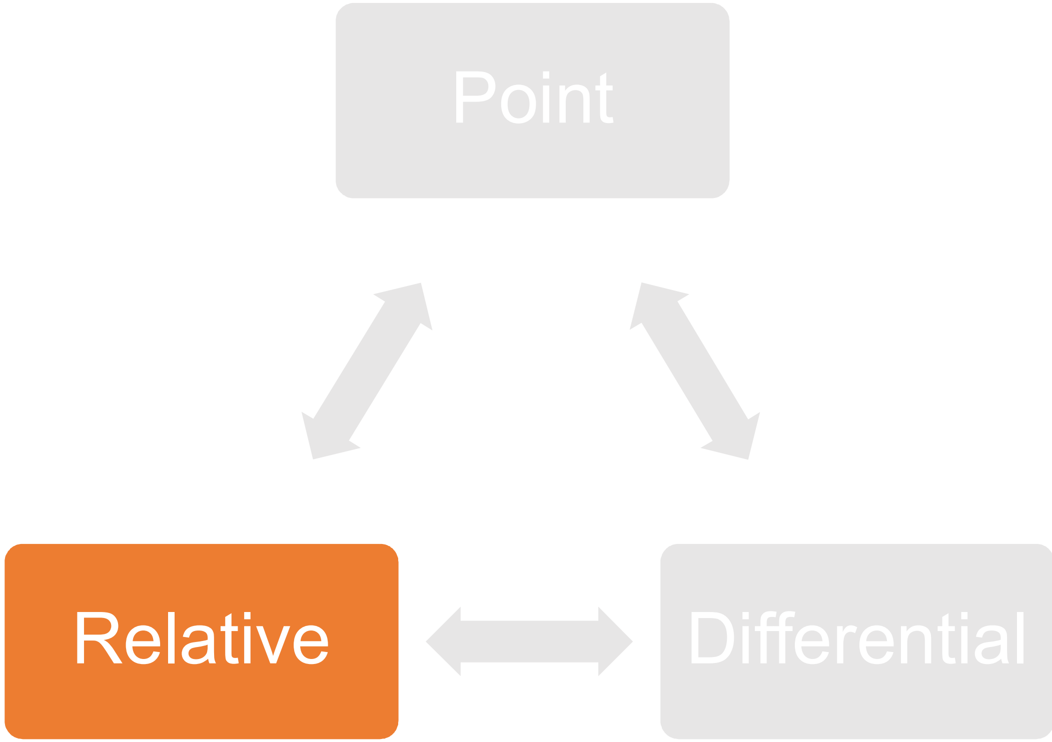
What are the data corrections transmitted in DGNSS/DGPS?

Do DGPS and SBAS differ?

If yes, how?

If no, why?

POSITIONING MODES



RELATIVE POSITIONING

- Differential GNSS with **carrier phases**
- User determines the position of an unknown point (rover) with respect to a known point (base)
  - At least a pair of receivers
- Simultaneous observations
  - Time-tagged GNSS measurements are transmitted from the base
  - The differentiation process takes place at the rover
- Both code and carrier possible, but only carrier-based offers cm-level accuracy
- **Baseline vector** and **position** are computed **at rover**

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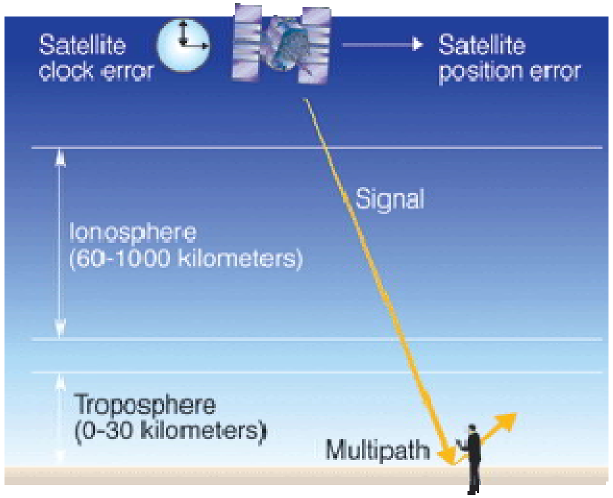
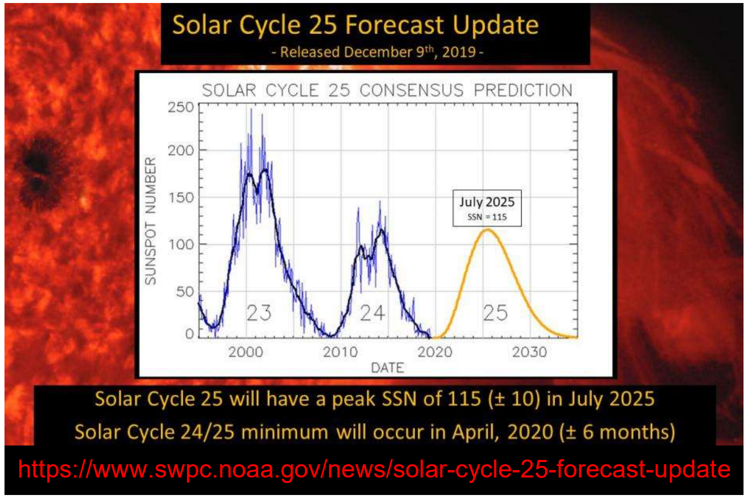
ABSOLUTE VS. RELATIVE





Error source	Absolute influence	Relative influence
Satellite orbit	2 ... 50 m	0.1 ... 2 ppm
Satellite clock	2 ... 100 m	0.0 ppm
Ionosphere	0.5 ... > 100 m	1 ... 50 ppm
Troposphere	0.01 ... 0.5 m	0 ... 3 ppm

ppm: parts per million

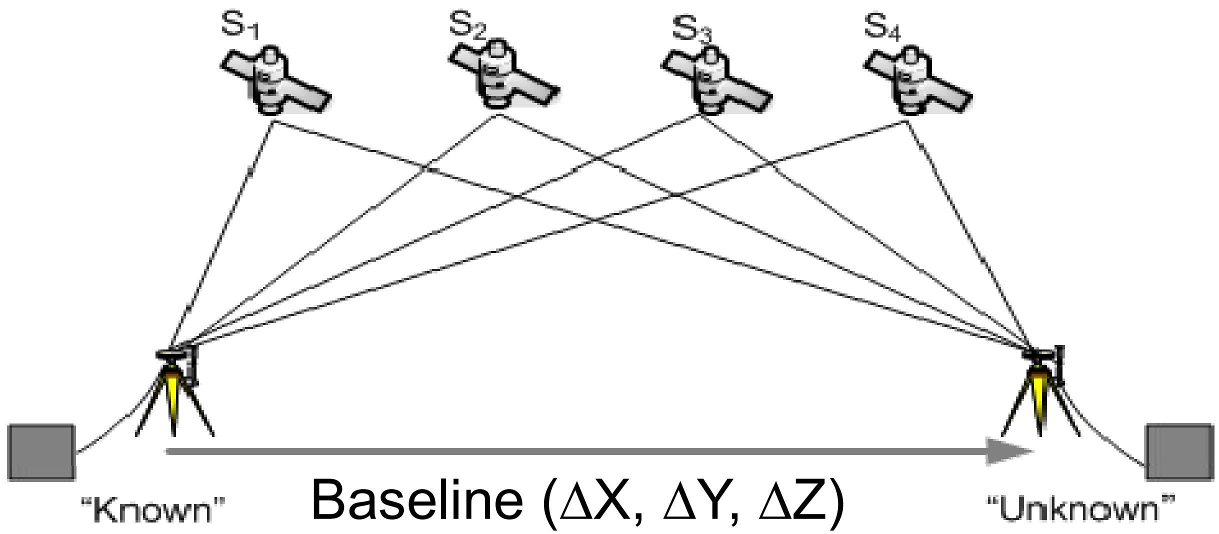
GNSS CARRIER PHASE POSITIONING

- **Static mode**
  - Measure carrier phases simultaneously at two or more points
  - Static surveying (an hour for each line, now a few minutes)
  - Relative positioning of ***few*** cm and ***few*** ppm

- **Kinematic mode**
  - Carrier phases at two or more receivers
  - One receiver stationary, one ***mobile*** from point to point
  - Fast / On-the-fly initialization
  - Centimeters in seconds => **Precision surveying / navigation**

STATIC RELATIVE POSITIONING

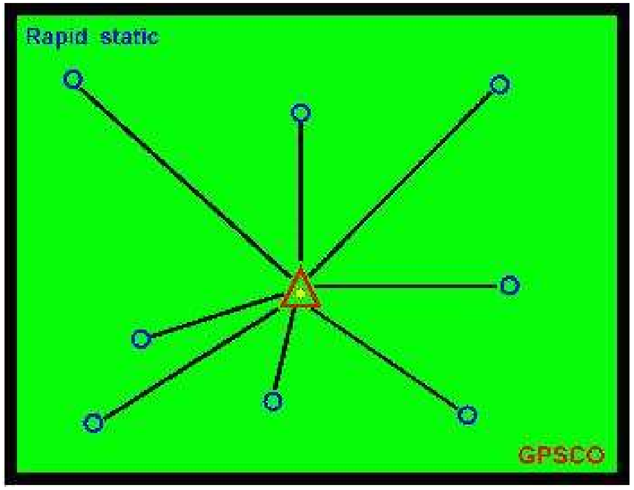
- Control and survey work
- Post-processing
- Reference, known position
- Rover, unknown position
- Epoch rate 15-30 sec
- Baseline accuracy
  - H: 3-5 mm + 0.5 ppm
  - V: 10 mm + 0.5 ppm



The ppm or parts per million component (1 mm per km) refers to the length of baseline between the RS and rover

RAPID STATIC

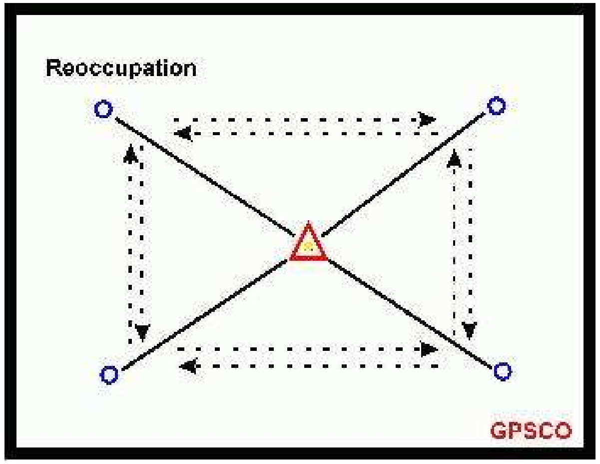
- Baselines up to 20 km
- Epoch rate 5 (10) sec
  - 10 min (5 s) vs. 60 min (30 sec)
- Baseline accuracy
  - Horizontal: 5-10 mm + 0.5 ppm
  - Vertical: 10-20 mm + 0.5 ppm



Method of Survey	Single Frequency	Dual Frequency
Static	30 min + 3 min / km	20 min + 2 min / km
Rapid Static	20 min + 2 min / km	10 min + 1 min / km

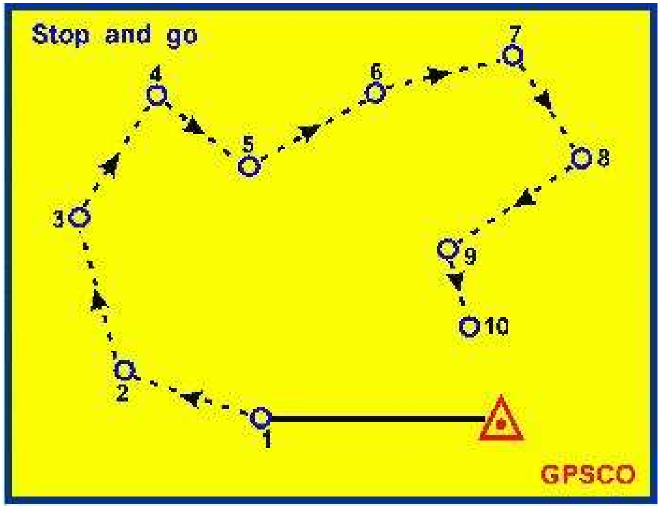
PSEUDO-KINEMATIC (REOCCUPATION)

- It exploits **changes** in satellite geometry across conventional observation sessions
- **At least** two short observation sessions (5 min each) on each point with at least 1 h time lapse between the sessions
- **Favorable** satellite geometry
- Alignment surveys
- Photo-control surveys
- Lower-order control surveys



KINEMATIC POSITIONING: STOP & GO

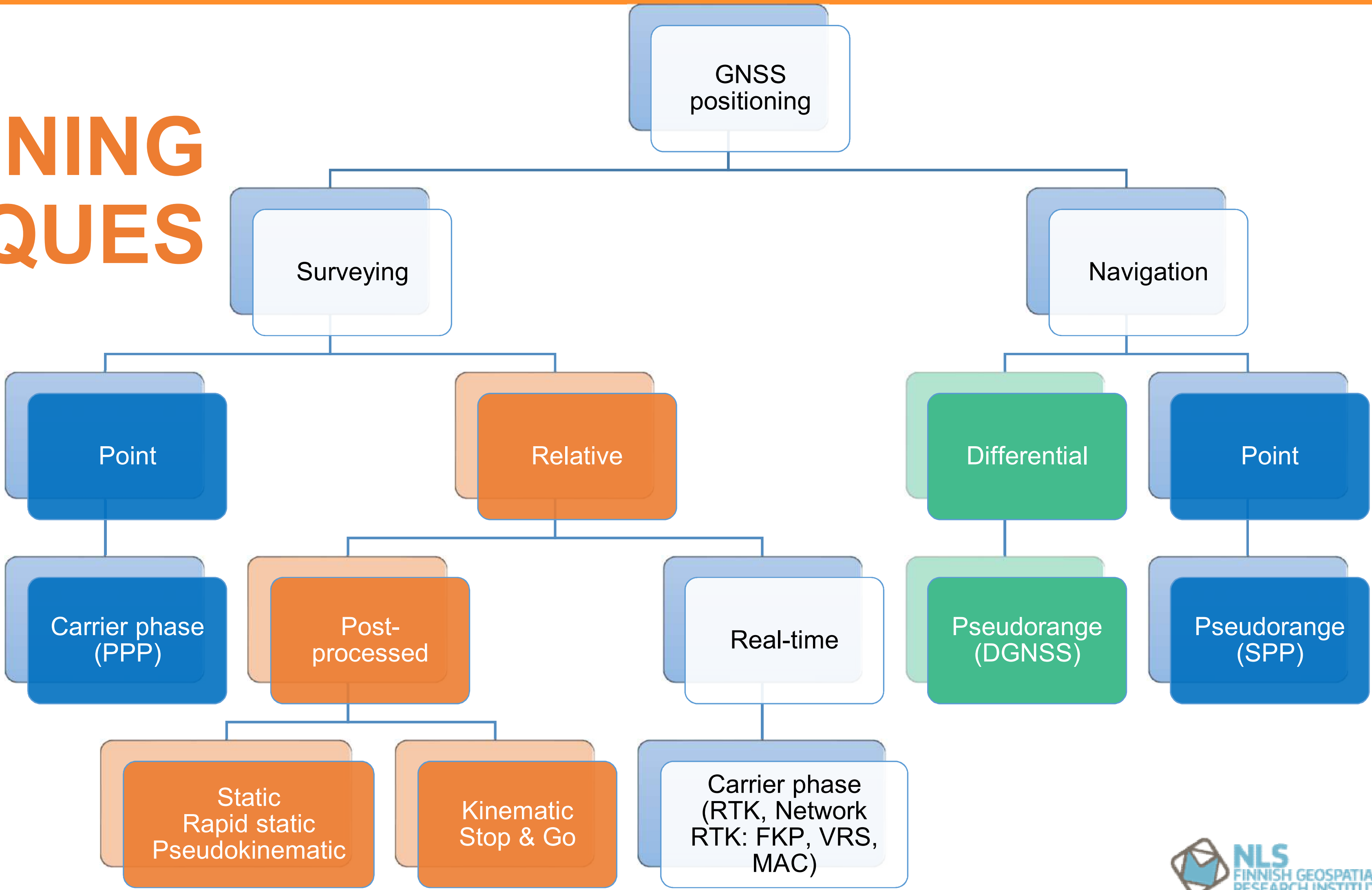
- **On-the-fly** ambiguity resolution
- Collect just a few minutes of **carrier phase data**
- The mobile receiver **must continues to track** satellites while it moves from site to site
- Attainable accuracies similar to rapid-static.



PPK @METSÄHOVI

Results in separate slides

GNSS POSITIONING TECHNIQUES



REFLECTION QUESTION

What is/are the main difference(s) between absolute and relative positioning?

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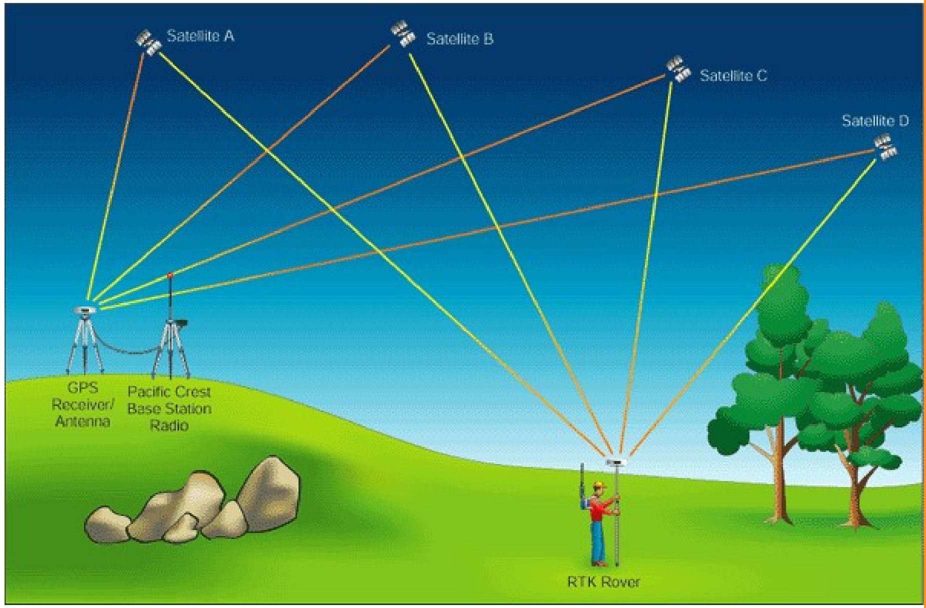
REAL TIME KINEMATIC (RTK)

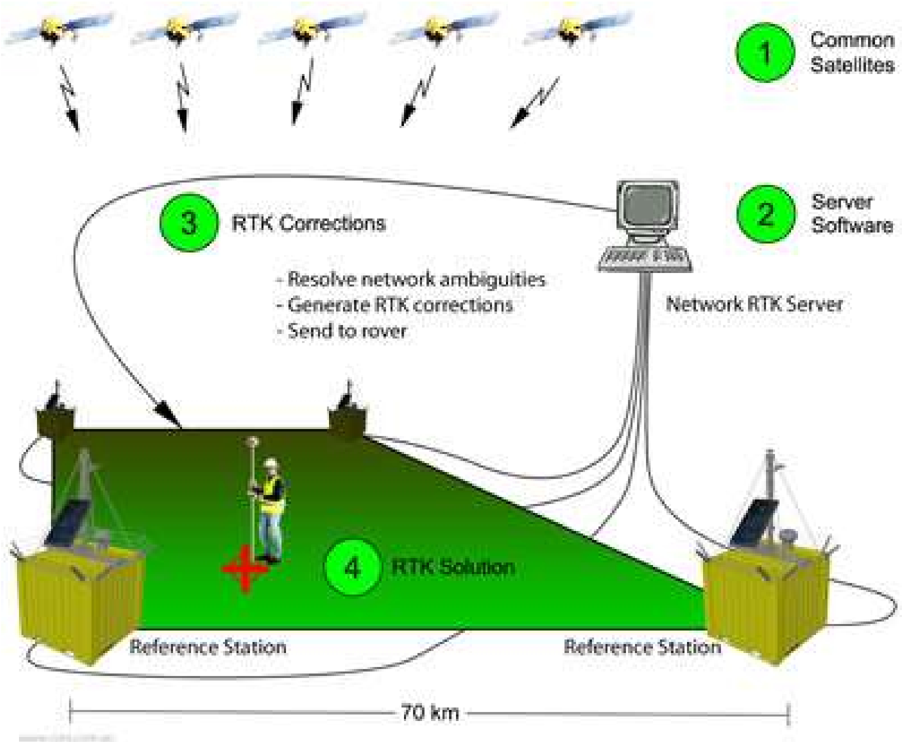
- Golden standard
- Base station at a known location.
- Base station transmits **code and phase measurement** to rover (e.g., over a radio link).
- Rover combines own GNSS data with time-tagged measurements from base station.
- **Baseline vector and position are computed by the rover.**



L1/L2:
H: 1 cm + 1 ppm
V: 2 cm + 2 ppm

NETWORK RTK: BASIC CONCEPT

1. Observing common satellites.
2. Resolving Network Ambiguities
3. Generating RTK Corrections
4. Producing RTK Solutions



NETWORK RTK: IMPLEMENTATIONS

- **Area Correction Parameters (FKP)**
  - The Flächen-Korrektur Parameter (FKP) is the oldest Network RTK method and was developed by Geo++ in the mid 1990s
- **Virtual Reference Station (VRS)**
  - Developed by Terrasat in the late 1990's
  - Pseudo Reference Station (PRS)
- **Master Auxiliary Concept (MAC)**
  - Proposed by Leica and Geo++ in 2001
  - MAX
  - individualized-MAX

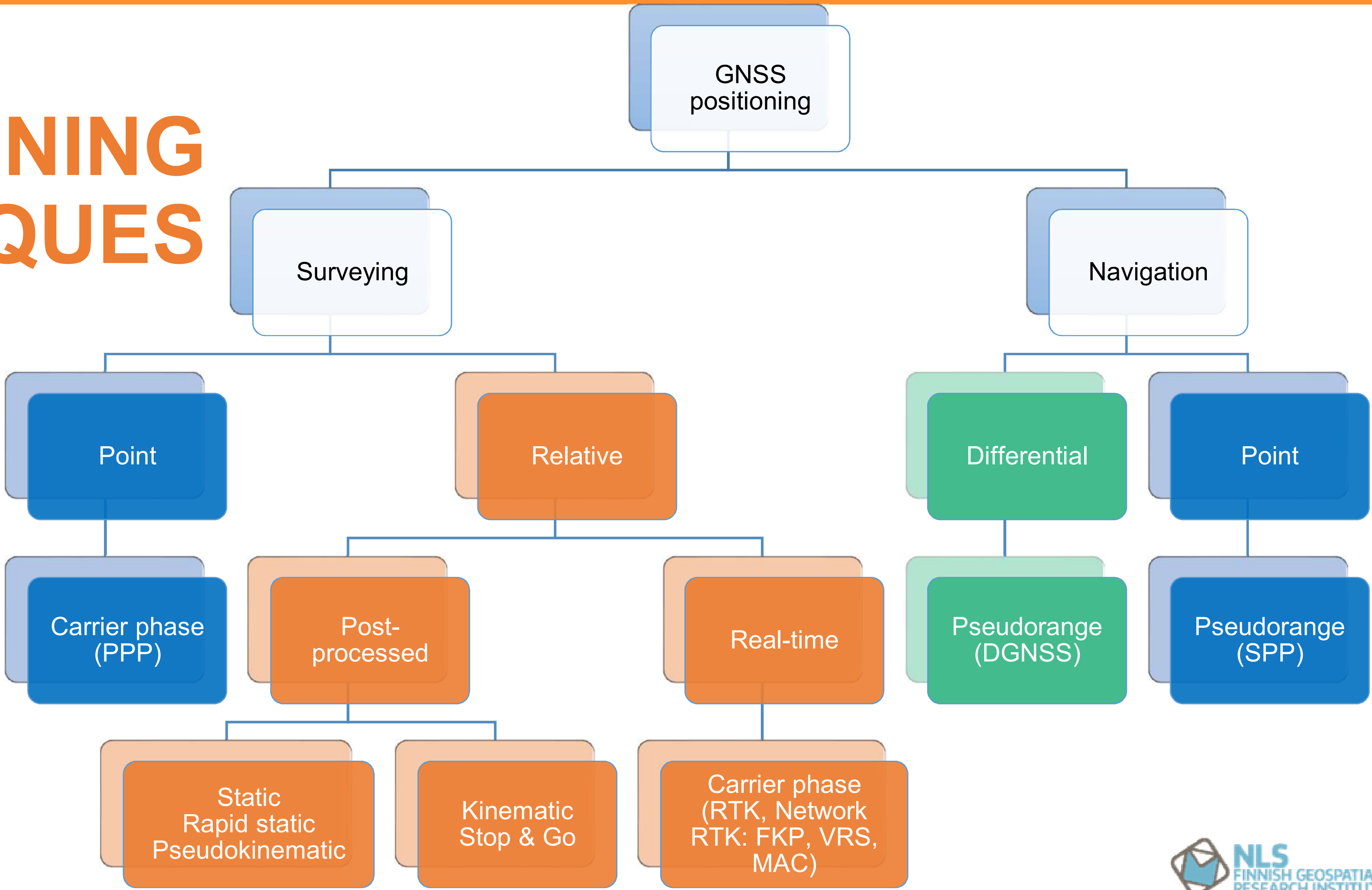
All approaches assume that a user will calculate **double differenced baseline** between one RS and the rover

NETWORK RTK: PROS & CONS

- **Advantages**
  - No need to set up a base station
  - The accuracies of the computed positions are more homogeneous
  - The accuracy is maintained over larger distances
  - The same area can be covered with fewer RS
  - Higher reliability and availability of RTK corrections

- **Disadvantages**
  - The cost to subscribe to an RTN and receive NRTK corrections

GNSS POSITIONING TECHNIQUES



SUMMARY

Results in separate slides

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SUMMARY

- **Content**
  - ➢ Various positioning modes: point, differential, relative.
  - ➢ Various positioning techniques: SPP, PPP, DGNSS, Static baseline, RTK

- Are you able?
  - ✓ **to distinguish** between different positioning modes.
  - ✓ **to choose** a suitable positioning technique for your application.