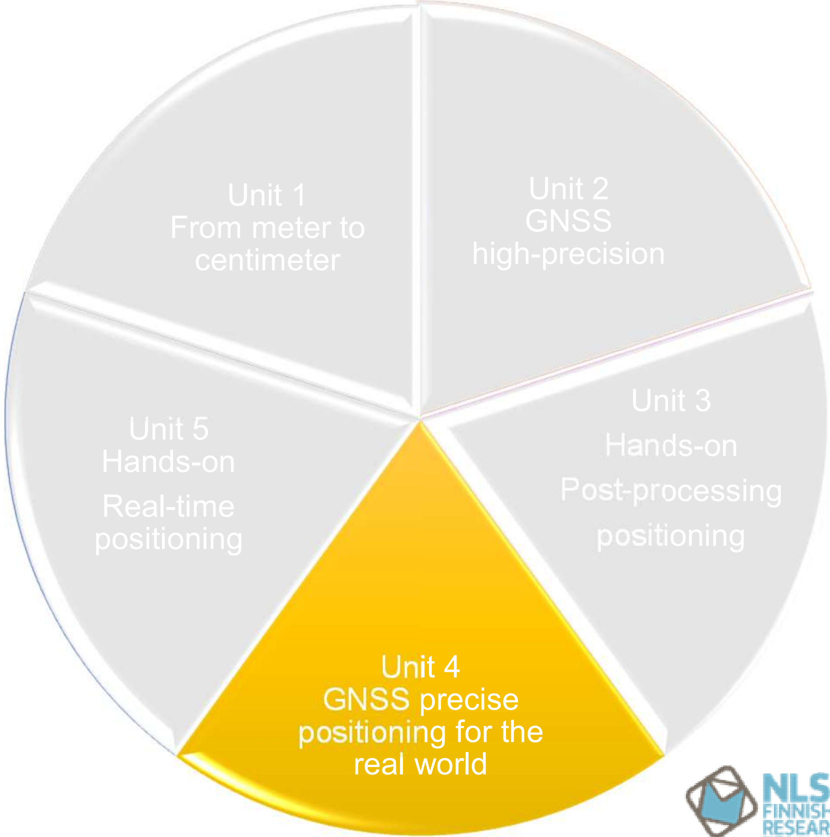
L4: GNSS PRECISE POSITIONING FOR THE REAL-WORLD

NLS
FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

UNIT STRUCTURE

- Lecture slides
- Reflection questions
- Examples, videos, & demos

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

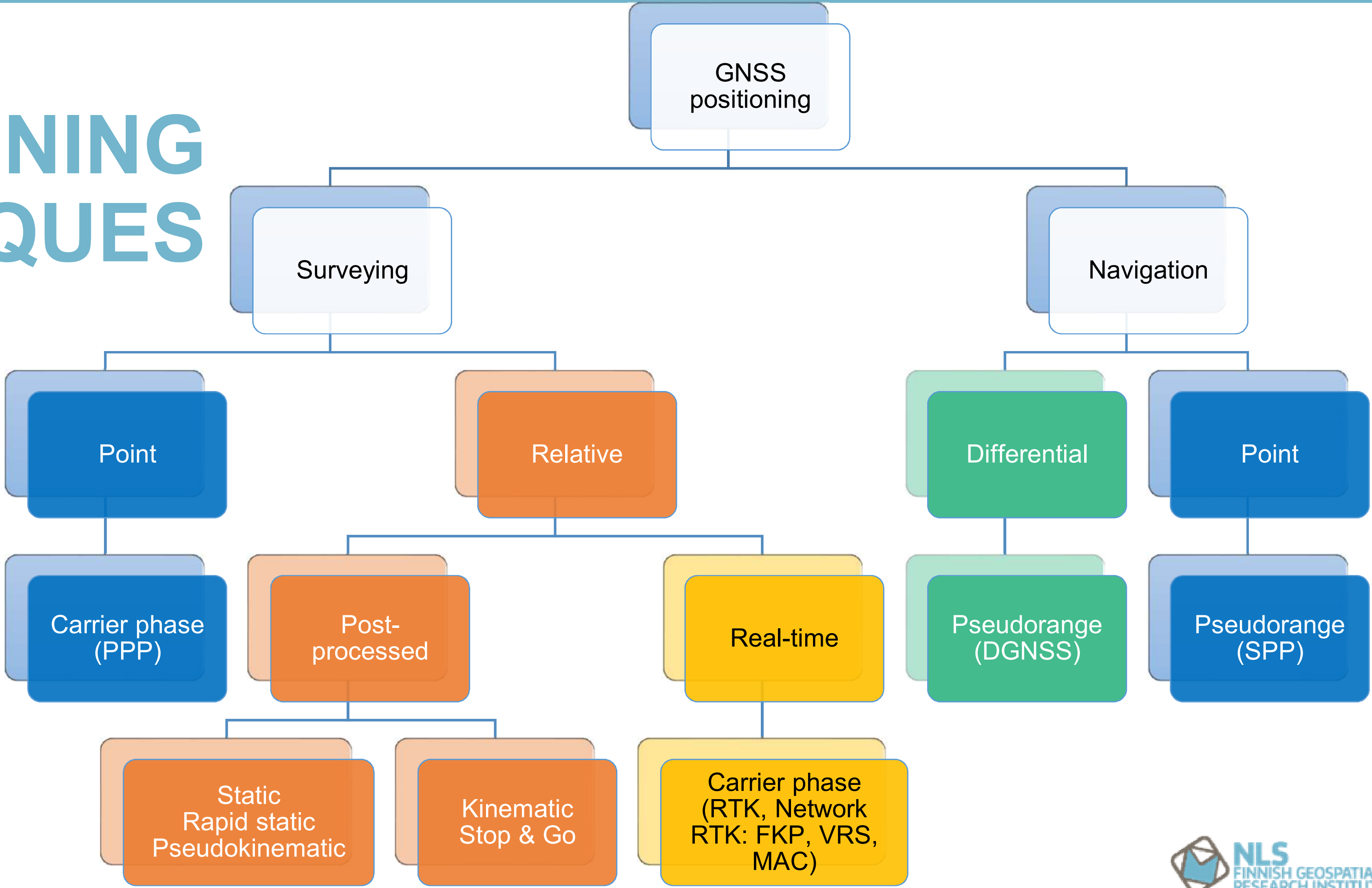


LEARNING OBJECTIVES

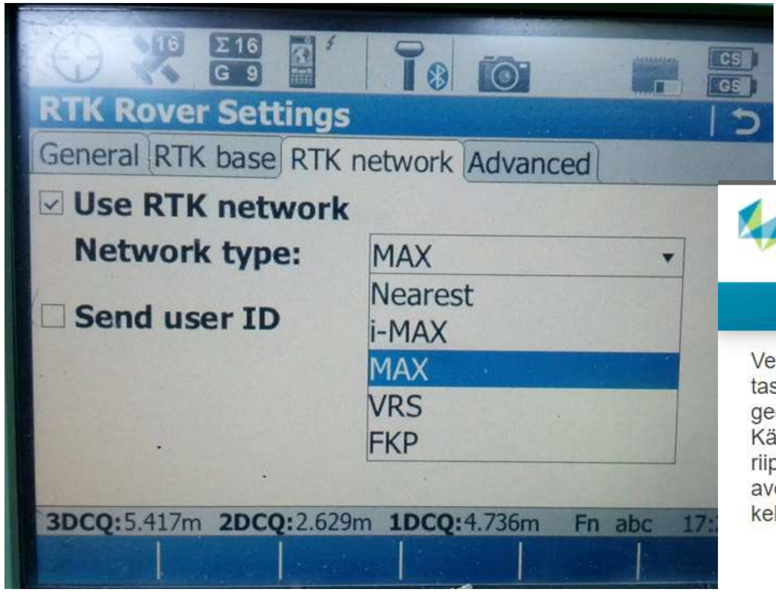
- **Content**
  - ➢ PPP-RTK, real-world applications, example, demos

- After this lecture, the participant should be able:
  - ✓ **to become familiar** with the future of GNSS high-accuracy services
  - ✓ **to propose** potential application using GNSS high-precision / high-accuracy positioning

GNSS POSITIONING TECHNIQUES



RTK / NRTK



HEXAGON | HxGN SmartNet

Verkko RTK korjauspalvelua käytettäessä mittaustarkkuus on tasossa noin 2 cm ja korkeudessa noin 4 cm. kun käytetään geodeettista kaksitaajuus vastaanotinta.
Käytettäessä HxGN SmartNet RTK-korjauspalvelua ei olla riippuvaisia etäisyydestä tukiasemiin. Korjausdata lähetetään avoimessa standarsoidussa RTCM-formaatissa 1 hz kellotaajuudella.

Edut

- Et tarvitse omaa tukiasemaa. Voit ottaa vanhan tukiaseman tuottavaan työhön
- Tarkat ja luotettavat RTK-korjaukset
- Liikkuvan saamat korjaustiedot ovat verkon alueella yhdenmukaiset
- Verkon ja tukiasemien laatua monitoroidaan 24/7 Bernese ohjelmalla
- RTK-korjaukset lähetetään standarsoidussa RTCM-formaatissa
- Sekä parhailla käytettävissä olevilla menetelmillä MAX ja iMAX

Trimnet VRS-palvelu

Nopea

Yhteys palveluun muutamassa sekunnissa.

24/7

Toimii 24/7. Helppo käyttää, varma toimivuus.

Soveltuu

Kaikkiin GNSS-mittaussovelluksiin

Monipuolinen

Useita lisenssivaihtoehtoja

Tarkkuusluokat

1 mm, 1 cm, 10 cm, 30 cm ja 50 cm

Avoin

Kaikille laitemerkeille ja tiedonsiirtotekniikoille

Apu lähellä

HelpDesk, web- ja mobiili-informaatiopalvelu

Räätälöitävissä

Ratkaisu joustaa tarpeiden mukaisesti

RTK VS. PPP

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)

PPP: TRADITIONAL MODEL

- Ionosphere-free linear combination (L_c, P_c / L_{IF}, P_{IF} / L_3, P_3)

$$L_{c\,r}^{\;s} = \rho_r^s + c(dt_r - dT^s) + T_r^s + B_{c\,r}^{\;s} + m_{Lc} + \varepsilon_{Lc}$$

$$P_{c\,r}^{\;s} = \rho_r^s + c(dt_r - dT^s) + T_r^s + m_{Pc} + \varepsilon_{Pc}$$

Ionosphere is removed

Estimates: Δx, Δy, Δz, dt, ztd, B_c

$$L_c = \frac{f_1^2 L_1 - f_2^2 L_2}{f_1^2 - f_2^2}; \quad P_c = \frac{f_1^2 P_1 - f_2^2 P_2}{f_1^2 - f_2^2}$$

$$B_c = \lambda_N \left(B_1 + \frac{\lambda_W}{\lambda_2} B_W \right), B_W = B_1 - B_2$$

$$\lambda_N = \frac{c}{f_1 + f_2}, \lambda_W = \frac{c}{f_1 - f_2}$$

but … AR not possible!

PPP-AR

- Several PPP-AR techniques using ionosphere-free comb
  - L_c, P_c, $L_{MW} = L_{WL} - P_{NL}$
- **Uncalibrated Phase Delay (UPD/FCB)**
  - Ge et al., 2008; Geng et al., 2012
- **Decoupled satellite clock (DSC)**
  - Collins et al., 2008
- **Integer recovery phase clock (IRC)**
  - Laurichesse et al., 2009

but … IF comb is a correlated obs with weak AR

- Practical differences but they provide **equivalent** user positioning results

PPP-RTK

RTK / NRTK
- OSR
- Local / Regional
- Integer ambiguity
- **cm accuracy**

PPP-RTK
- SSR
- Local / Regional
- Integer ambiguity
- **cm accuracy**

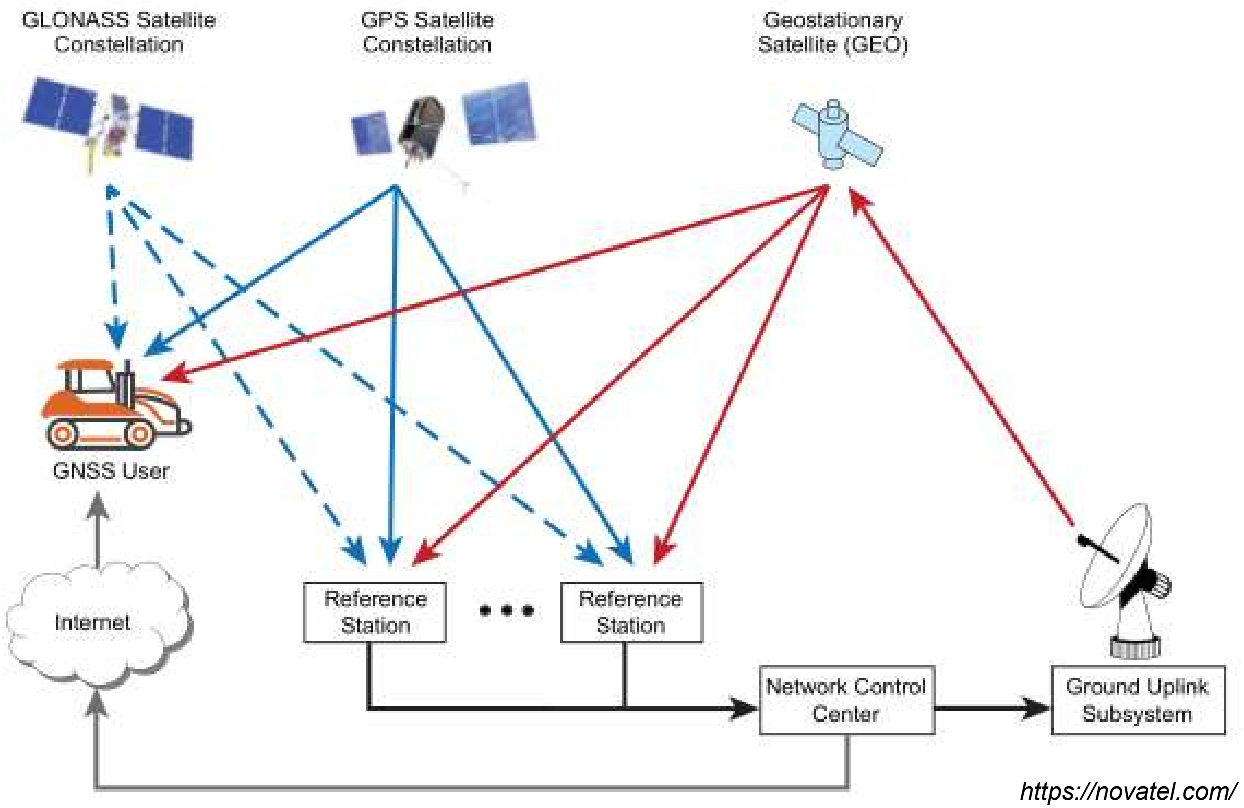
PPP
- SSR
- Global
- No integer ambiguity
- **dm accuracy**

http://www.geopp.com/pdf/ion2005_fw.pdf

PPP-RTK: DEFINITION

- Combine **absolute** and **differential** positioning
  - un-differenced phase and code observations
  - State Space Representation of the all GNSS errors from a RTN
- Perform **single-receiver integer ambiguity resolution**
- Obtain **cm-level** positioning within **few** seconds

PPP-RTK: SYSTEM OVERVIEW



https://novatel.com/

- Global network of RS
- NCC (2+)
- Satellite clock & orbit corrections
- Satellite code/phase biases
- Local / Regional atmospheric corrections
- Upload link
- GEO satellites or Internet
- High-latitude outages

PPP-RTK: NETWORK & USER MODELS

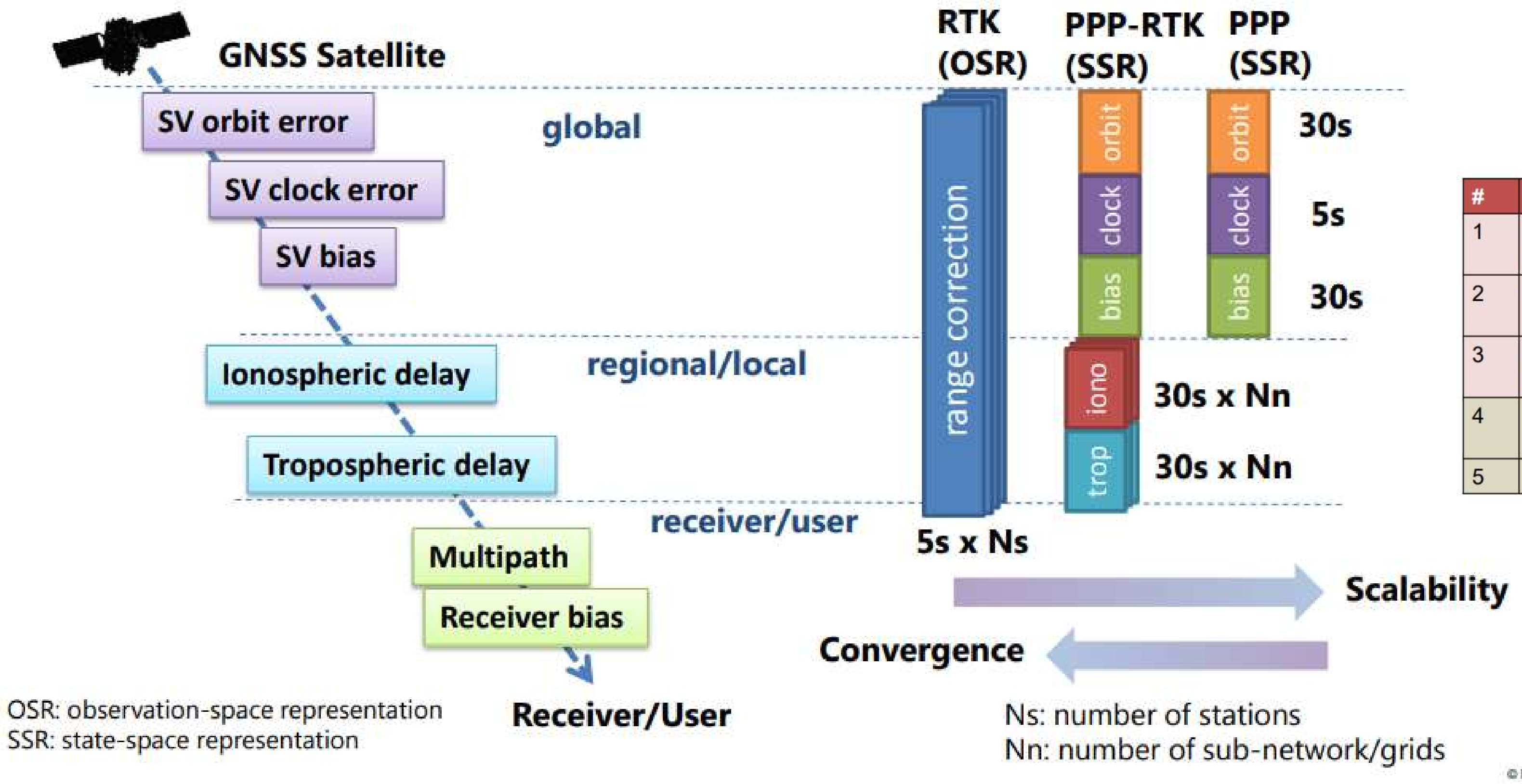
- **Un-differenced** code & phase observations
- **Network constraints**
  - Fix one receiver (code / phase)
  - Fix the ionosphere
  - Fix ambiguity at the same receiver
  - Fix ambiguity at one satellite
- **Estimate parameters**
  - Satellite biases (code & phase)
  - Receiver biases (code & phase)
  - DD ambiguities

- User uses similar obs eqs
- Sat orbit, clocks & biases (code & phase) from the network
- One user receiver => 3 unknown parameters
- User amb => DD integer ambiguities
  - user receiver
  - fixed receiver from the network model
  - fixed satellite ambiguity (@ pivot satellite)
  - tracked satellite

PPP-RTK: USER NEEDS

- **Hardware**
  - Dual-frequency
  - L-band
  - Decode data corrections
- **Error mitigation**
  - Iono: dual-frequency
  - Orbit / clock / bias: external data correction
  - Tropo: dry (model), wet / gradient (estimated)
  - Site related displacements
- **Algorithm**
  - Extended Kalman Filter (EKF)
  - Position
  - Receiver clock
  - Tropo: wet delay + gradients
  - Carrier phase ambiguity

PPP-RTK: STANDARDIZATION



#	Type	Publisher	Application
1	RTCM 3 (2004-2011)	RTCM	RTK/NRTK PPP
2	Compact SSR (2015)	Melco	PPP/PPP-RTK
3	LPP (2019)	3GPP	RTK/NRTK PPP/PPP-RTK
4	SSRZ	Geo++	PPP/PPP-RTK
5	SAPA	Sapcorda	PPP/PPP-RTK

https://www.unoosa.org/documents/pdf/psa/activities/2019/UN_Fiji_2019/STS-39.pdf

FUTURE: HIGH ACCURACY SERVICES

- ✓ Open PPP/PPP-RTK correction services are available.
- ✓ Low cost dual-frequency receivers are available in the mass-market.
- ✓ Open High-Accuracy GNSS Positioning would be commodity in the middle of 2020.

u-blox F9P

Broadcom BCM47755

Interoperability between correction services and receivers becomes highly important.

List of Open Satellite-Based High-Accuracy GNSS Correction Service

System	Service	Satellite	Status	Signal	Data Rate	Format
QZSS CLAS	PPP-RTK	IGSO/GEO	Operational (2018-)	1.278GHz (L6D)	2,000bps	Compact SSR
QZSS MADOCA	PPP	IGSO/GEO	Experimental (2017-)	1.278GHz (L6E)	2,000bps	RTCM SSR
Galileo HAS	PPP	MEO	Development (2021-)	1.278GHz (E6b)	500bps	Compact SSR as starting point
GLONASS	PPP	MEO/IGSO	Development (2020?)	1.207GHz (L3)	?	?
Beidou 3	PPP	GEO	Development (2020?)	1.207GHz (B2b I/Q)	1,000bps	?
Austrian SBAS	PPP	GEO	Development(2023-)	1.5GHz (L)	?	?

https://www.unoosa.org/documents/pdf/psa/activities/2019/UN_Fiji_2019/STS-39.pdf

QZSS CLAS

https://qzss.go.jp/en/technical/download/pdf/ps-is-qzss/ps-qzss-002.pdf

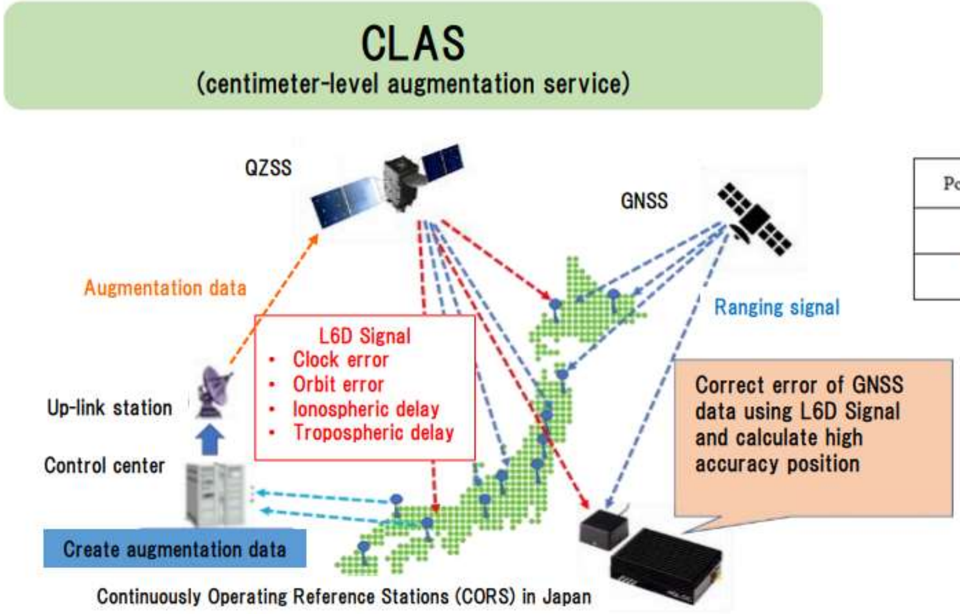
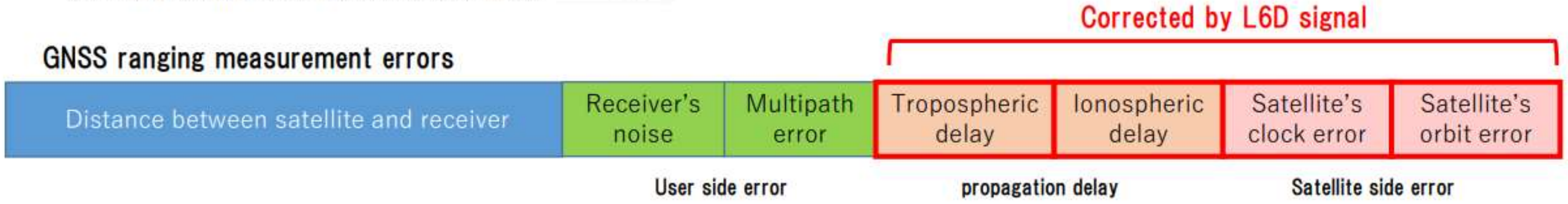


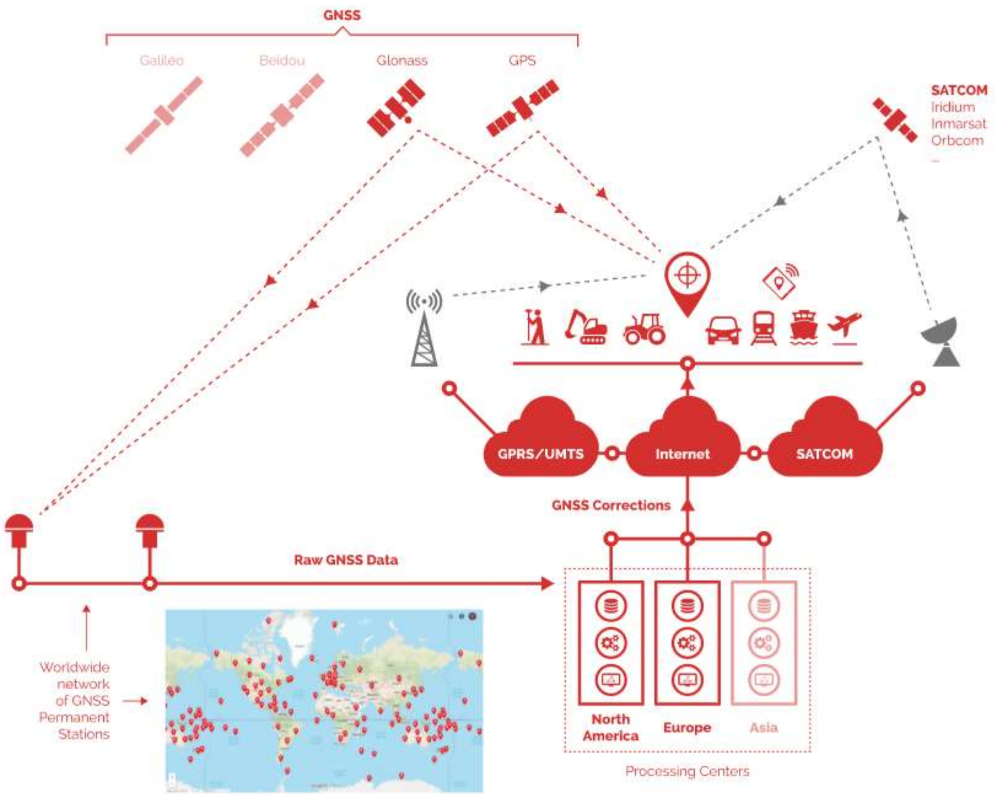
Table. 6.3-1 Positioning Accuracy

Positioning Type	Positioning Error		Remark
	Horizontal	Vertical	
Static	≤ 6cm(95%) (3.47cm(RMS))	≤ 12cm(95%) (6.13cm(RMS))	(*)(**)
Kinematic	≤ 12cm(95%) (6.94cm(RMS))	≤ 24cm(95%) (12.25cm(RMS))	(*)(**)

RTK class performance without base station



GEOFLEX: PPP-CNES



GEOFLEX, NEW SERVICES OPERATOR TO AUGMENT GNSS

GEOFLEX, USING CNES (*CENTRE NATIONAL D'ETUDES SPATIALES - THE FRENCH GOVERNMENT SPACE AGENCY*) PATENTS, IS **OPERATOR** OF NEW GNSS (*GLOBAL NAVIGATION SATELLITE SYSTEMS*) AUGMENTATION SERVICES BASED ON THE **PPP-CNES TECHNOLOGY** (*PRECISE POINT POSITIONING*).

ABSOLUTE POSITIONING ACCURACY OF **4 CM** (2D-95%)*, **EVERYWHERE** IN THE WORLD, ON THE GROUND, ON THE SEA AND IN THE AIR, **ALL THE TIME**, WITH **ONLY ONE RECEIVER**, **WITHOUT ANY NEARBY GNSS REFERENCE STATION**: **PRECISION**, **AVAILABILITY** AND **INTEGRITY**

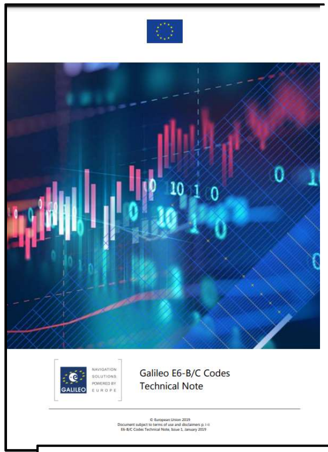
**Depending on the level of service subscribed: Absolute positioning precision of 2, 4, 10, 50 or 80 cm (2D-95%)*

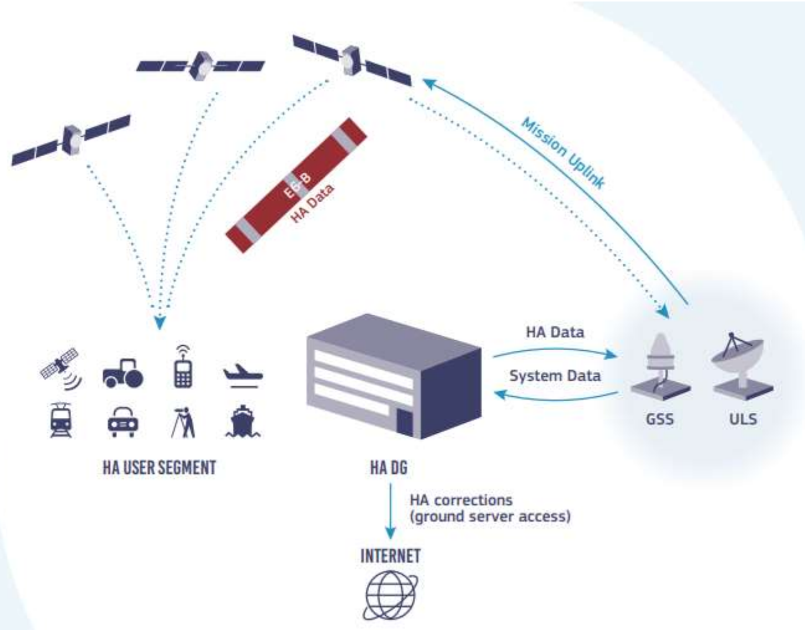
COMPATIBLE WITH **GPS**, **GLONASS**, **BEIDOU** AND **GALILEO** CONSTELLATIONS AND **MONO** AND **MULTI-FREQUENCIES RECEIVERS**

Single-frequency PPP multi-GNSS	**RT-PPP-L1** Accuracy of 80 cm Convergence of 30 minutes
Single-frequency PPP multi-GNSS + iono. SBAS	**RT-PPP-L1 "Fast and Precise"** Accuracy of 50 cm Convergence of 1 minute
Dual-frequency PPP multi-GNSS with float ambiguities	**RT-PPP-L1/L2** Accuracy of 10 cm Convergence of 30 minutes
Dual-frequency PPP multi-GNSS with fix ambiguities	**PPP-IAR** Accuracy of 4 cm Convergence of 30 minutes
Tri-frequency PPP multi-GNSS with fix ambiguities	**PPP-RTK** Accuracy of 2-4 cm Convergence of 5 minutes

http://www.geoflex.fr/

GALILEO HAS





https://www.gsc-europa.eu/sites/default/files/sites/all/files/Galileo_HAS_Info_Note.pdf

HAS	Service Level 1	Service Level 2
Coverage	Global	Europe
Corrections	Orbit, clock, biases (code & phase)	Orbit, clock, biases (code & phase) **Atmospheric corrections**
Format	Open format similar to Compact SSR	
Dissemination	Galileo E6B 448 bits per sat per second / terrestrial (Internet)	
Constellations	Galileo, GPS	
Frequencies	E1/E5a/E5b/E6; E5 AltBOC L1/L5; L2C	
Horizontal 95%	< 20 cm	
Vertical 95%	< 40 cm	
Convergence	< 300 s	< 100 s
Availability	99 %	
User helpdesk	24 / 7	

https://www.gsa.europa.eu/sites/default/files/uploads/ucp_2020_galileo_high_accuracy_service_0.pdf

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

SUMMARY

	RTK	Network RTK			Precise Point Positioning		
	RS	FKP	VRS/PRS	MAC	PPP	PPP-AR	PPP-RTK
Correction data	Orbit error, clock error, code / phase biases, ionosphereic delay, tropospheric delay				Orbit error, clock error		
						Code / phase biases	
							Iono / Tropo
Approach	OSR (Observation State Representation)				SSR (State Space Representation)		
Accuracy	cm				dm		
Convergence	< 5 s				20 min	< 10 min	5 – 60 sec
Coverage area	Local	Regional			Global	Global	Regional / Global
Dual frequency	Yes						
Bandwidth	Medium	Medium	High	Medium	Low	Low	Low-Medium

octavian.andrei@nls.fi

REFLECTION QUESTION

Which technique would you choose: RTK, PPP, PPP-RTK, other or None? Explain why?

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

APPLICATIONS

https://www.usegalileo.eu

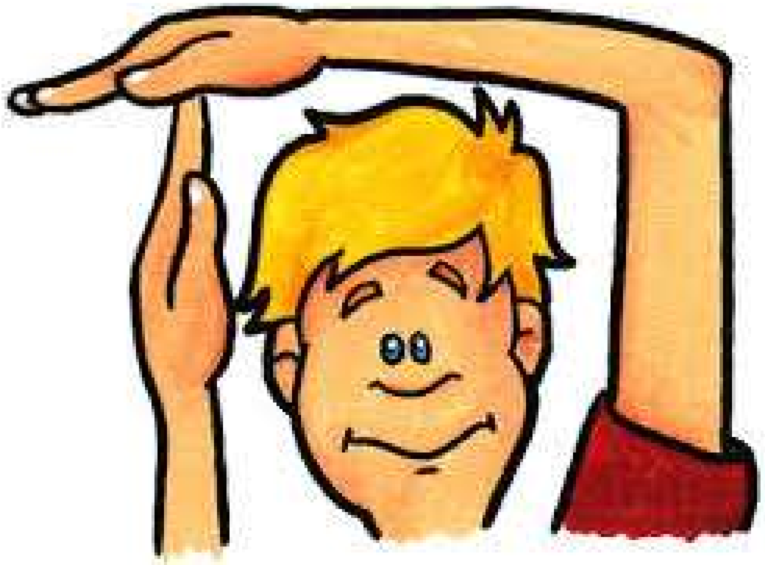
EXAMPLES OF GNSS APPS

Professional

Safety of Life

Mass Market

TIME FOR BREAK

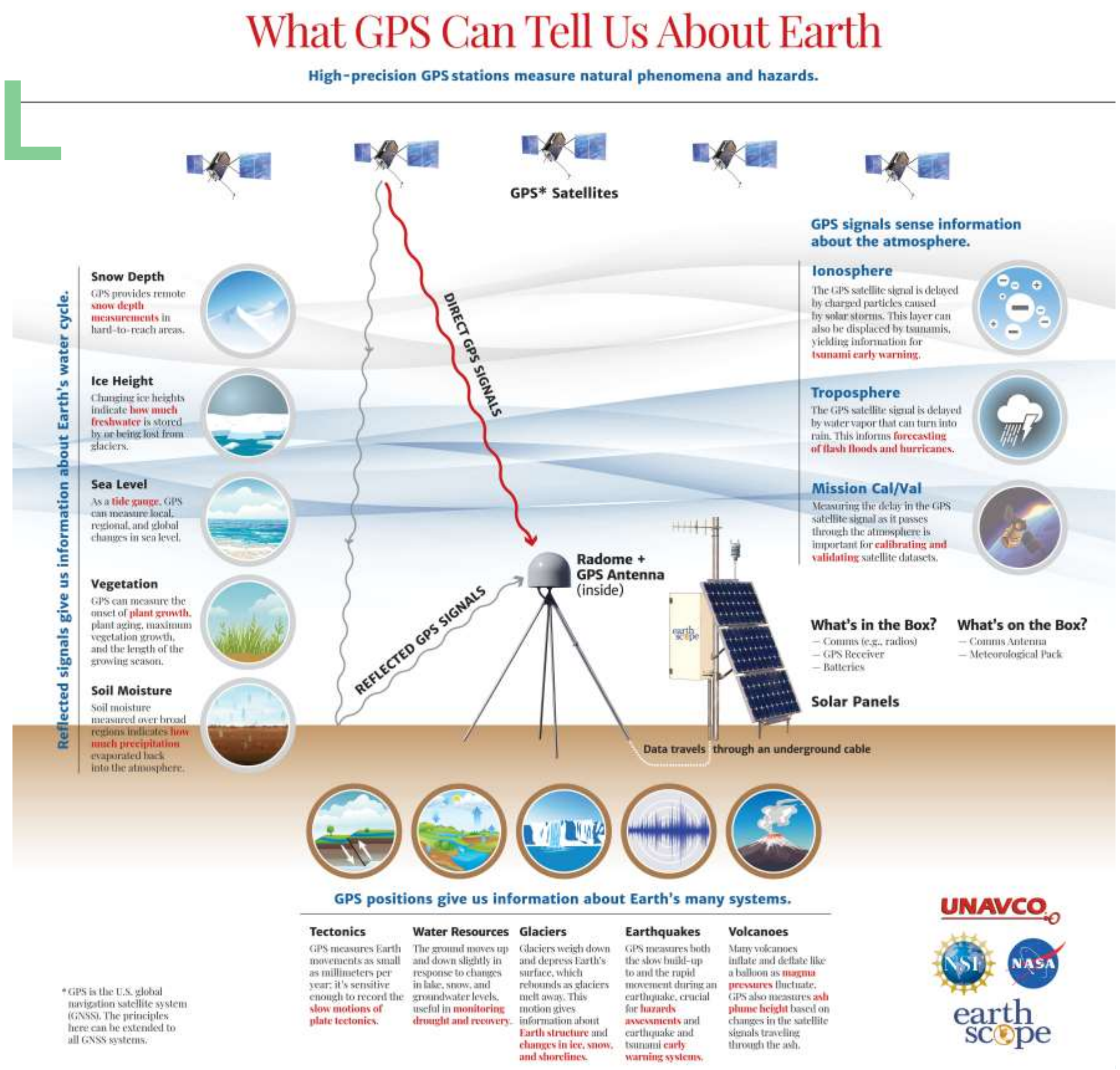


MAPPING

https://www.youtube.com/watch?v=_2zVSpfenTI

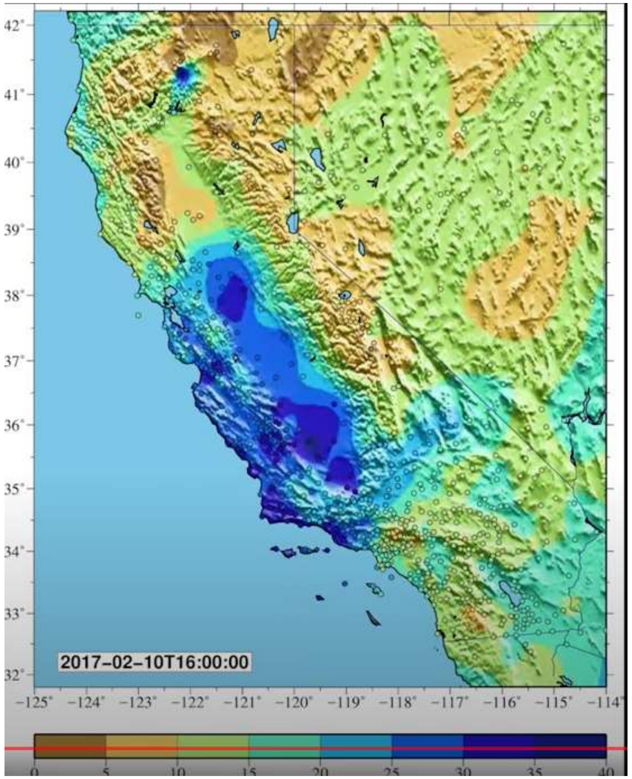
NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

ENVIRONMENTAL MONITORING



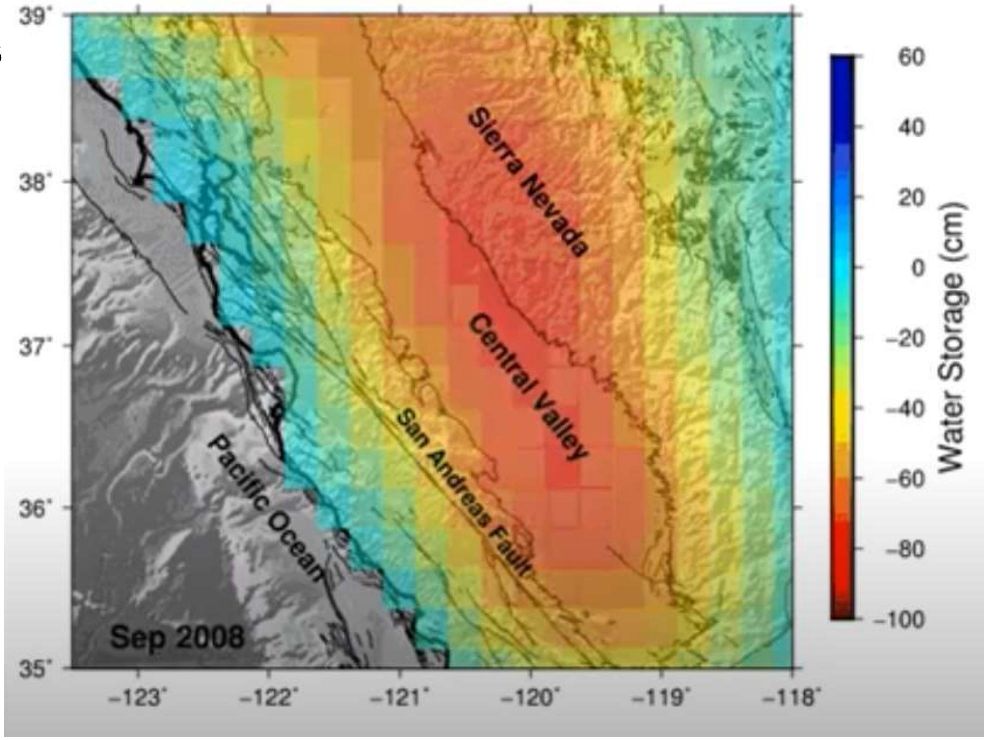
https://www.youtube.com/playlist?list=PLzmugeDoplFM5pPI80wwi3qmtZH99Ism2

PRECIPITABLE WATER & DROUGHT



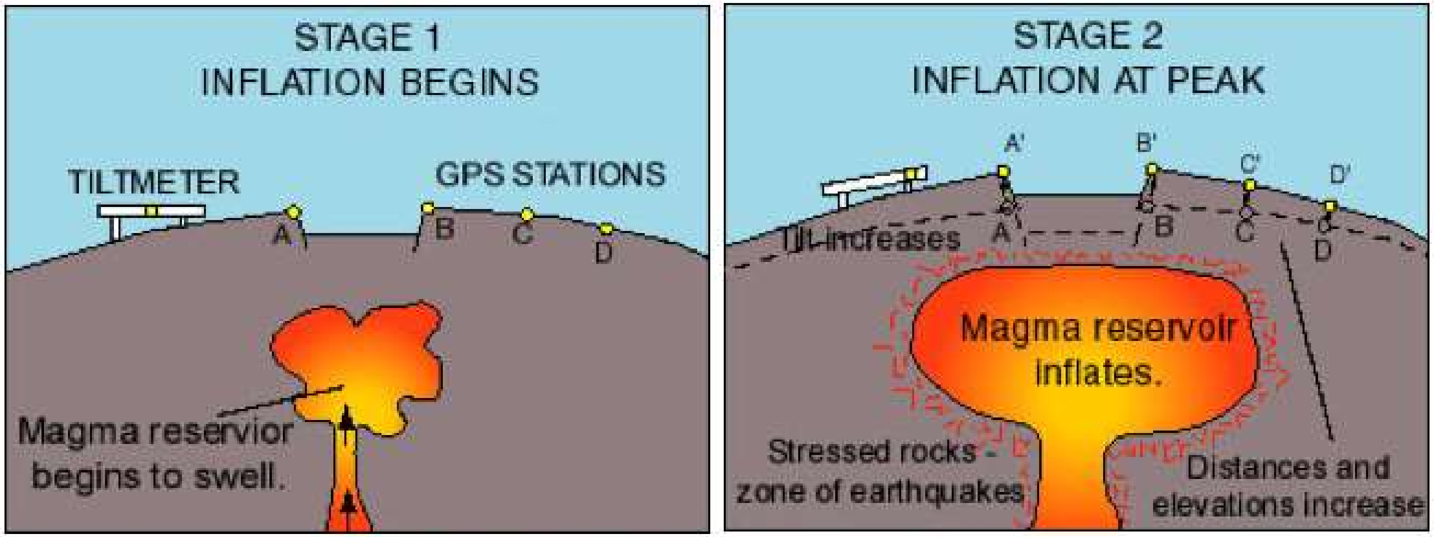
https://www.youtube.com/watch?v=f4Z9v7ujnIE

S

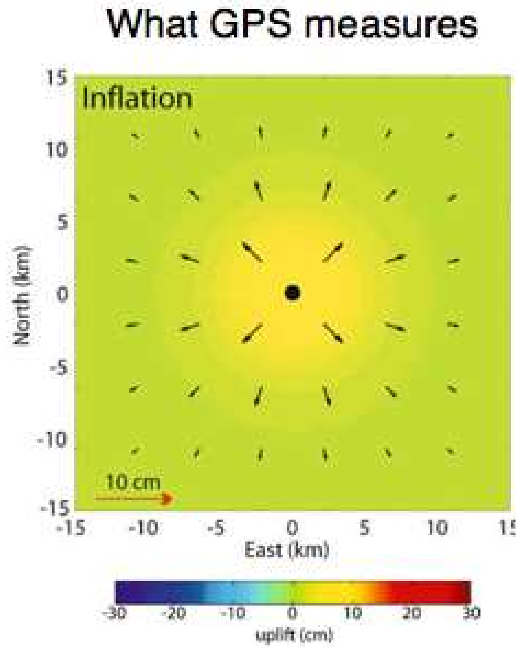


https://www.youtube.com/watch?v=Z4cbSOakviI

VOLCANOS



What's going on inside the volcano

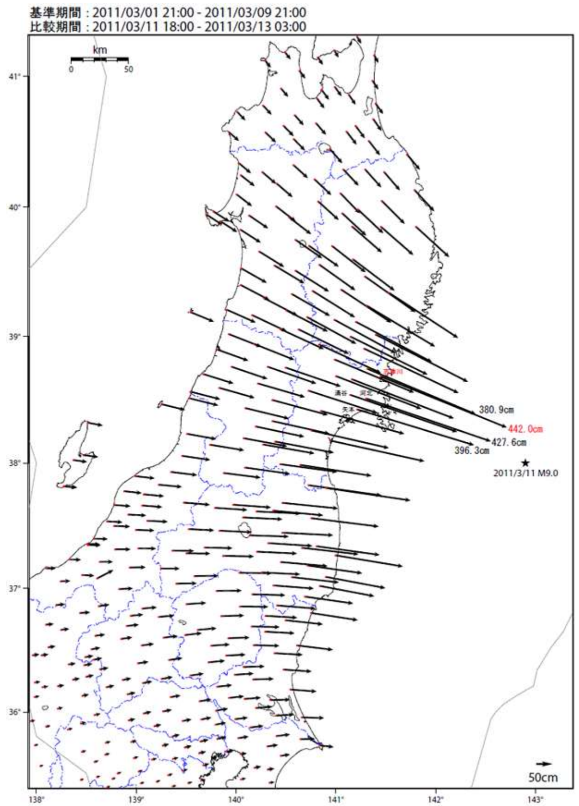


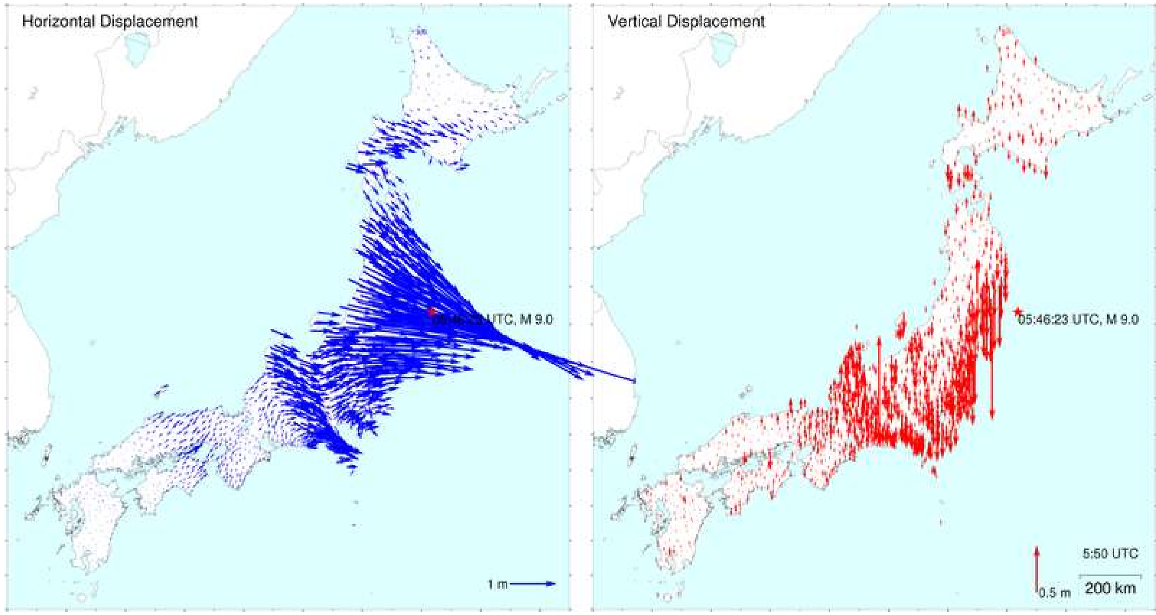
https://spotlight.unavco.org/how-gps-works/gps-and-tectonics/gps-and-volcanoes.html

Reykjanes, Island, 2021: https://twitter.com/i/status/1373340849036259338

NATURAL HAZARDS

http://www.gps.alaska.edu/ronni/sendai2011.html





https://blogs.agu.org/mountainbeltway/2011/03/15/new-gps-vectors /

March 20, 2021: https://twitter.com/i/status/1373245417165631491

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

PHYSICAL APPS

REVIEW ARTICLE

Physical applications of GPS geodesy: a review

Yehuda Bock[1] and Diego Melgar[1,2]

Published 23 August 2016 • © 2016 IOP Publishing Ltd

Reports on Progress in Physics, Volume 79, Number 10

Citation Yehuda Bock and Diego Melgar 2016 *Rep. Prog. Phys.* 79 106801

+ Article information

Abstract

Geodesy, the oldest science, has become an important discipline in the geosciences, in large part by enhancing Global Positioning System (GPS) capabilities over the last 35 years well beyond the satellite constellation's original design. The ability of GPS geodesy to estimate 3D positions with millimeter-level precision with respect to a global terrestrial reference frame has contributed to significant advances in geophysics, seismology, atmospheric science, hydrology, and natural hazard science. Monitoring the changes in the positions or trajectories of GPS instruments on the Earth's land and water surfaces, in the atmosphere, or in space, is important for both theory and applications, from an improved understanding of tectonic and magmatic processes to developing systems for mitigating the impact of natural hazards on society and the environment. Besides accurate positioning, all disturbances in the propagation of the transmitted GPS radio signals from satellite to receiver are mined for information, from troposphere and ionosphere delays for weather, climate, and natural hazard applications, to disturbances in the signals due to multipath reflections from the solid ground, water, and ice for environmental applications. We review the relevant concepts of geodetic theory, data analysis, and physical modeling for a myriad of processes at multiple spatial and temporal scales, and discuss the extensive global infrastructure that has been built to support GPS geodesy consisting of thousands of continuously operating stations. We also discuss the integration of heterogeneous and complementary data sets from geodesy, seismology, and geology, focusing on crustal deformation applications and early warning systems for natural hazards.

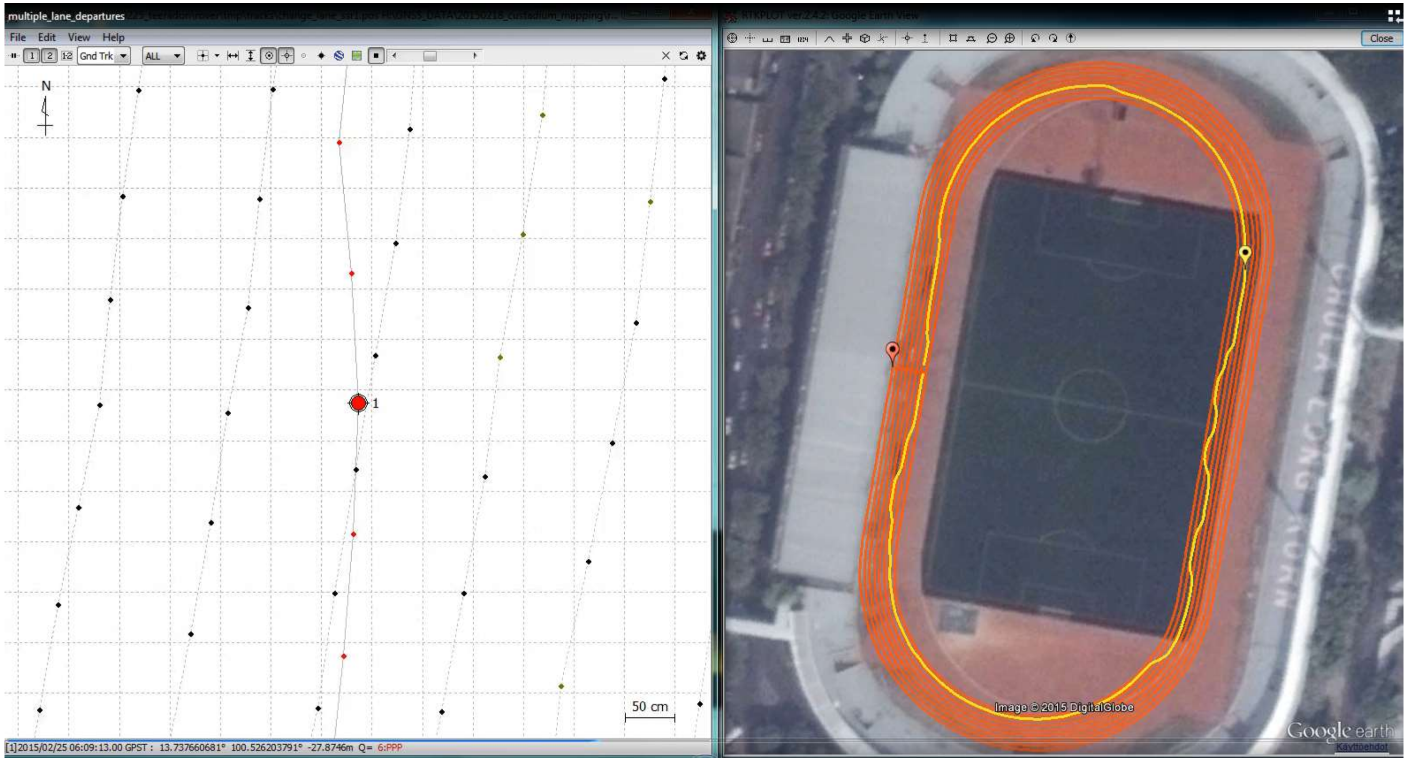
https://iopscience.iop.org/article/10.1088/0034-4885/79/10/106801

DRIVING

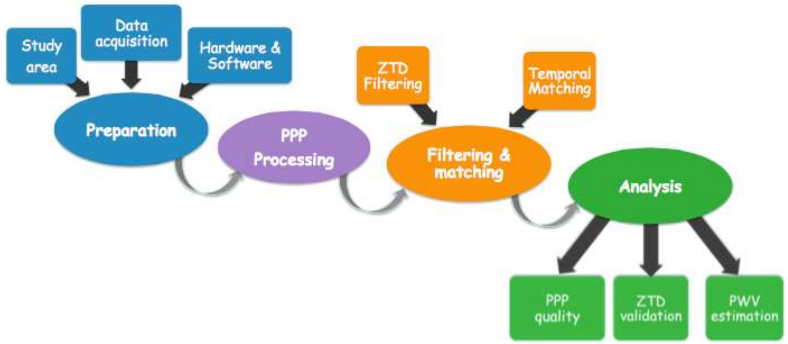

https://www.youtube.com/watch?v=OGnA-oiStJM
Driving with Galileo

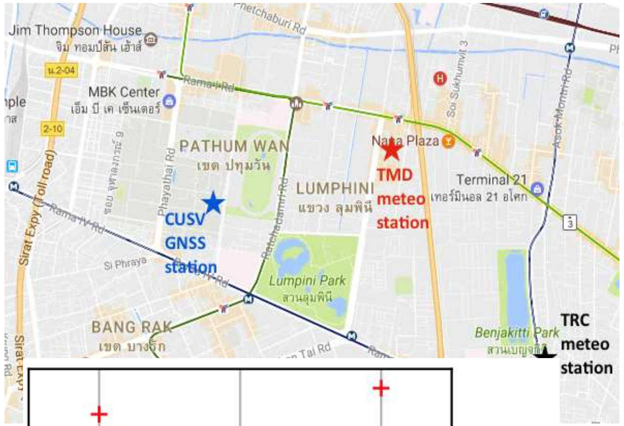
IN-LANE POSITIONING

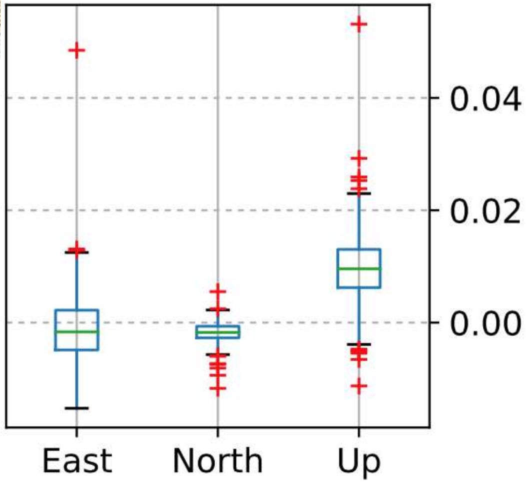
- Chula 2015

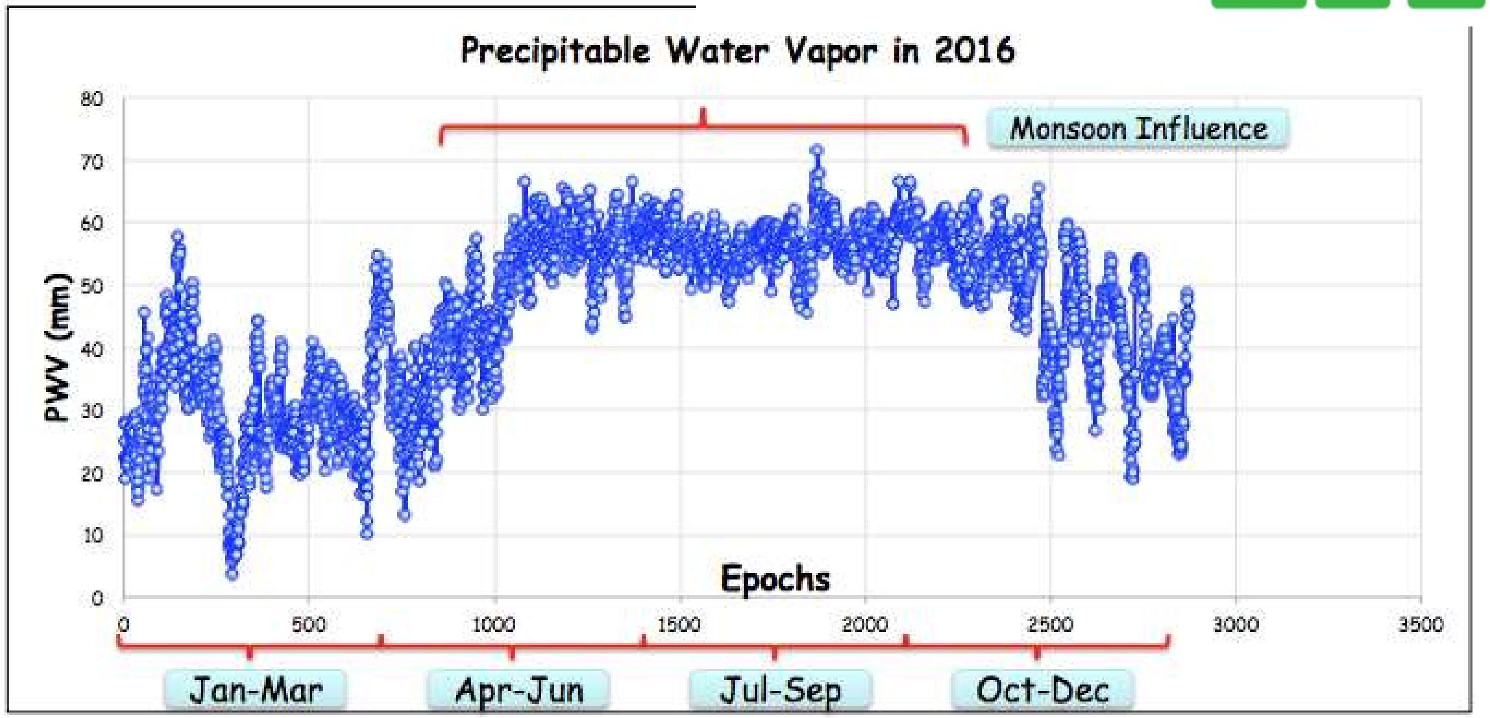


MONSOON SEASON



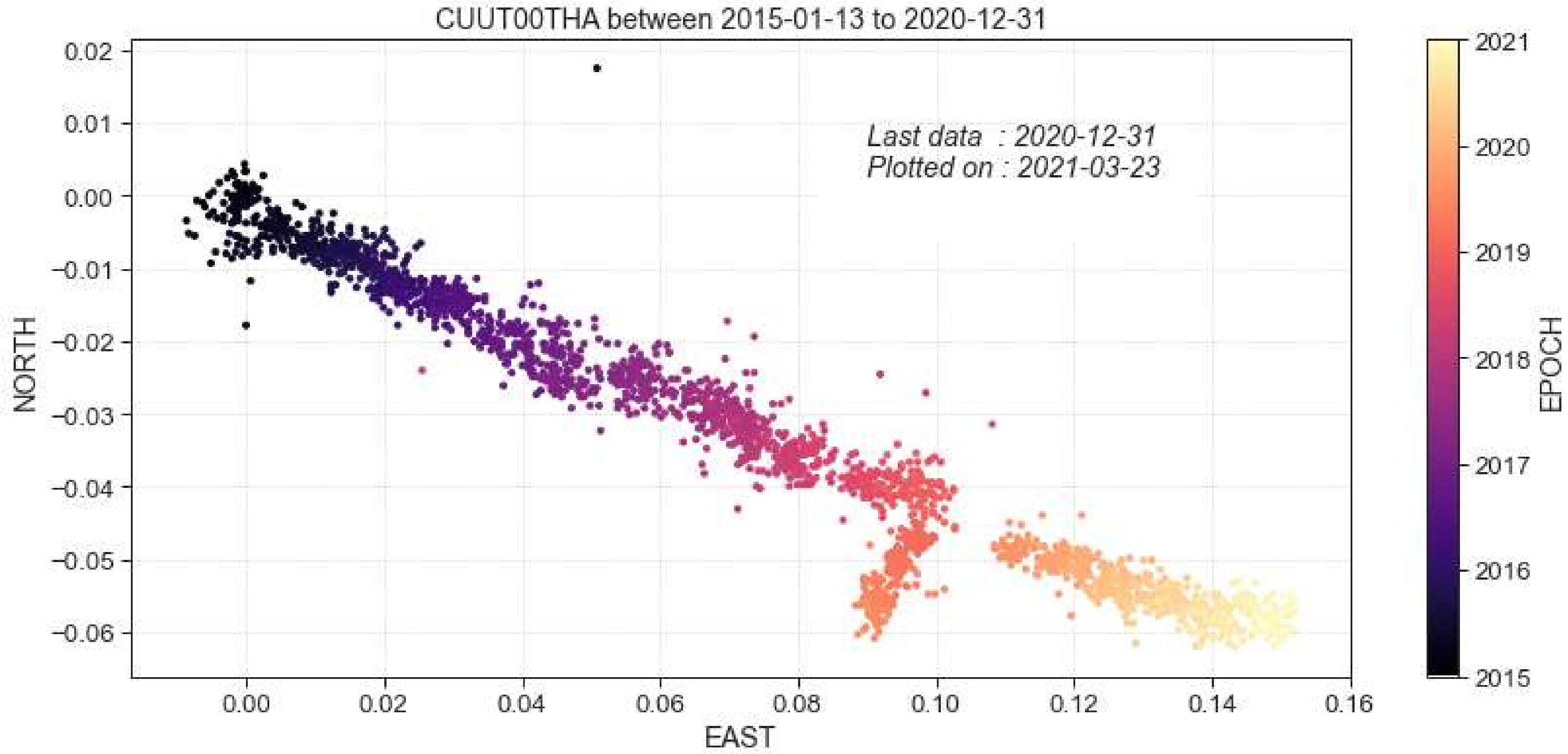




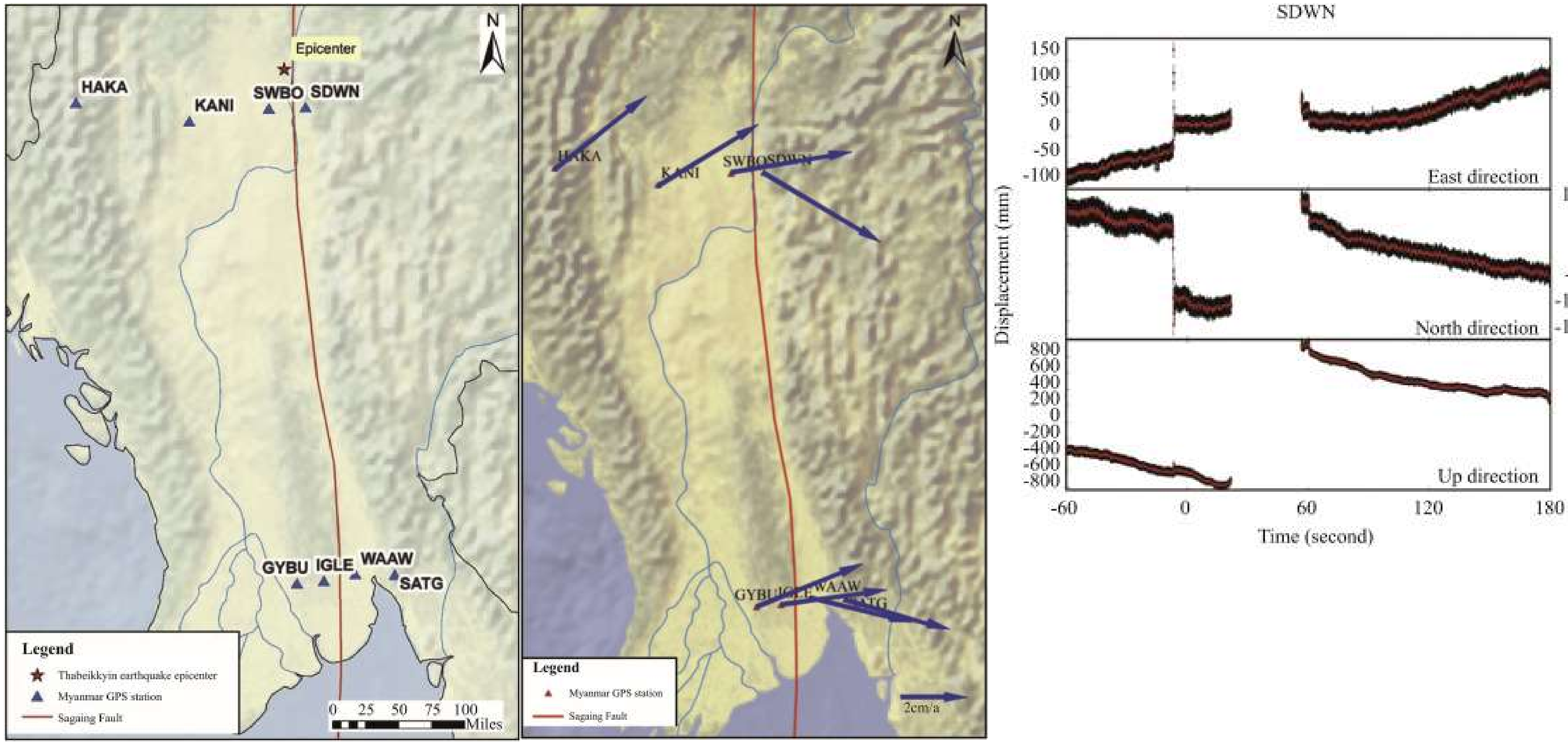


Hankansurijat, C., **Andrei, C-O.** 2018. *Atmospheric Water Estimation Using GNSS Precise Point Positioning Method*. Engineering Journal, 22(6): 37-45, https://doi.org/10.4186/ej.2018.22.6.37

DYNAMIC EARTH



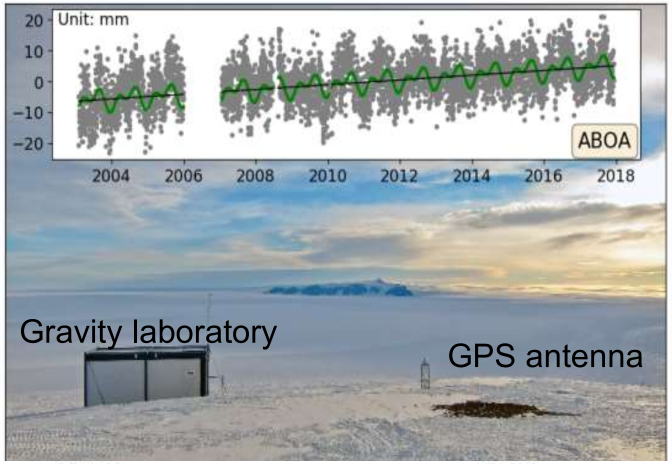
GAMIT/GLOBK/TRACK @MYANMAR

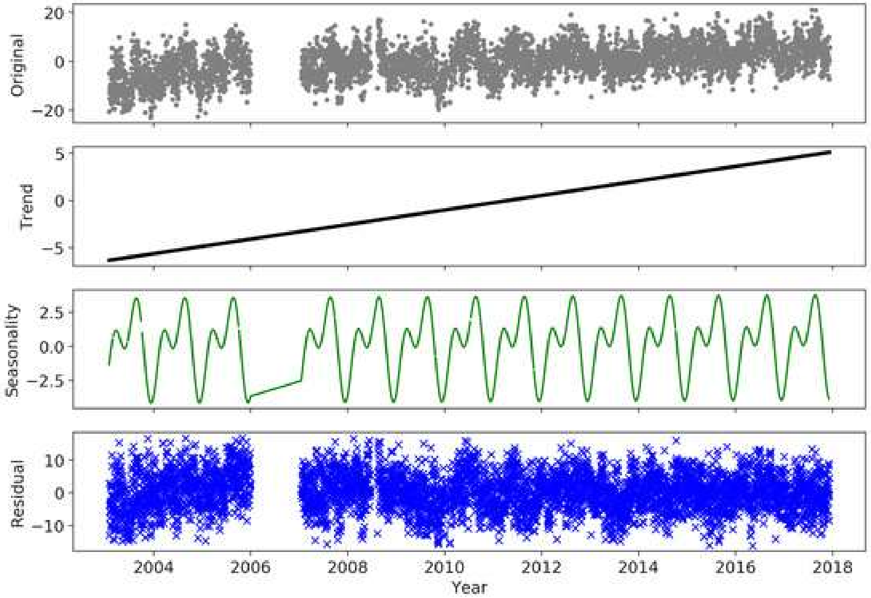


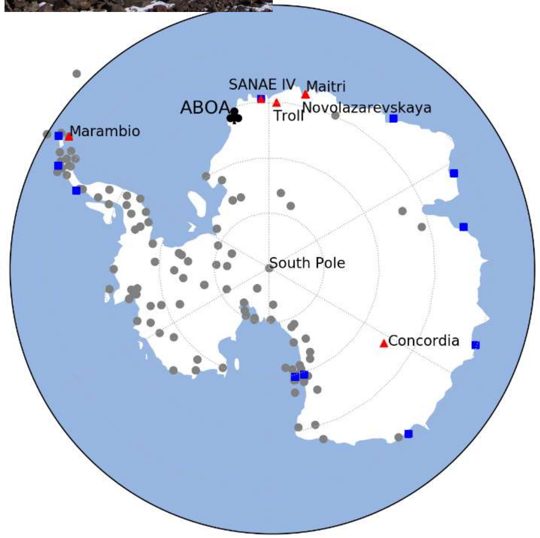
NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE

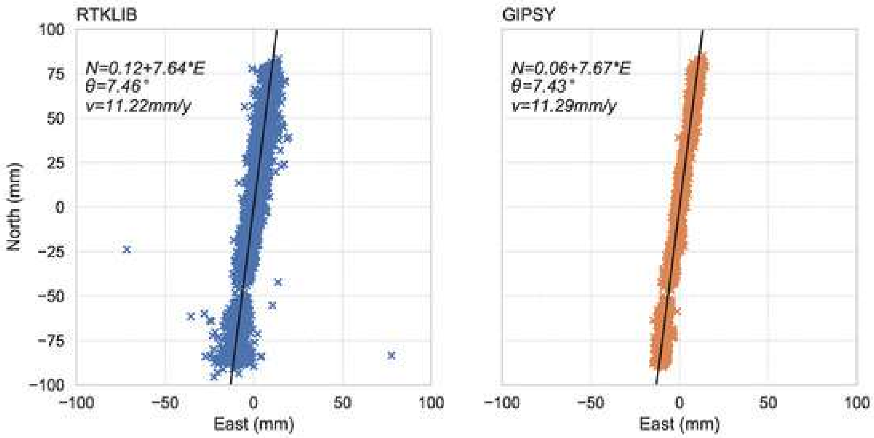
Aung, P.S., Satirapod, C., **Andrei, C-O.,** 2016. Sagaing Fault slip and deformation in Myanmar observed by continuous GPS measurements. Geodesy and Geodynamics, 7(1),56-63. https://doi.org/10.1016/j.geog.2016.03.007 .

ABOA TIME SERIES



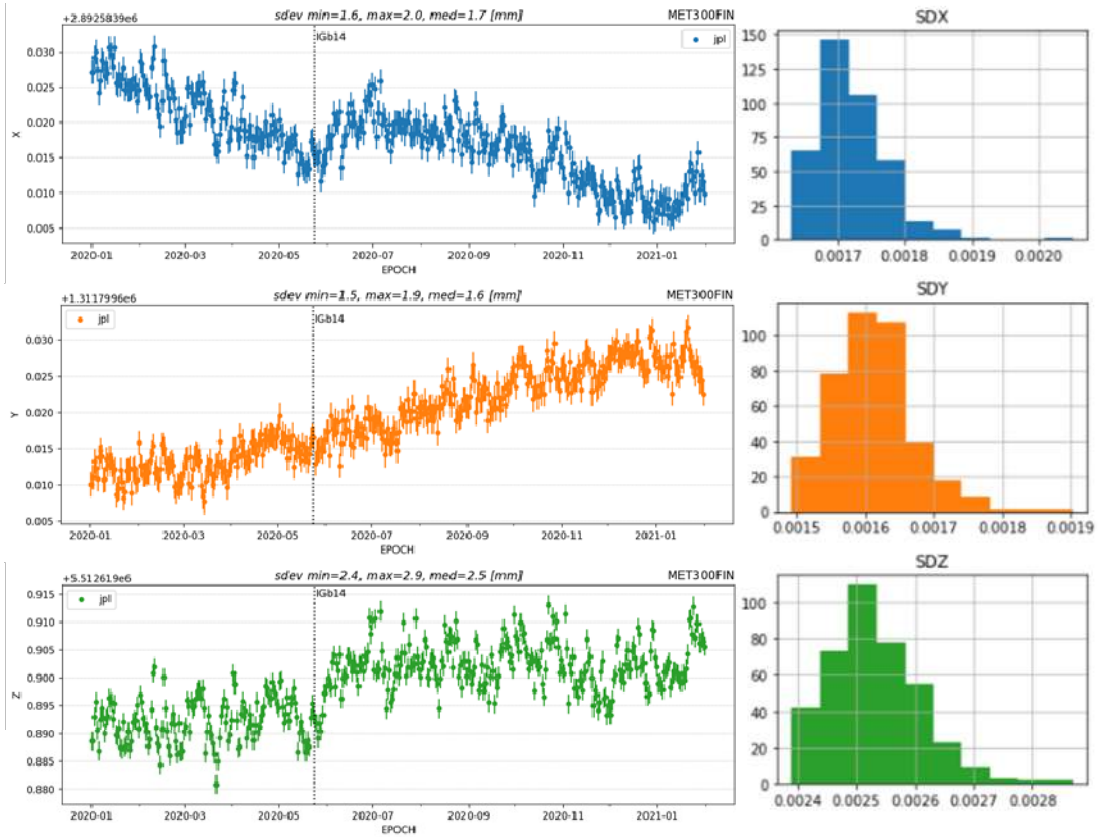


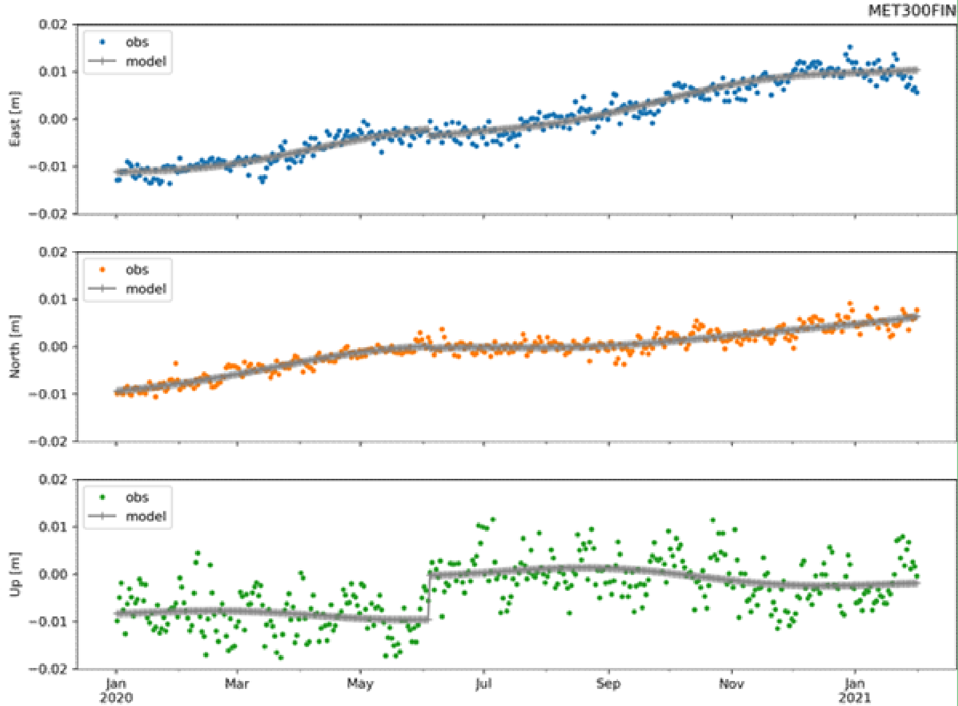




Andrei, C-O., Lahtinen, S., Nordman, M., Näränen, J., Koivula, H., Poutanen, M., and J. Hyyppä, 2018. GPS Time Series Analysis from Aboa the Finnish Antarctic Research Station. Remote Sensing, 10(12),1937. https://doi.org/10.3390/rs10121937 .

GIPSY @METSÄHOVI





	EAST	NORTH	UP	2D	3D
obs	0.007	0.004	0.007	0.008	0.011
linear	0.007	0.004	0.006	0.008	0.010
model	0.007	0.004	0.005	0.008	0.010
resid	0.002	0.001	0.004	0.002	0.005

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

REFLECTION QUESTION

Describe your own application. Build your argumentation around the three main questions:

- *Why? (explain the reason)*
- *How? (explain the process)*
- *What? (explain the features)*

NLS
FINNISH GEOSPATIAL RESEARCH INSTITUTE
FGI

SUMMARY

- **Content**
  - ➢ PPP-RTK, real-world applications, example, demos

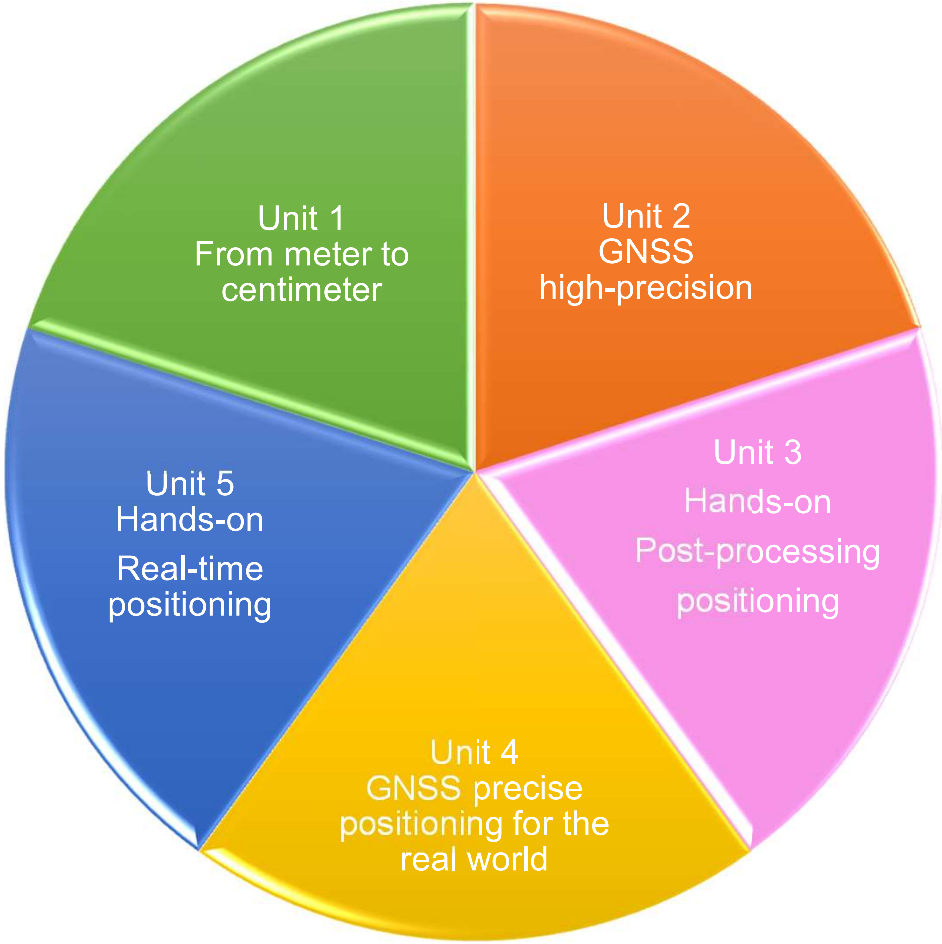
- After this lecture, the participant should be able:
  - ✓ **to become familiar** with the future of GNSS high-accuracy services
  - ✓ **to propose** potential application using GNSS high-precision / high-accuracy positioning

RESOURCES: MAGAZINES

- GPS World, https://www.gpsworld.com/
- Inside GNSS, https://insidegnss.com/
- GEO Informatics, https://geoinformatics.com/
- GIM International, https://www.gim-international.com/
- GEO International, https://www.geoconnexion.com/
- Positio-lehti, https://www.maanmittauslaitos.fi/positio

RESOURCES: SCIENTIFIC

- Journal of Geodesy, https://www.springer.com/journal/190
- Journal of Geodetic Science, https://www.degruyter.com/journal/key/JOGS/html
- Geodesy and Geodynamics, http://www.keaipublishing.com/en/journals/geodesy-and-geodynamics/
- Marine Geodesy, https://www.tandfonline.com/toc/umgd20/current
- Advancing Earth and Space Science, https://agupubs.onlinelibrary.wiley.com/
- GPS Solutions, https://www.springer.com/journal/10291
- Journal of Navigation, https://www.cambridge.org/core/journals/journal-of-navigation
- Remote Sensing, https://www.mdpi.com/journal/remotesensing
- …



https://www.usegalileo.eu