Geodetic Challenges on Positioning&Navigation for Mobile GIS presented along the NAVKA-Disy Project PREGON-X

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RaD

www.dfhbf.de, www.geozilla.de, www.goca.info, www.navka.de

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Introduction

GNSS/MEMS/Optical based State Estimation

Sensors providing Space / Parameter Relation

1.) State Transition-Equations for the body (b) in the e-frame

$$\mathbf{y}(t) = \left[x^e \ y^e \ z^e \mid \dot{x}^e \ \dot{y}^e \ \dot{z}^e \mid r^e \ p^e \ y^e \,\|\, \ddot{x}^e \ \ddot{y}^e \ \ddot{z}^e \mid \omega^b_{eb,x} \ \omega^b_{eb,y} \ \omega^b_{eb,z} \right]^T$$

Space Curve of the body (b) in the e-frame

$$\begin{bmatrix} \mathbf{x}(t) \\ \dot{\mathbf{x}}(t) \\ \ddot{\mathbf{x}}(t) \end{bmatrix} = \begin{bmatrix} \mathbf{I} & [\Delta t] & \left[\frac{1}{2}\Delta t^2\right] \\ \mathbf{0} & \mathbf{I} & [\Delta t] \\ \mathbf{0} & \mathbf{0} & \mathbf{I} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{x}(t-\Delta t) \\ \dot{\mathbf{x}}(t-\Delta t) \\ \ddot{\mathbf{x}}(t-\Delta t) \end{bmatrix}$$

Rotation Rates of the Body (b) with respect to the e-frame

$$\mathbf{\Omega}^b_{eb}(t) = \mathbf{\Omega}^b_{eb}(t-\Delta t)$$

Orientation / Attitude

$$\mathbf{R}^b_e(t) = \mathbf{R}^b_e(t-\Delta t) \cdot [I + \mathbf{\Omega}^b_{eb} \cdot \Delta t + \frac{1}{2!} \cdot (\mathbf{\Omega}^b_{eb})^2 \cdot \Delta t^2 + \ldots] \text{ with } \mathbf{\Omega}^b_{eb} = \mathbf{\Omega}^b_{ib}(\text{Sensor}) - \mathbf{\Omega}^b_{ie}$$

Modifcation of the State Parameters and Equations

by

Considering Special Conditions Detected in Multithreading Computing

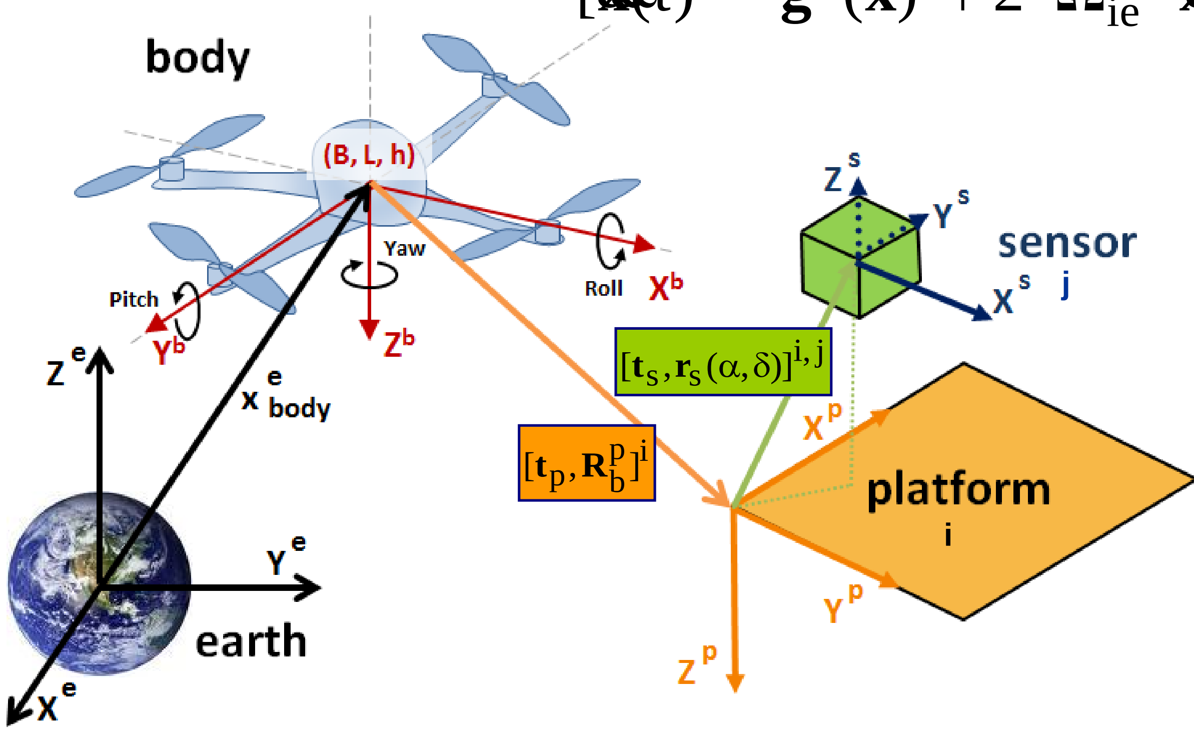
2.) Sensors GNSS/MEMS/OPTICAL - Multisensor/Multiplatform

Accelerometer- Sensorobservation j (Rawdata, on i-th Platform (p) – one-dimensional!)

$$a_{s_{i,j}} = \mathbf{r}^{p_i}_{s_{i,j}} \cdot \mathbf{a}^{p_i}_{s_{i,j}} \quad \Rightarrow \quad \mathbf{a}^{p_i}_{s_{i,j}} = \mathbf{R}^{p,i}_{b} \cdot \mathbf{R}^{b}_{e}(r,p,y) \cdot \mathbf{a}^{e,i}_{s_{i,j}}$$

$$a_{s_{i,j}} = \mathbf{r}^{p_i}_{s_{ij}} \cdot \mathbf{R}^{p,i}_{b} \cdot \mathbf{R}^{b}_{e}(r,p,y) \cdot [\ddot{\mathbf{x}}(t)^e - \mathbf{g}^e(\mathbf{x}) + 2 \cdot \mathbf{\Omega}^e_{ie} \cdot \dot{\mathbf{x}}(t)^e + \mathbf{\Omega}^e_{ie} \cdot \mathbf{\Omega}^e_{ie} \cdot \mathbf{x}(t)^e]_{s_{i,j}}$$

Observation-Equation for Sensor j on Platform i



$$\mathbf{r}^{pi}_{si,j} = \begin{bmatrix} \cos\delta \cdot \cos\alpha \\ \cos\delta \cdot \sin\alpha \\ \sin\delta \end{bmatrix}^{i,j}$$

Orientation j-th Sensor (s) on i-th Platform (p)

2.) Sensors GNSS/MEMS/OPTICAL - Multisensor/Multiplatform

(1)

$$a_{s_{i,j}} = \mathbf{r}^{p_i}_{s_{ij}} \cdot \mathbf{R}^{p,i}_{b} \cdot \mathbf{R}^{b}_{e}(r,p,y) \cdot [\ddot{\mathbf{x}}(t)^e - \mathbf{g}^e(\mathbf{x}) + 2 \cdot \boldsymbol{\Omega}^e_{ie} \cdot \dot{\mathbf{x}}(t)^e + \boldsymbol{\Omega}^e_{ie} \cdot \boldsymbol{\Omega}^e_{ie} \cdot \mathbf{x}(t)^e]_{s_{i,j}}$$

„l(i,j)“

Observation-Equation for <u>Sensor</u> j on Platform i

<u>Referencing</u> : Platform p(i) on Body (b) and Sensor s(i,j) on Platform (i) – „Leverarms“

(2)

$$\mathbf{x}^e_{s_{i,j}} = \mathbf{x}^e_b + \mathbf{R}^e_b(r,p,y) \cdot [\mathbf{t}^b_{b,p_i} + \mathbf{R}^b_{p_i} \cdot \mathbf{t}^{p_i}_{p_i,s_{i,j}}]$$

$$\mathbf{y}(t) = \left[x^e \; y^e \; z^e \,|\, \dot{x}^e \; \dot{y}^e \; \dot{z}^e \,|\, r^e \; p^e \; y^e \,\|\, \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \,|\, \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z}\right]^T$$

From 15 to 18 Parameters y(t)

Change of the State Transition Model 1.)

$$\mathbf{y}(t) = \left[x^e \; y^e \; z^e \,|\, \dot{x}^e \; \dot{y}^e \; \dot{z}^e \,|\, r^e \; p^e \; y^e \,\|\, \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \,|\, \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \,|\, \dot{\omega}^b_{eb,x} \; \dot{\omega}^b_{eb,y} \; \dot{\omega}^b_{eb,z}\right]$$

3.) General M-Estimation & Additional State Information

3.1) Robust Kalmanfiltering using L1-Norm Simplex Algorithms

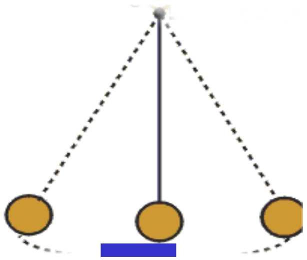
3.2) Parallel Processing Algorithms

Condition Equations

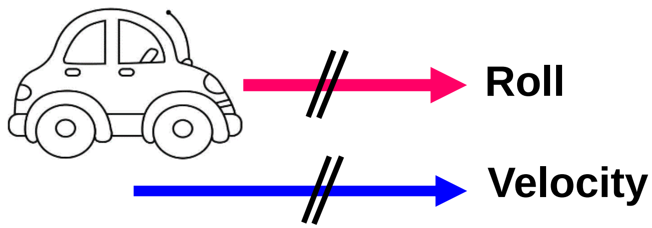
$$\mathbf{F}(\mathbf{y}(t)) = \mathbf{0}$$

Condition In-Equations

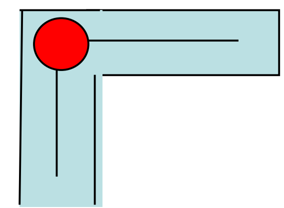
$$\mathbf{u} \leq \mathbf{F}(\mathbf{y}(t)) \leq \mathbf{o}$$



Zero-Updates („ZUPT“)



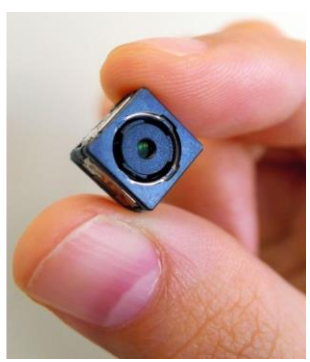
„Automotive Mode“



„Indoor-Map-Matching“

3.3) Sensorintegration

Tachometer

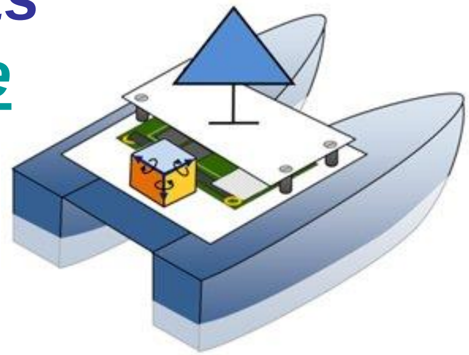


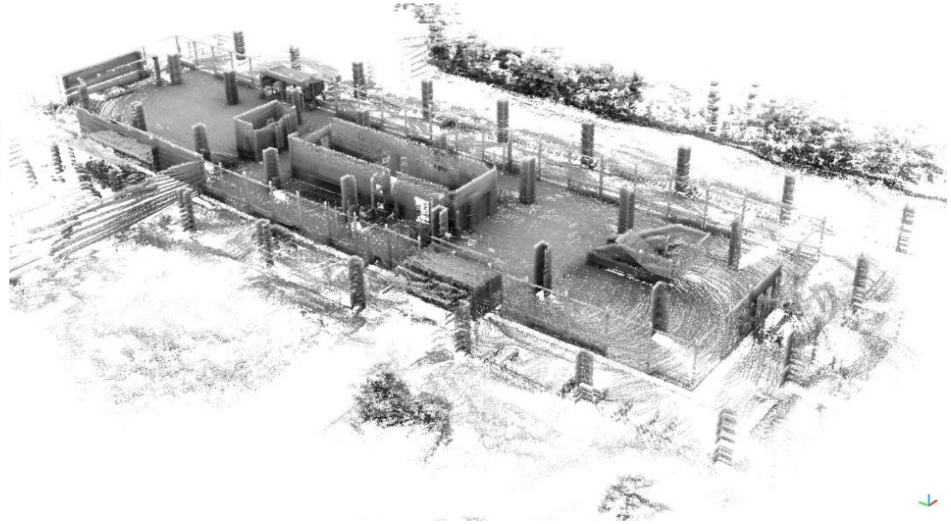
MOEMS

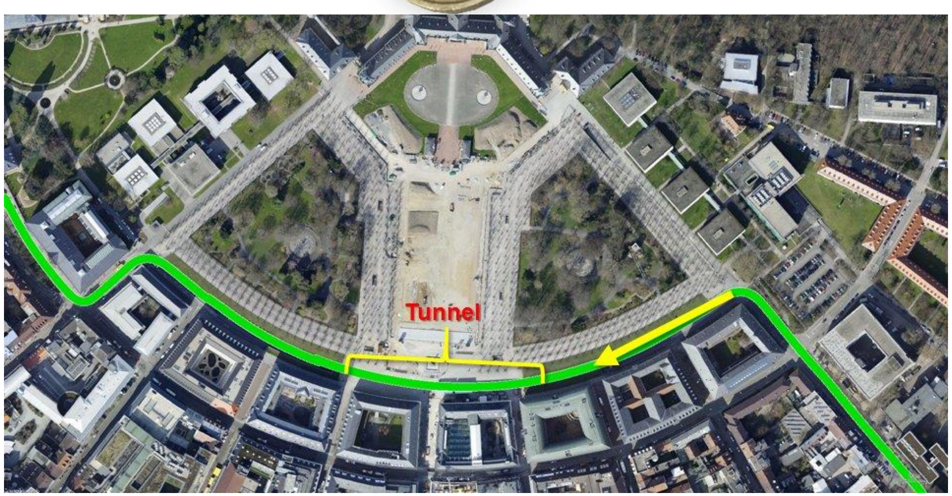
Laser-
scanner

NAVKA-Projects

[*www.navka.de*](http://www.navka.de)







ZIM Cooperation Project on Mobile GIS
PREGON-X

- **Precision GNSS and Georeferencing on Smartphones, Tablets etc. = x –**
-

Funded as ZIM (Zentrales Innovationsprogramm Mittelstand) project by the German Ministry on Economy and Energy ((Bundesministerium für Wirt-schaft und Energie).

NAVKA-Project IAF/HSKA
www.navka.de

and DISY (www.disy.net)

PREGON-X

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

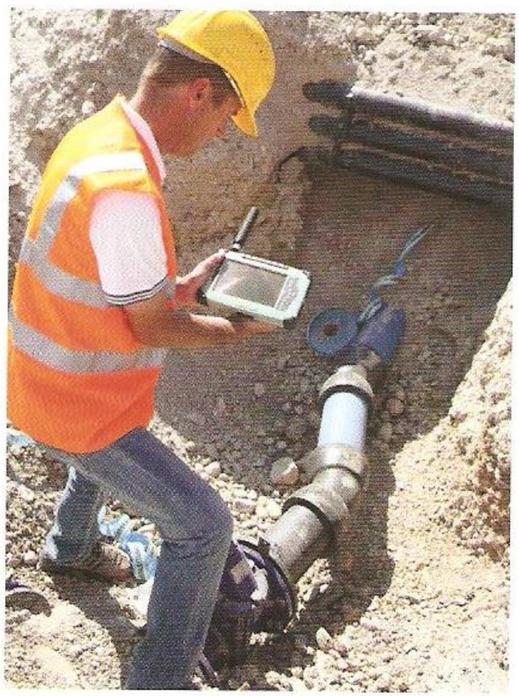
Smartphone and Tablets for Mobile GIS and Geo-Referencing
Survey on Existing Solutions

„Mobile GIS“ Leica Geosystems
L1-based: 40 cm Accuracy ~. 7000.- EUR
L1/L2 based 5 cm ~ 9000.- EUR

„Mobile GIS“ Trimble

Smartphone and Tablets for Mobile GIS and Geo-Referencing
Survey on Existing Solutions
1.) Limitation concerning Direct Object Access

Die neuen schnellen GIS Instrumente



Leitungseinmessung mit dem Leica CS25 GNSS plus

Die beiden TabletPC-Varianten Leica CS25 plus und CS25 GNSS plus (mit integrierter GNSS-Funktionalität für Messgenauigkeiten <10 cm) bestechen im Vergleich zum Vorgängermodell mit deutlich höherer Speicherkapazität und schnellerer Prozessorleistung. Die neue 5 Megapixel-Kamera und das verbesserte 7" große Touchscreen-Display runden die Gesamtleistung der handlichen und ultrarobusten Tablets für die GIS-Datenerfassung ab.

Nach Militärstandards entwickelt, halten diese TabletPC's sowohl extremen Temperaturen als auch Stürzen von über 1 m Fallhöhe und starken Vibrationen bestens stand. Gemäß Staubdichtheit und Strahlwasserschutz werden die Vorgaben der IP65-Schutzklasse voll erfüllt.

Neben dieser Allwettertauglichkeit gewährleisten die langen Akkulaufzeiten sowie das geringe Gewicht einen Einsatz über einen kompletten Messtag hinweg. Basierend auf dem Betriebssystem Windows®7 (Ultimate Edition) kann zur einfachen Datenerfassung sowohl die eigens entwickelte Onboardsoftware Leica ZenoField verwendet als auch auf maßgeschneiderte Softwarelösungen von zahlreichen Leica-Softwarepartnern zurückgegriffen werden.

Roland Reiser

Smartphone and Tablets for Mobile GIS and Geo-Referencing Survey on existing Solutions. 2.) Contact-free Georeferencing: Not new, but unprecise & incomplete

About Spike

Spike is a smart laser measurement solution for all kinds of industries and professional use that allows you to capture measurements and location of an object – all from a photo. From that photo you can capture real time measurements including height, width, area, length and target location.

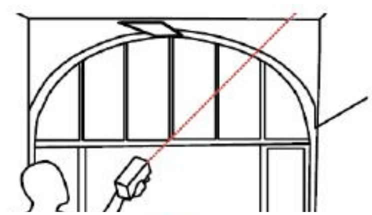
Spike gives you the flexibility to measure when and how you want, whether in the field or at the office, using the Spike mobile app or Spike Cloud.

http://www.ikegps.com/spike/

Spike works with both Apple iOS and Google Android devices, and attaches to a smartphone with a quick-release clamp or to a tablet case with high-strength bonding tape. The Spike device pairs with your smartphone or tablet via Bluetooth. Spike's laser rangefinder works together with your

Already „done in 2012“ by NAVKA
http://www.navka.de/index.php/en/overview

- **PPP-K not operable**
- **In „advance to time“**



Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => New Age, starting in 2016

Google to provide raw GNSS measurements

July 10, 2016 - By Steve Malkos

Facebook Twitter Google LinkedIn

User location takes center stage in new Android OS

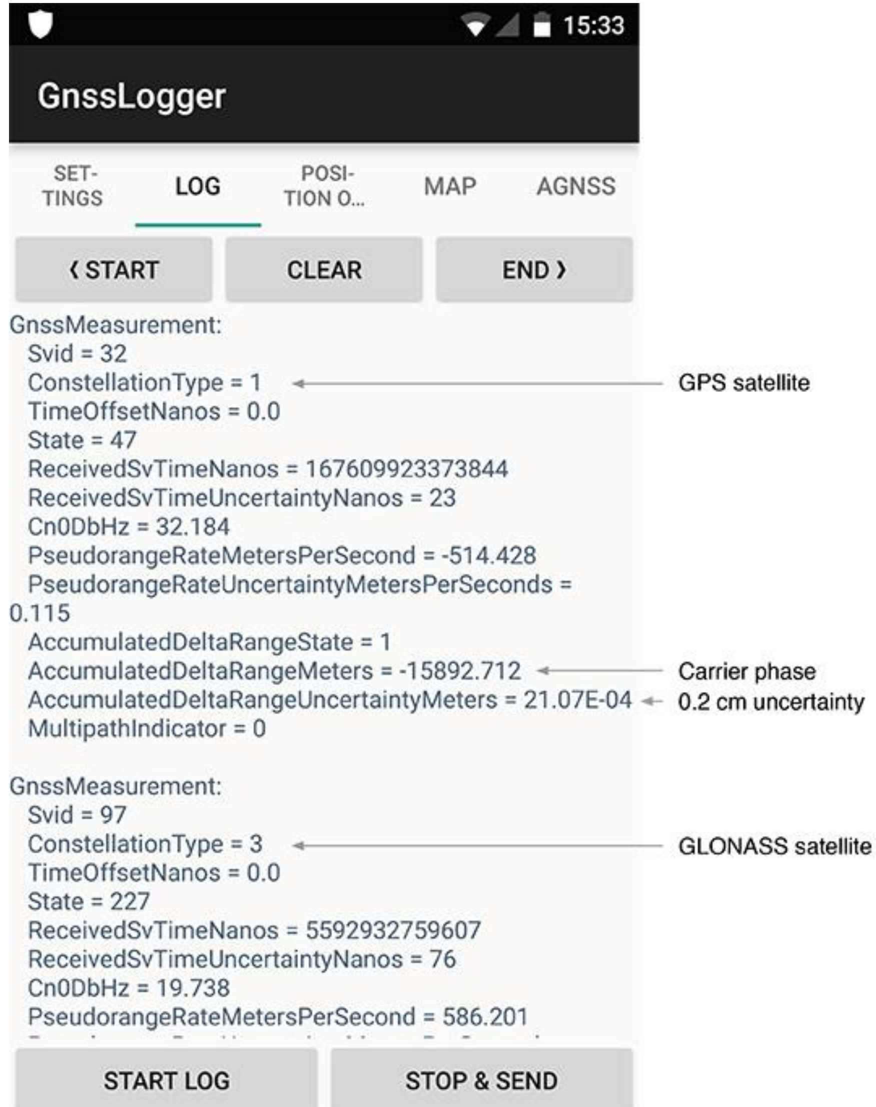
Raw GNSS measurements from Android phones. Yep, they are coming. At Google we have been working with our GNSS partners to give application developers access to raw GNSS measurements from a phone.

This is really exciting, and marks a new era for our GNSS community. At Google I/O in May, we announced that raw GNSS measurements are available to apps in the Android N operating system, which will be released later this year. This means you can get pseudoranges, Dopplers and carrier phase from a phone or tablet.

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smatphone => New Age, starting in 2016

http://gpsworld.com/innovation-precise-positioning-using-raw-gps-measurements-from-android-smartphones/

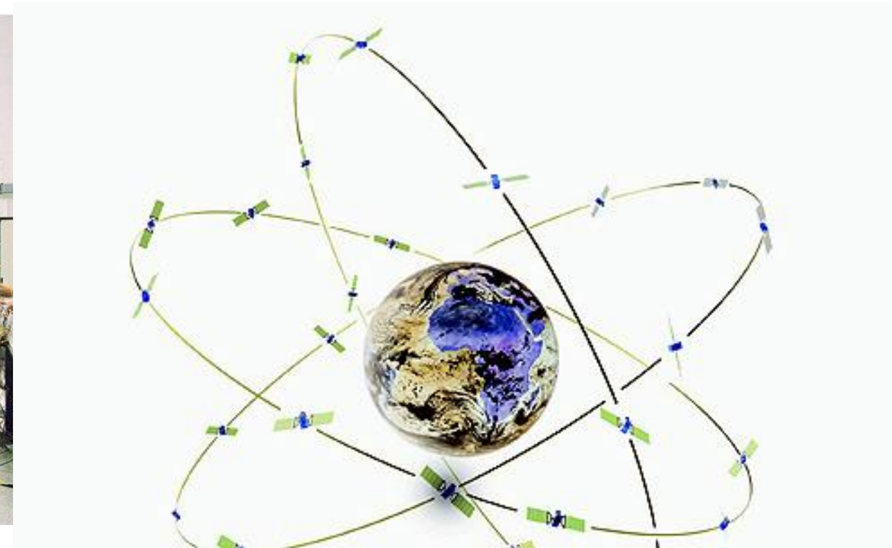
GnssLogger screenshot, showing raw measurements from a GPS satellite and a GLONASS satellite.



Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => New Age, in 2017/2018

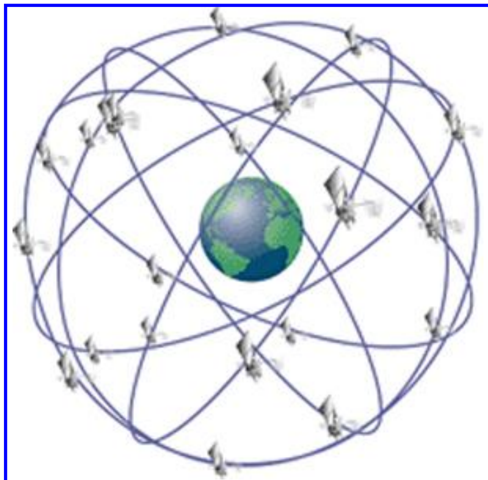
28 Dec.2005 **Giove-A** lift off 05:19 UTC Baikonour, Kazakhstan

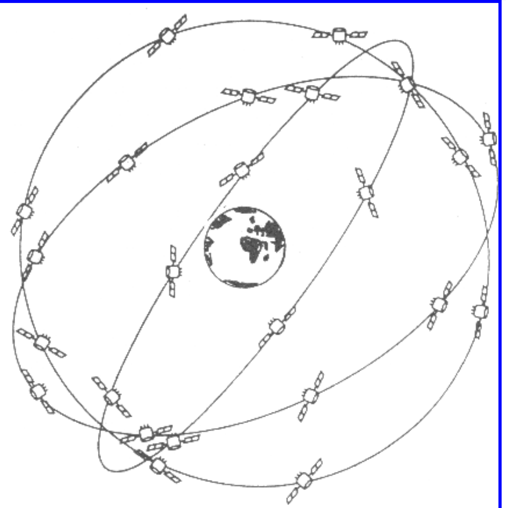
Galileo Satellite



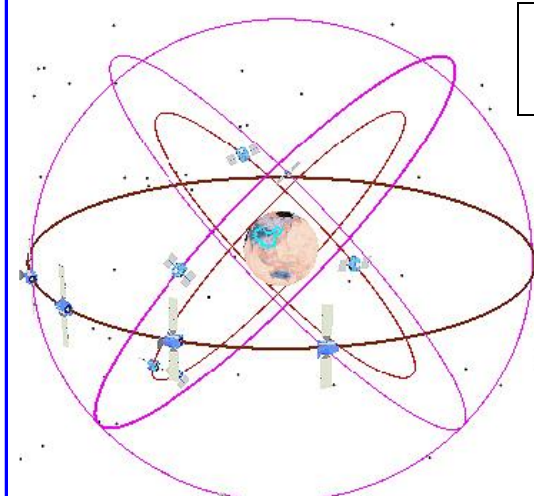
Orbit – Segment Galileo

Image courtesy of: ESA-J. HUART





GPS Orbit and GlONASS Orbit



Chinese COMPASS Orbit

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => New Age, in 2018

Ublox NEO 8MN
29.- EUR

contains receiver's position vector | precise corrections from weather model | compensation by estimation (option) | to be eliminated | to be estimated (and fixed)

RANGE MEASUREMENT = DISTANCE RECEIVER - SATELLITE + TROPOSPHERIC SLANT DELAY + IONOSPHERIC SLANT DELAY

CARRIER PHASE MEASUREMENT = DISTANCE RECEIVER - SATELLITE + TROPOSPHERIC SLANT DELAY − IONOSPHERIC SLANT DELAY − AMBIGUITY TERM

ADDITIVE COMBINATION OF CODE RANGE AND CARRIER PHASE MEASUREMENTS ELIMINATES IONOSPHERE
(RANGE + PHASE)/2

CODE-PLUS-CARRIER = DISTANCE RECEIVER - SATELLITE + TROPOSPHERIC SLANT DELAY eliminated! $-\frac{1}{2}$ AMBIGUITY TERM

SUBTRACTIVE COMBINATION OF CODE RANGE AND CARRIER PHASE MEASUREMENTS REVEALS IONOSPHERIC DELAY
RANGE - PHASE

CODE-MINUS-CARRIER = Iono. monitoring! 2 IONOSPHERIC SLANT DELAY + AMBIGUITY TERM

Vereinfachte Beobachtungsgleichung „Code-plus-Carrier“:

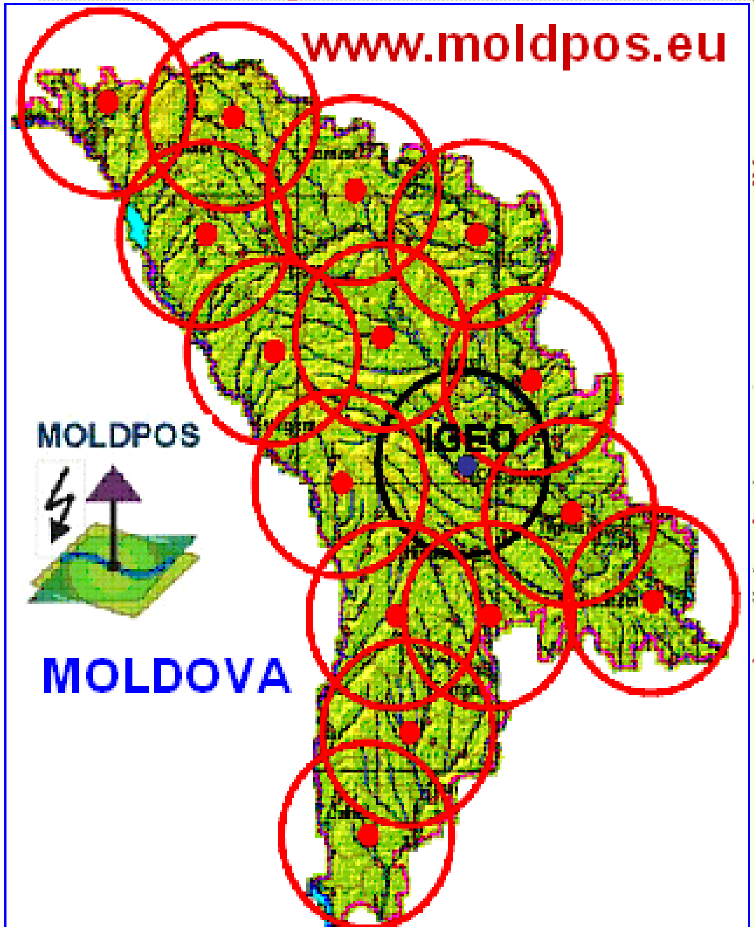
$$\frac{PR+\phi}{2} = \rho - \frac{\lambda}{2}\cdot N + \left(\frac{c_2}{4\cdot f^3} + \frac{c_3}{3\cdot f^4}\right) + SPD$$

kombinierte Beobachtung | Entfernung | Mehrdeutigkeit | Ionosphärenfehler höherer Ordnung | troposphärische Laufzeitverzögerung (Slant Path Delay)

GALILEO - E1 Code/Phase Linear-Combination

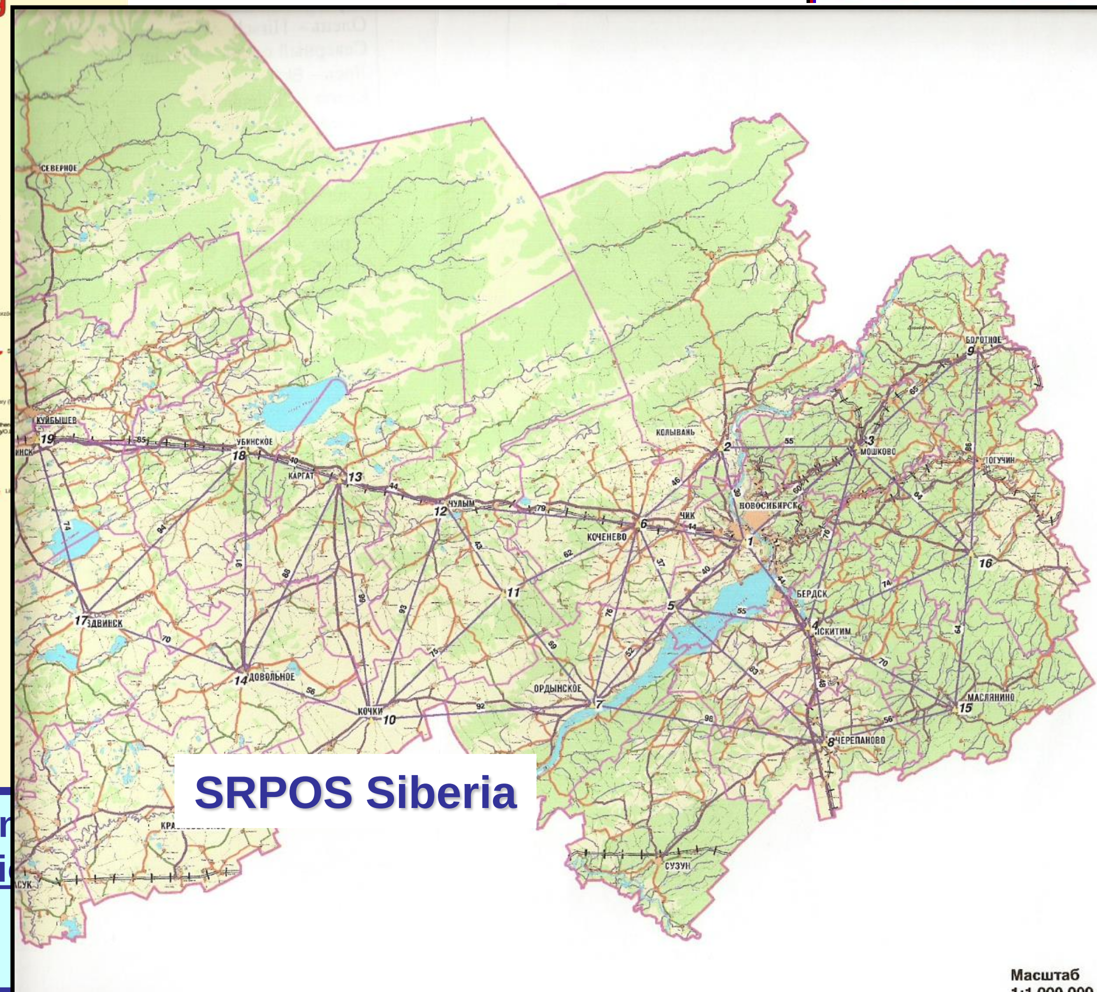
Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => From DGNSS to PPP-K

1



2

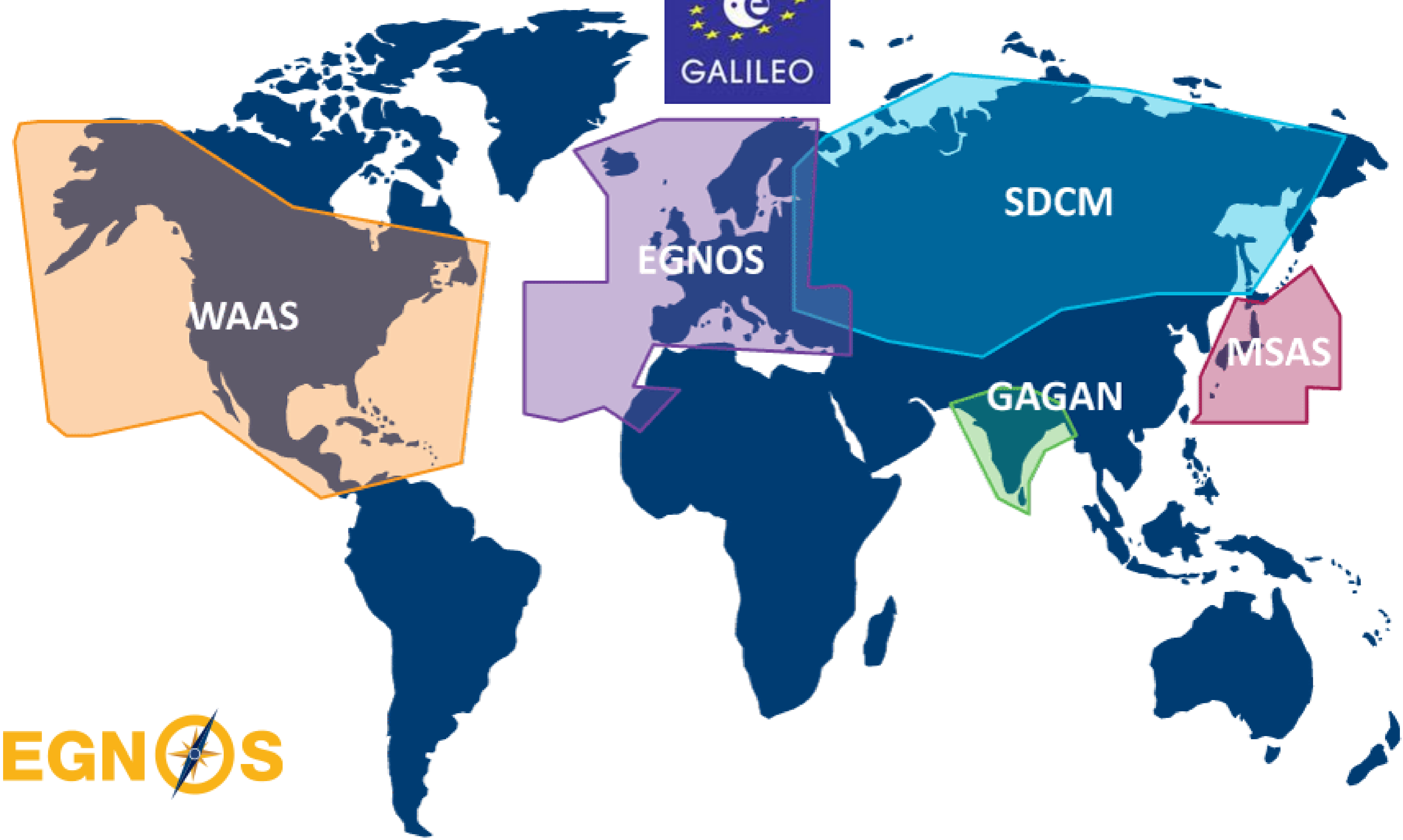
SmartNet EUROPE



4 RTCM Services: 1-3 cm Horizontal ar
Geodetic Infrastructures for GNSS-Servi
www.moldpos.eu
www.geozilla.de

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => From DGNSS to PPP-K

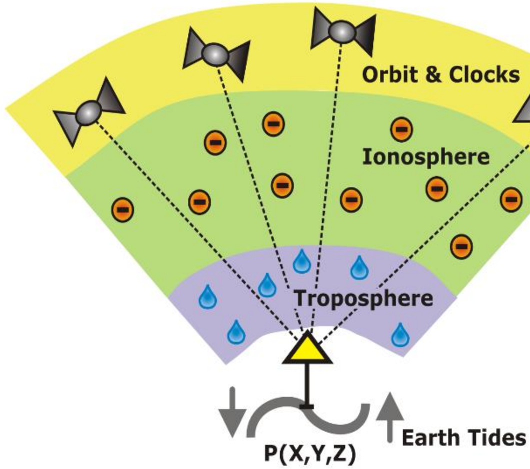
GALILEO



EGNOS

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => From DGNSS to PPP-K

1



- SSR-based: Abs. Prec. OPPP
- Starfire™ GPS-Corrections
- Starfire Receiver (left)
- Global Accuracy: „dm“

NAVCOM A John Deere Company

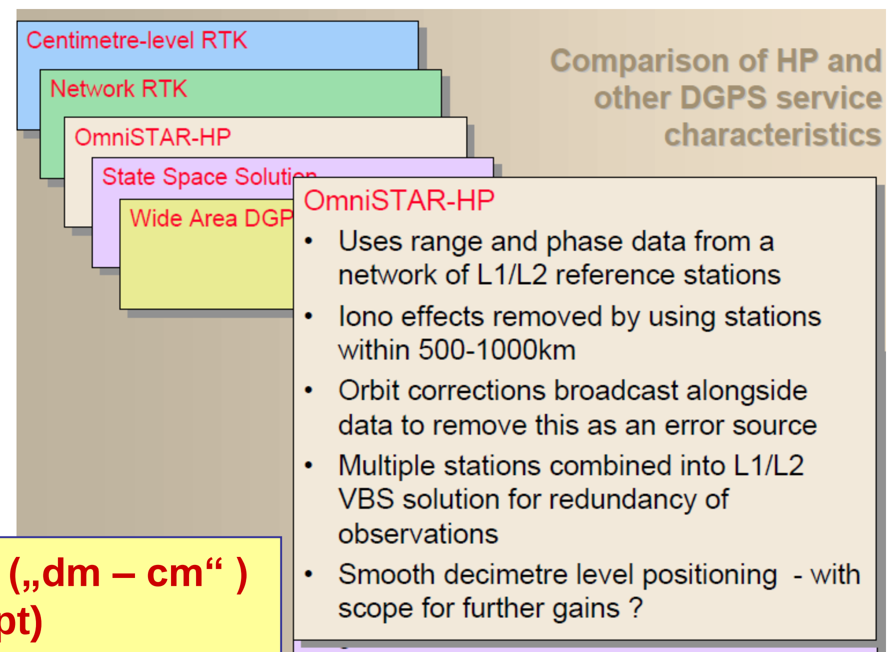
Leica SteerDirect steering solutions

Abs. GNSS = „Non-DGNSS“
No Reference-Stations
But: NAVCOM Roverclients!

OmniSTAR. The Global Positioning System — Trimble.

2

„RTX“



OSR (= Observation-)related: Networked, scalabe („dm – cm“)
DGNSS RTCM Correction (VRS-Concept)
• RTCM-Standard =>Open for any Rover- and Software-Type

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => From DGNSS to PPP-K

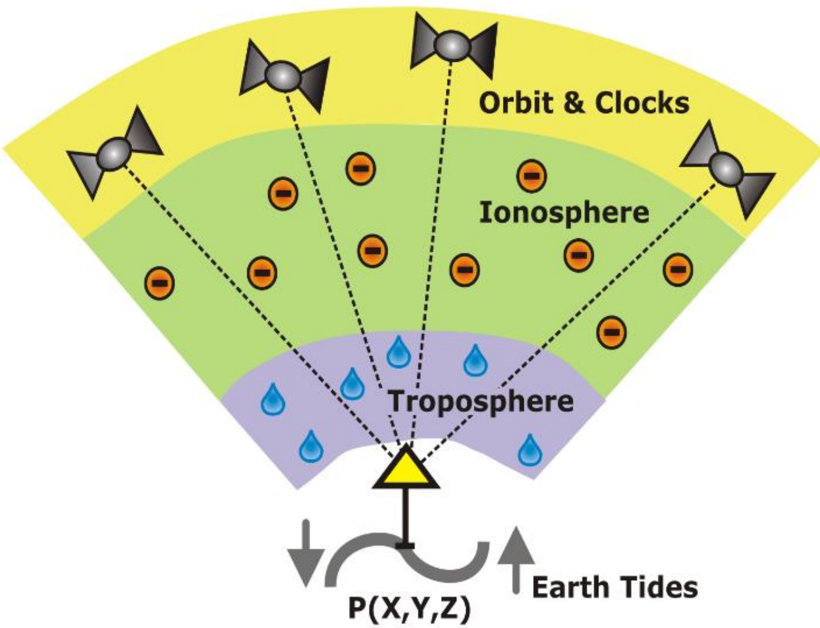
NAME	Service	Accuracy performance	Supported constellations	Method	Provider
OmniStar	G2	<10cm	GPS+GLONASS	PPP	Trimble
RTX	CenterPoint	<4cm	GPS+GLONASS+BDS	PPP	Trimble
StarFix	G2+	3cm	GPS+GLONASS	PPP	Fugro
	G4	5-10cm	GPS+GLONASS+BDS+Galileo	PPP	
StarFire	SF2	5cm	GPS+GLONASS	PPP	John Deere
	SF3	3cm	GPS+GLONASS Future(BDS+Galileo)	PPP	
Veripos	C2	5cm	GPS+GLONASS	PPP	Hexagon AB
	Apex²	5cm	GPS+GLONASS	PPP	
TerraStar	TerraStar C	2-3cm	GPS+GLONASS	PPP	Hexagon AB

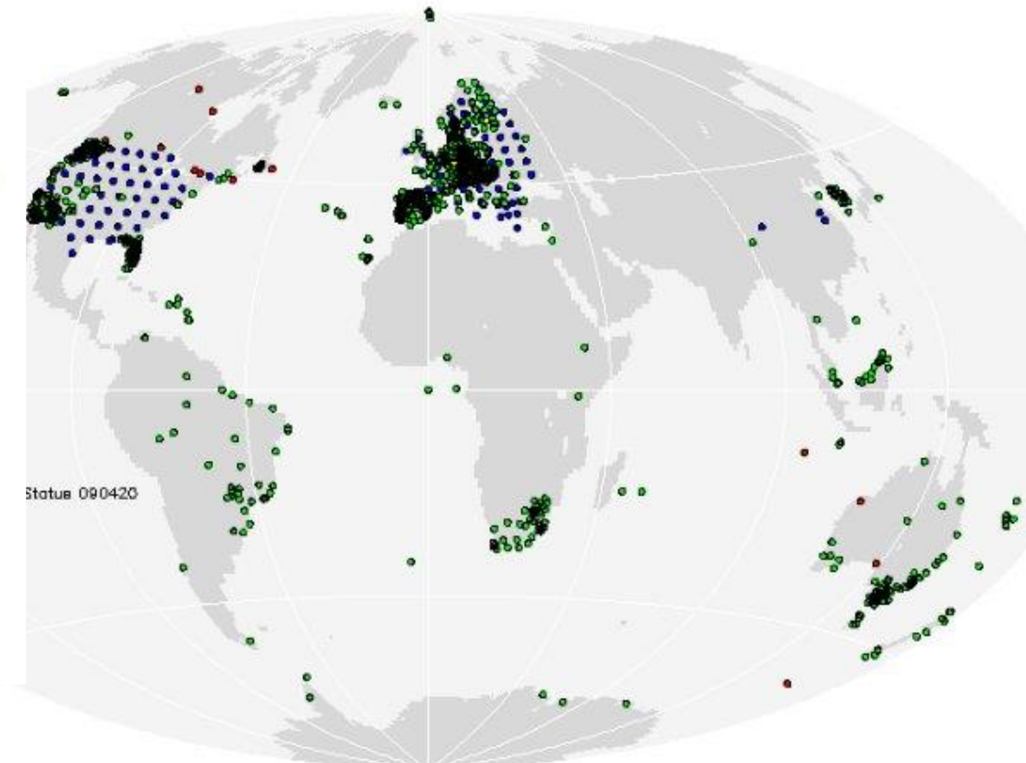
August 2017: Joint Venture „Sapcorda Services“ (Bosch, Geo++, Mitsubishi, ublox)

Smartphone and Tablets for Mobile GIS and Geo-Referencing GNSS Raw-Data on Smartphone => From DGNSS to PPP-K

International GNSS-Service (IGS

„RTS“: http://rts.igs.org/





Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone => New Age, in 2017/ 2018

OPPP – E1/E5 and L1/L5 Phasemeasurements – <u>21. Sept. 2017 -</u>

Broadcom launches dual-frequency GNSS receiver for mass market

September 21, 2017 - By Tracy Cozzens

GNSS receiver „BCM47755“

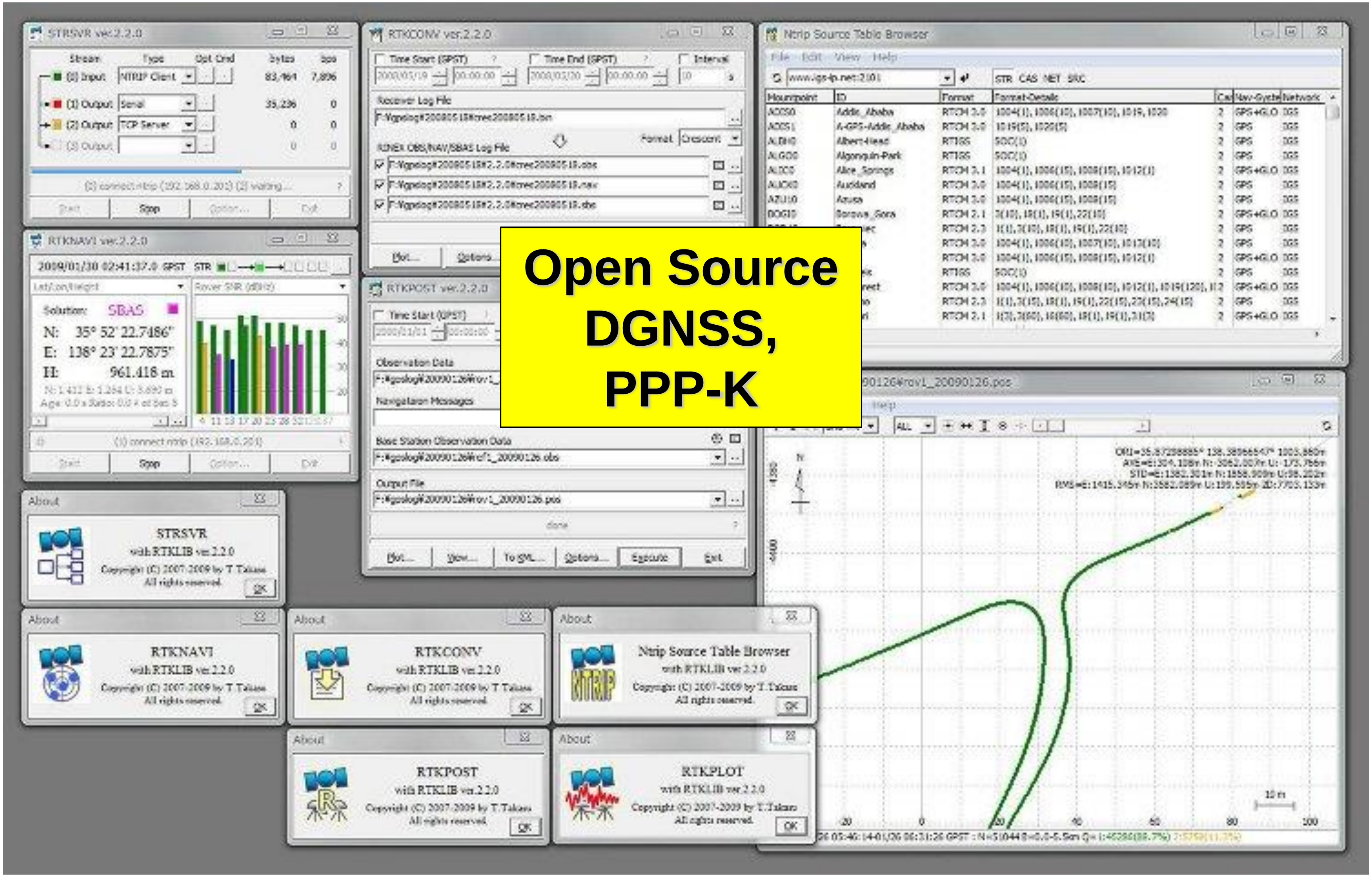
<u>1 cm</u>

<u>OPP-K global Positioning</u>

- **GNSS-Receivers**
- **Smartphones**

Smartphone and Tablets for Mobile GIS and Geo-Referencing GNSS Raw-Data on Smartphone => New Age, in 2017/2018

RTKLIB - Open Source Software (DGNSS/RTK, GNSS-PPP, Postprocessing



ZIM Cooperation Project on Mobile GIS PREGON-X

- Precision GNSS and Georeferencing on Smartphones, Tablets etc. = x – -

Funded as ZIM (Zentrales Innovationsprogramm Mittelstand) project by the German Ministry on Economy and Energy ((Bundesministerium für Wirtschaft und Energie).

NAVKA-Project IAF/HSKA

www.navka.de

PREGON-X

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

and DISY (www.disy.net)

ZIM Cooperation Project NAVKA ⇔ DISY on "Mobile GIS" Precise GNSS/Georeferencing On Smartphones (PREGON-X)

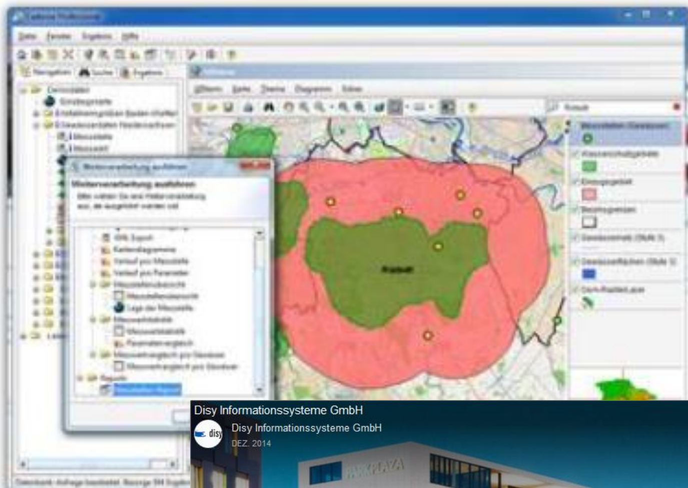
disy
GIS. Reporting. Datenmanagement.

Contact Career Resources DE/EN

News & Events | Products | Services | Industries | Our customers | About Disy | Suchbegriff

Cadenza

Benefits Platform **as GIS** Desktop Web Mobile



Cadenza is a desktop GIS, Web GIS and mobile GIS

Cadenza includes all functions that distinguish a geoinformation system (GIS). In addition, Cadenza offers u…

geodata. As a c… …ile

mobile. A map d…

device or as GIS…

experts, but also… …ive

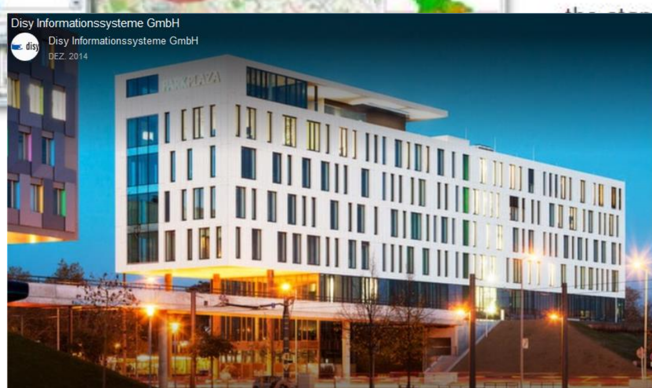
map and layer in… …e.

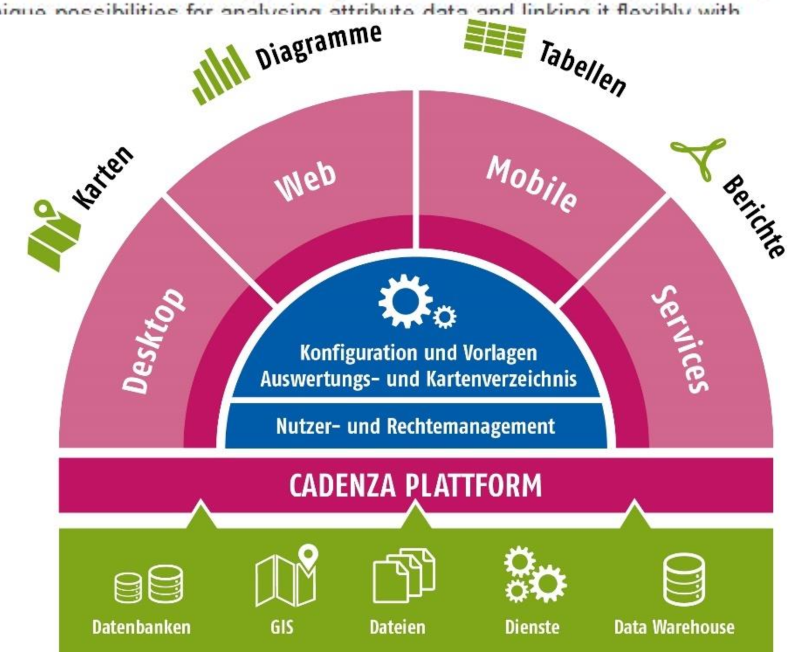
Cadenza works … … on

the standards of…

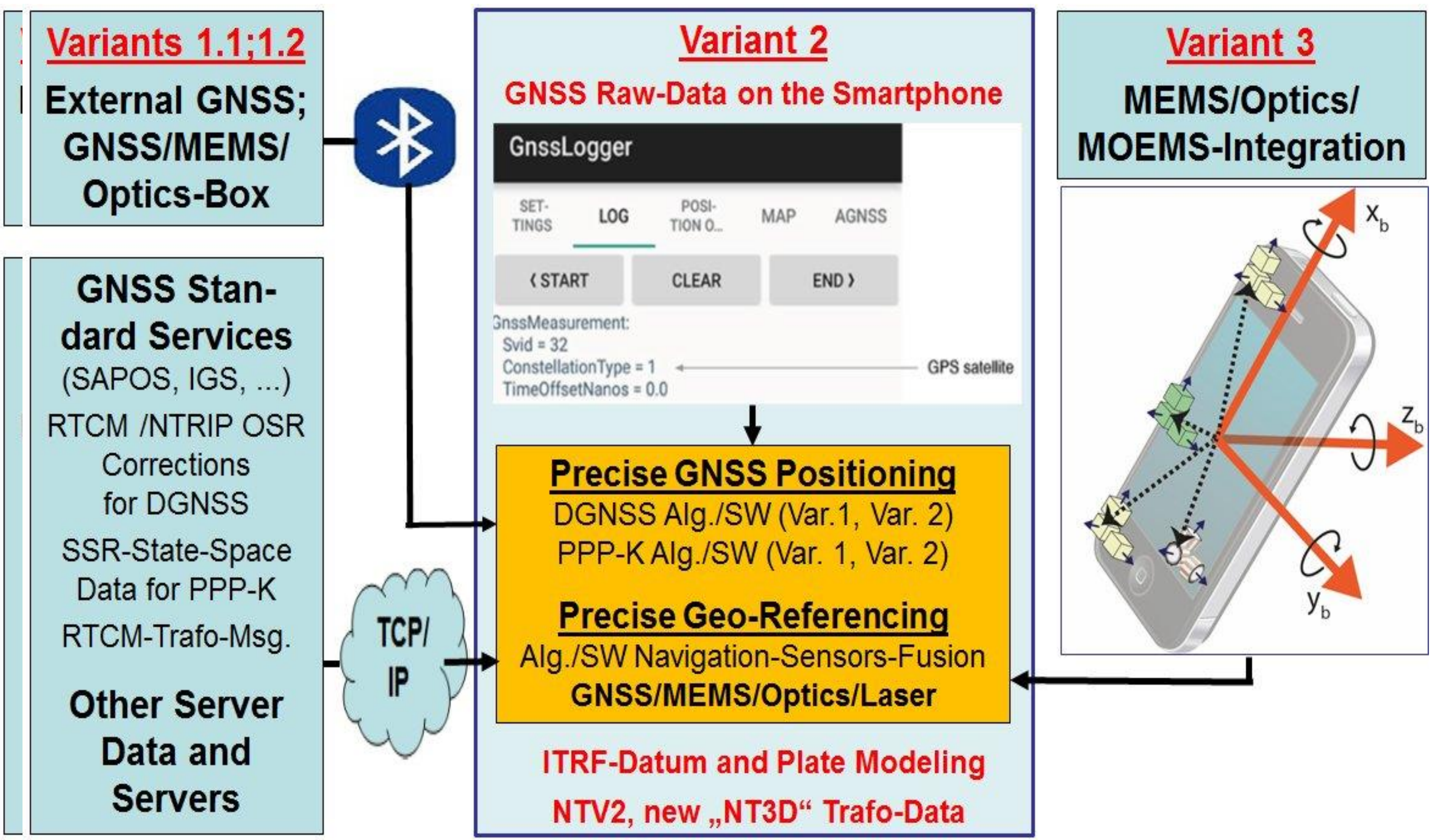
…neous c… …ust

…ut more



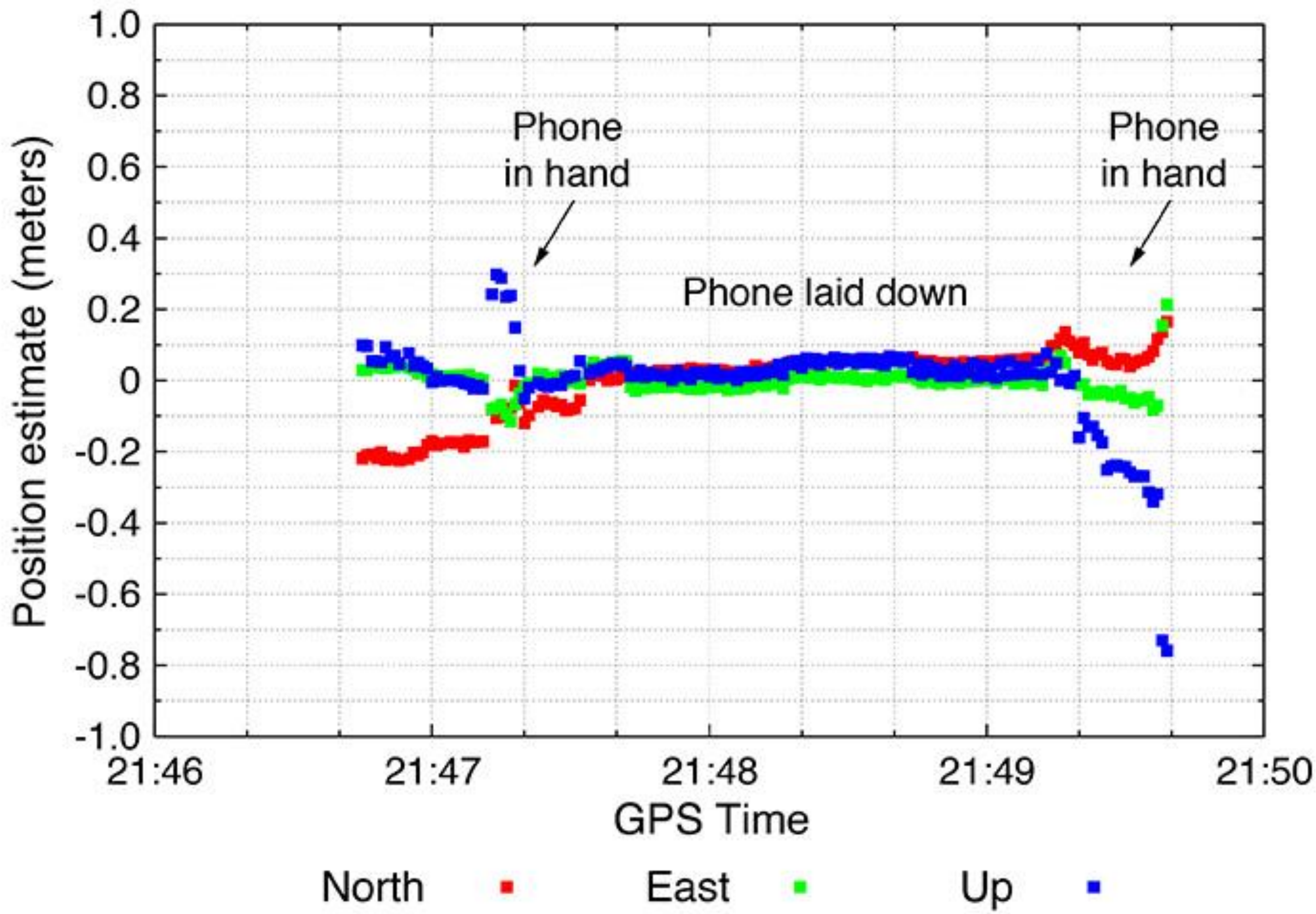


PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variants 1.1, 1.2, 2 and 3



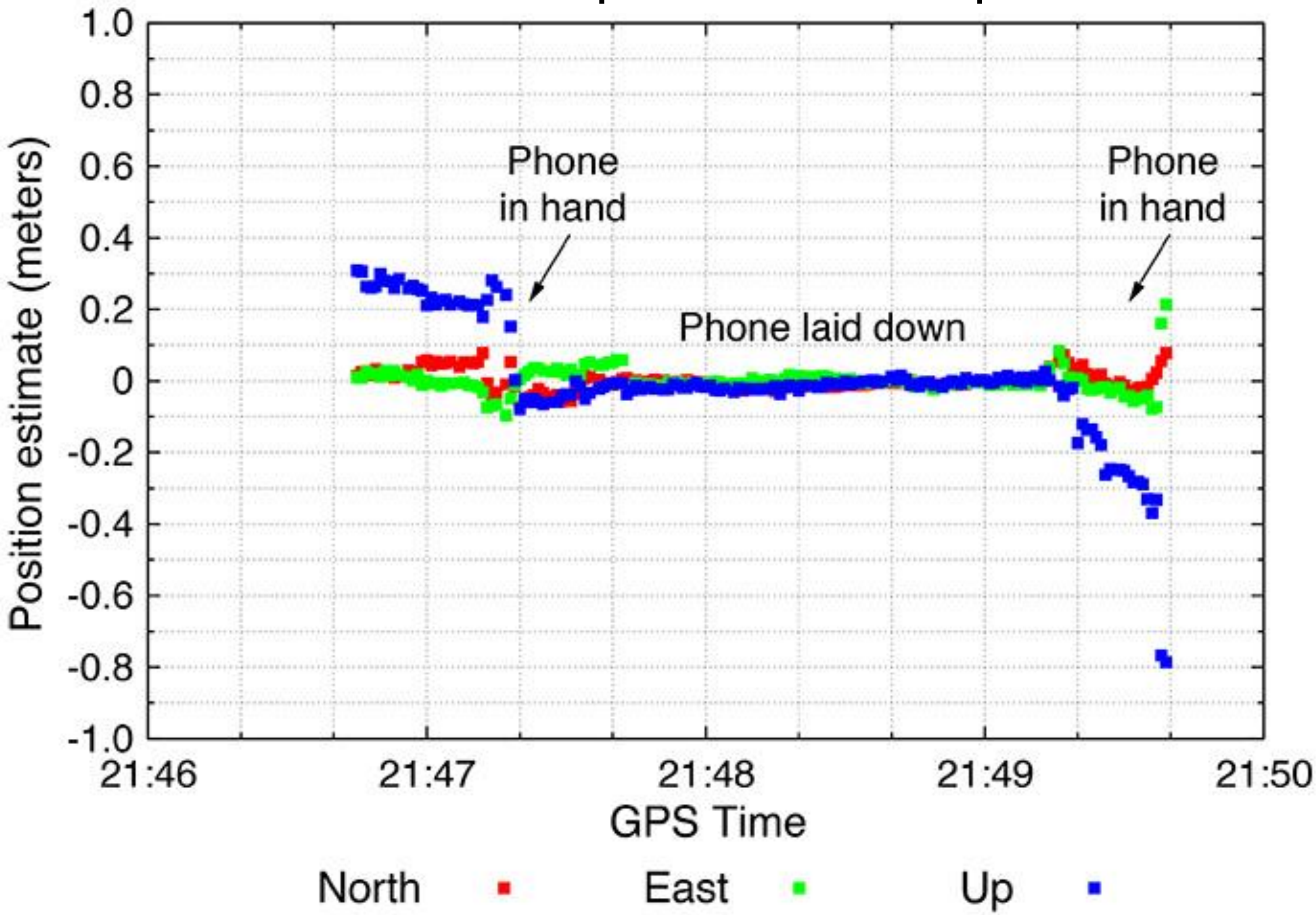
Smartphone and Tablets for Mobile GIS and Geo-Referencing GNSS Raw-Data on Smatphone – Risks for Variants 2 and 3

Position estimates using pseudorange, Doppler and carrier-phase data. The plotted estimates are differences with respect to the mean values in each component



Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smatphone – Risks for Variants 2 and 3

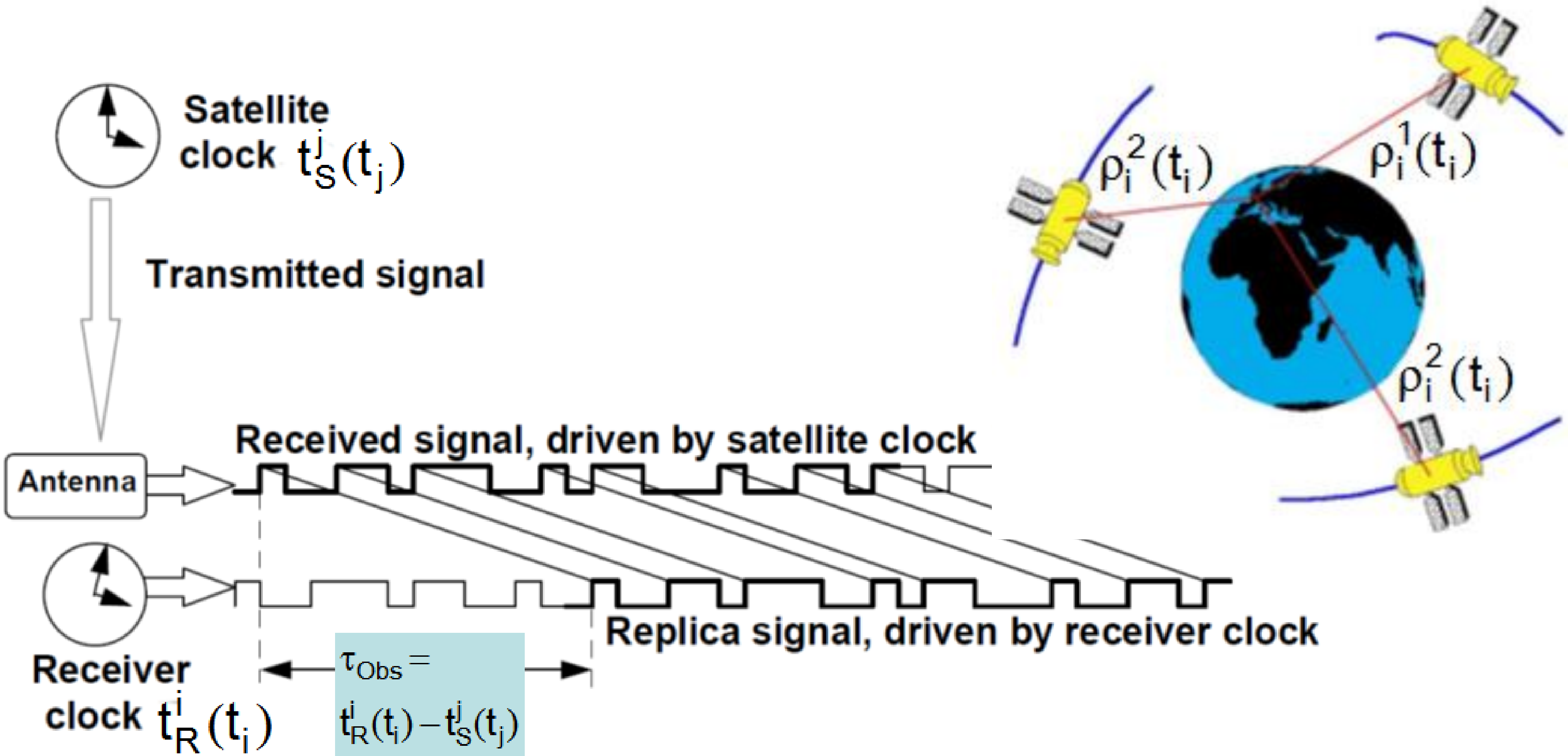
Position estimates as above but with precise external ionospheric information.



GNSS and Challenges

Pseudorange or Code-Observation

$$\rho_i^j(t_i)_{Obs} = c \cdot \tau^j_{i\,Obs} = c \cdot (t_R^i(t_i) - t_S^j(t_j)) = c \cdot ((t_i + \Delta\bar{t}_{R,i}) - (t_j + \Delta\bar{t}_{S,j}))$$

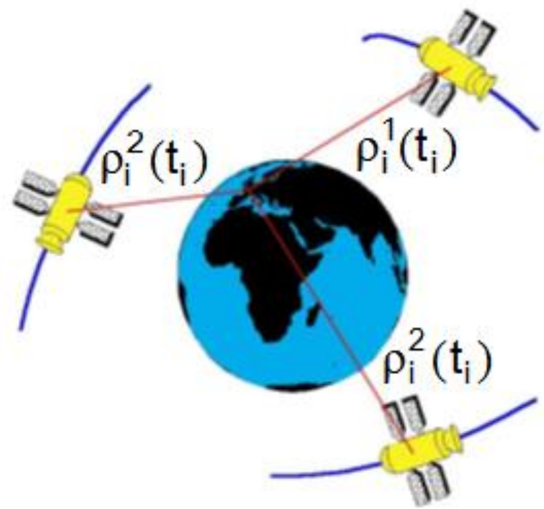


Pseudorange Modeling in ECEF and GNSS-time

$$\rho_i^j(t_i)_{Obs} = c\cdot\tau^j_{i\,Obs} = c\cdot(t_R^i(t_i) - t_S^j(t_j)) = c\cdot((t_i+\Delta\bar{t}_{R,i}) - (t_j + \Delta\bar{t}_{S,j}))$$

$$\text{with} \quad \tau^j_{i\,Obs} = t_R^i(t_i) - t_S^j(t_j)$$

1. Without Atmosphere corrections



$$\rho(t_i)_{Obs} = c\cdot(t_R^i(t_i) - t_S^j(t_j)) = c\cdot(t_i - t_j) + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j}$$

$$\rho(t_i)_{Obs} = \tilde{\rho}(t_i, t_j, \mathbf{o}^j) + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j}$$

$$\rho(t_i)_{Obs} = \left|\tilde{\mathbf{x}}_R^l(t_i) - \tilde{\mathbf{x}}_S^j(t_j, \mathbf{o}^j)\right| + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j}$$

$$\rho(t_i)_{Obs} = \left|\tilde{\mathbf{x}}_R^l(t_i) - \tilde{\mathbf{x}}_S^j(t_i - \tau_i, \mathbf{o}^j)\right| + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j}$$

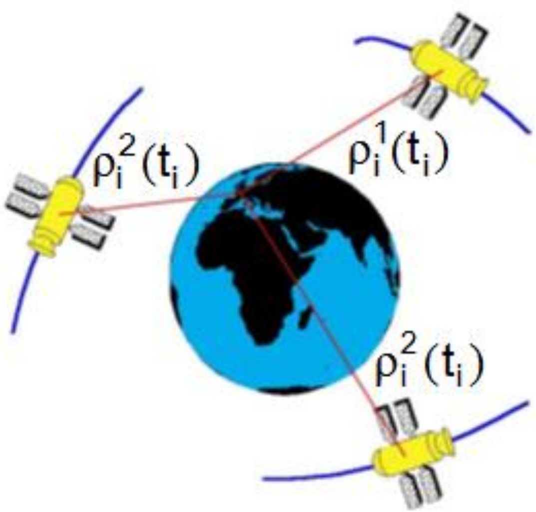
$$\rho(t_i)_{Obs} = \left|\tilde{\mathbf{x}}_R^l(t_i) - \tilde{\mathbf{x}}_S^j\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j\right)\right| + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j} \quad \text{with} \quad \tilde{\rho}(t_i) = \left|\tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}\right)\right|$$

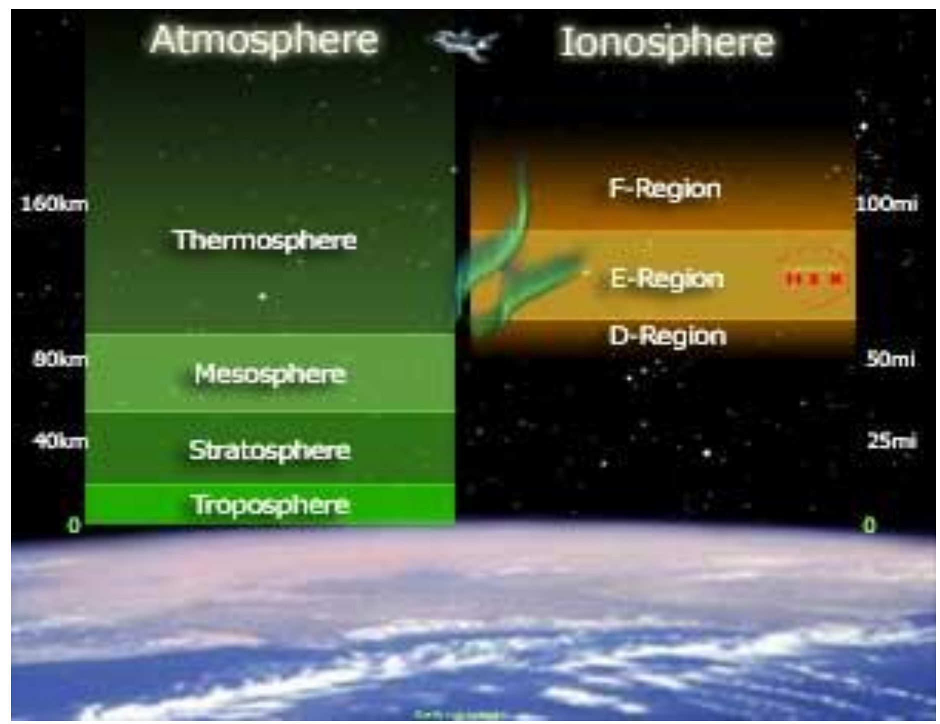
Pseudorange Modeling in ECEF and GNSS-time

2. With Atmosphere (Ionosphere and Troposphere)

$$\rho(t_i)_{Obs} = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j\right) \right| + c \cdot \Delta\bar{t}_{R,i} - c \cdot \Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP}$$

with $\tilde{\rho}(t_i) = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}\right) \right|$





Light Time Equation

$$\left| \underbrace{\tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}\right), \mathbf{o}^j)}_{\tilde{\rho}_i^j(t_i)\text{ - Iteration: "Light Time Equation"}} \right|$$

- Can be solved iteratively exactly based on GNSS time t(i), Orbit $\mathbf{o}^j$ and good position $\mathbf{x}_R$(t(i))
- Must be solved in repeated parameter estimation, if $\Delta t_{R,i}(t_i)$ and $\mathbf{x}_R$(t(i)) are unknown

3. Geodynamic Corrections

1. 3D-Earth Tide Corrections

$$\Delta r = \sum_{j=2}^{3} \frac{GM_j}{GM} \frac{r^4}{R_j^3} \left\{ \left[3 l_2 (\boldsymbol{R}_j * \boldsymbol{r}) \boldsymbol{R}_j \right] + \left[3 \left(\frac{h_2}{2} - l_2 \right) (\boldsymbol{R}_j * \boldsymbol{r})^2 - \frac{h_2}{2} \right] \boldsymbol{r} \right\} \left[-0.025 sin\rho \; cos\rho \; sin(\theta_g + \lambda) \right] \boldsymbol{r}$$

3.2. Ocean Loading (IERS Standards, 1996)

3.3. Atmospheric Loading

3.4. Earth Orientation

$$\mathbf{R}_i^e(t) = \mathbf{R}_P \cdot \mathbf{R}_E \cdot \mathbf{R}_N \cdot \mathbf{R}_{Pr} \qquad \mathbf{x}^e(t) = \mathbf{R}_i^e(t) \cdot \mathbf{x}^i(t)$$

Pseudorange Modeling in ECEF and GNSS-time

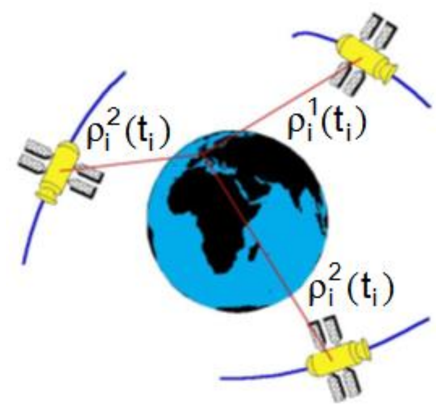
$$\rho(t_i)_{Obs} = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j\right) \right| + c \cdot \Delta\bar{t}_{R,i} - c \cdot \Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP}$$

$$\text{with} \quad \rho(t_i)_{Obs} = \left| \underbrace{\tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}\right), \mathbf{o}^j)}_{\tilde{\rho}_i^j(t_i)\text{ - Iteration: "Light Time Equation"}} \right| \quad \text{and} \quad \tau_i = \frac{\tilde{\rho}_i^j(t_i)}{c}$$

4. Additionally: Relativistic effects (Special and General Relativity)

4.1 Special and General Relativity in general

$$\frac{t'-t}{t} = \frac{\Delta t}{t} = \frac{x'-x}{x} = \frac{\Delta x}{x} = -\frac{f'-f}{f} = -\frac{\Delta f}{f} = \frac{m'-m}{m} = \frac{\Delta m}{m} = -\left(\frac{1}{2} \cdot \left(\frac{v}{c}\right)^2 + \frac{\Delta U}{c^2}\right)$$



4.2 GNSS pseudorange-observation scenario

$$\text{"t"} = \tau_i = \frac{\tilde{\rho}_i^j(t_i)}{c} \quad \text{and} \quad \frac{\Delta U}{c^2} = \frac{\mu}{c^2} \cdot \left[\frac{1}{R_E + h(t_i)} - \frac{1}{R_E} \right]$$

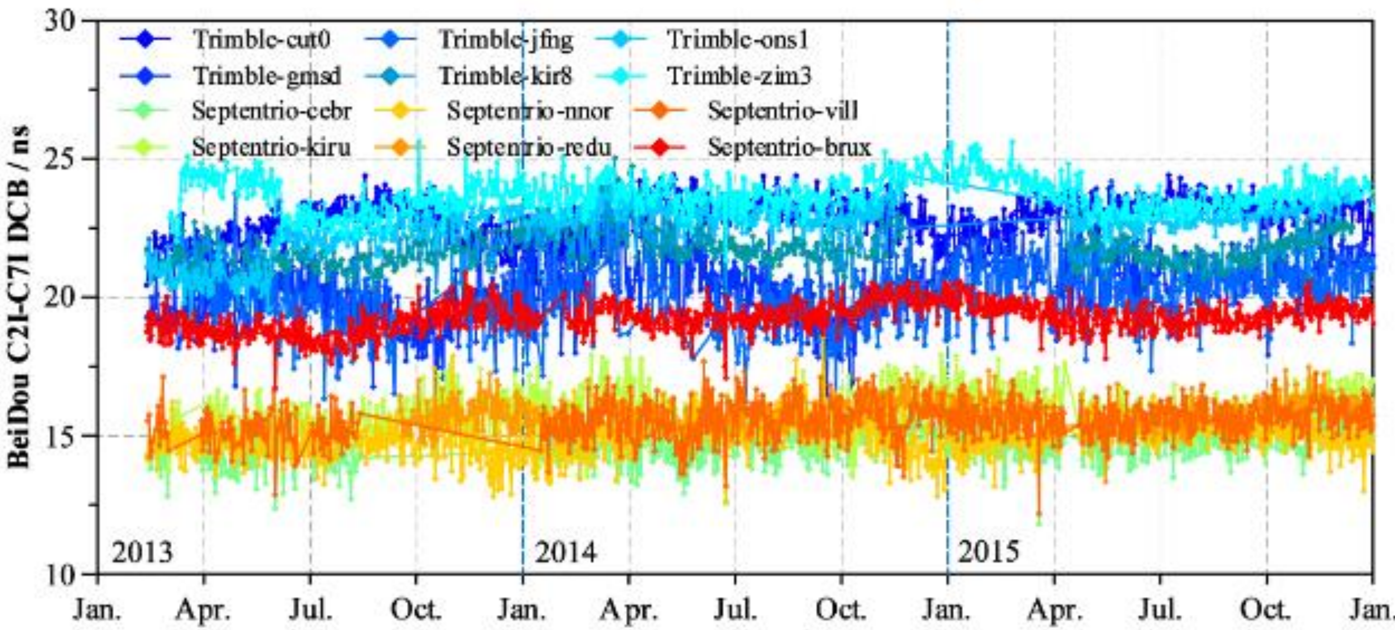
Pseudorange Modeling in ECEF and GNSS-time

$$\rho(t_i)_{Obs} = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S\left(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j\right) \right| + c\cdot\Delta\bar{t}_{R,i} - c\cdot\Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP}$$

Further Clock/Time-Bias

Trimble NETR9 receivers: 18.0~24.0 ns
Septentrio receivers: 13.0~19.0 ns

- **GNSS differential code biases (DCB)**



Time series of BeiDou C2I-C7I DCBs for the selected receivers during the period 2013–2015

DCB products available from 01/2013
IGG – updated daily (daily interval)
DLR – updated quarterly (both weekly and daily intervals)

Pseudorange Modeling in ECEF and GNSS-time

$$\rho(t_i)_{Obs} = \left| \tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}, \mathbf{o}^j) \right| + c \cdot \Delta\bar{t}_{R,i} - c \cdot \Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP}$$

5. Final Rough Pseudo-Range observation equation

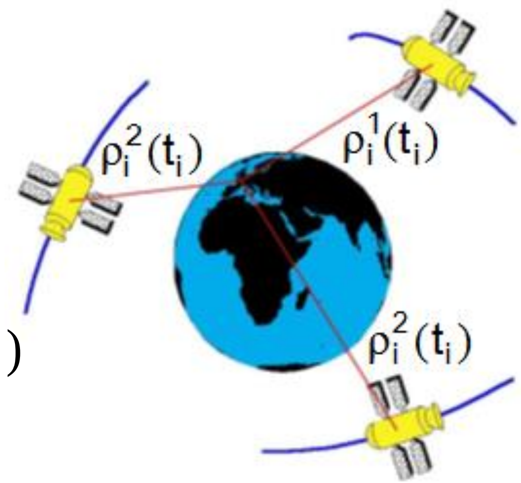
$$\rho(t_i)_{Obs} = \rho(t_i)_{Obs} = \left| \underbrace{\tilde{\mathbf{x}}_R(t_i) - \tilde{\mathbf{x}}_S(t_i - \frac{\tilde{\rho}_i^j(t_i)}{c}), \mathbf{o}^j)}_{\tilde{\rho}_i^j(t_i)\text{ - Iteration: "Light Time Equation"}} \right|$$

$$+ c \cdot (\Delta t_{R,i}(t_i) + \frac{1}{c^2} \cdot (\mathbf{x}^i_R(t_i) - \mathbf{x}^j_S(t_i)) \cdot (\boldsymbol{\omega}_E \times \mathbf{x}^i_R(t_i))$$

$$- c \cdot (\Delta t_{S,j}(t_i) - \left[\frac{2}{c^2} \sqrt{\mu \cdot a} \cdot e \cdot \sin(E(t_i)) \right]^j) + \Delta\rho^j_{i,ION}(t_i) + \Delta\rho^j_{i,TROP}(t_i)$$

Observations:

$t^i_R(t_i)$ and $\rho^j_i(t_i)_{Obs} = c \cdot \tau^j_{i\,Obs}$



Unknowns: $(x, y, z)_R(t_i), \Delta t_{R,i}(t_i)$

Corrections: Sagnac $R_{i,}$ Relativity S_j Clock S_j

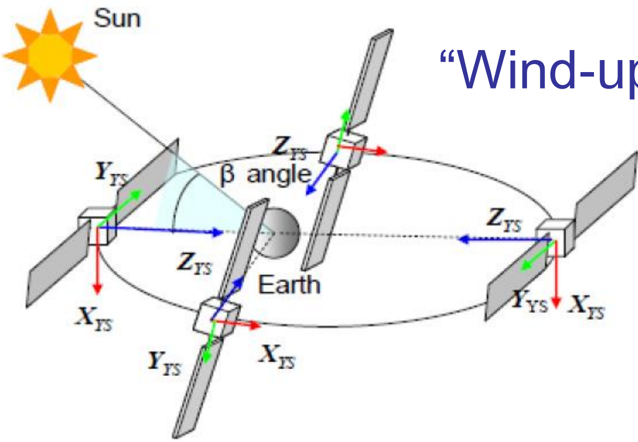
Further Corrections, Add. rel. clock variations, Add. ModelsION, TROP, Earth Dynamics

Phase Modelling in OPPP / PPP-K

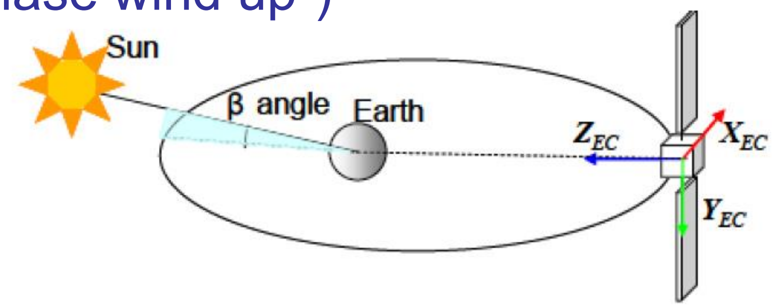
$$\underbrace{\lambda_i^j(t_i)_{Obs} + D_i^j(t_i)_{Obs}}_{\text{Stored as "Phase-Observations" at } t_{i,R}} = \tilde{\rho}_i^j(t_i) + c \cdot \Delta\bar{t}_{R,i} - c \cdot \Delta\bar{t}_{S,j} + \Delta\rho^j_{i,ION} + \Delta\rho^j_{i,TROP} + \lambda \cdot (\Delta\varphi_i + \Delta\varphi_j - N_i^j)$$

Uncalibrated phase delays (**UPD**) relevant to undifferen-ted integer fixing for PPP

"Wind-up ("Phase wind up")



Yaw-steering Mode



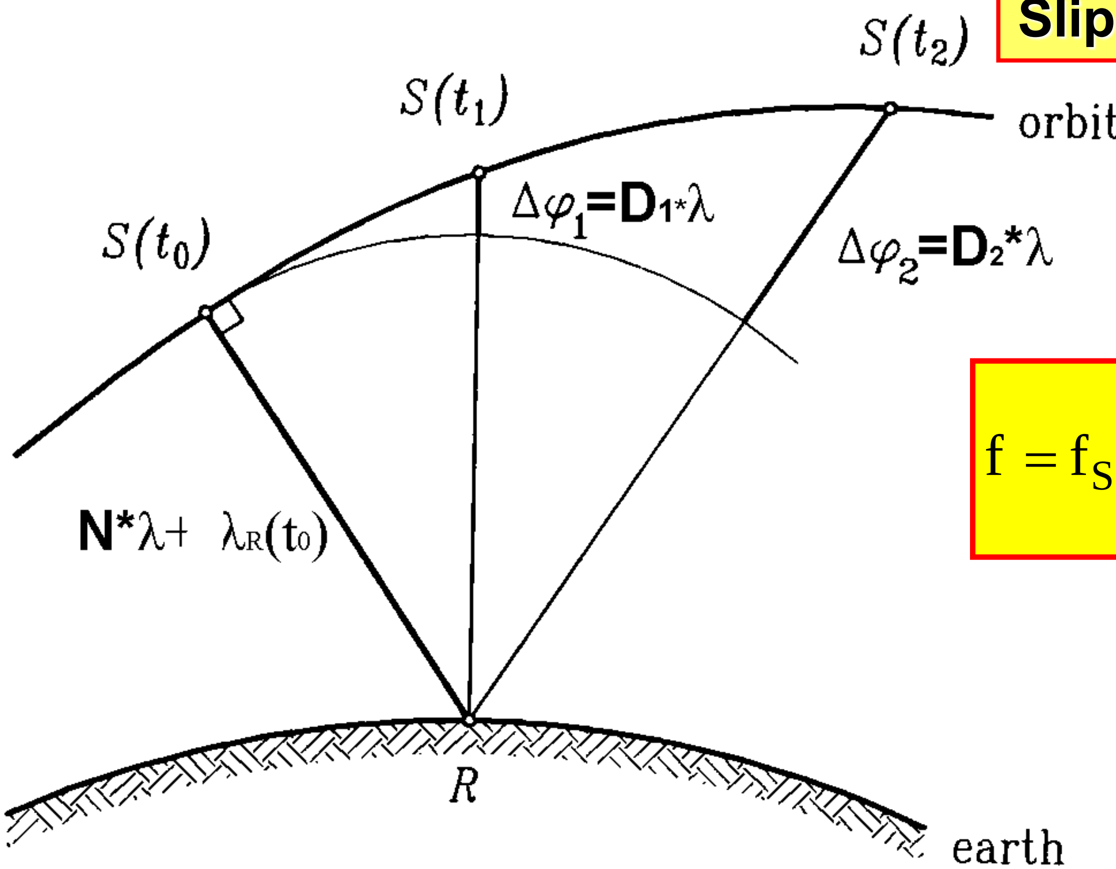
Orbit-normal („Earth-centered") Mode

Affects only carrier phase measurements (circularly polarized waves of GNSS signals).
A correction dPHi is only required for PPP absolute positioning.
DPhI depends on relative orientation of satellite and receiver antennas, and the direction of the line of sight. While moving in the orbit the satellites perform a rotation to keep its solar panels pointing to the sun direction in order to obtain the maximum energy, while the satellite antenna keeps pointing to the earth's centre. This rotation causes the a phase variation dPHi.

http://www.navipedia.net/index.php/Carrier_Phase_Wind-up_Effect

Doppler-Frequency Measurement Types

$$D_i = \mathrm{int}(\Delta\varphi'_i\,[\mathrm{cyc}]) = \mathrm{int}\left(\int_{t_0}^{t_i} (f_R - f_S)^t\, dt\right)$$



1.) Add. Measurement for Positioning by Phase-Measurements

Cycles D_i at Phase-Measurements. Error: „Cycle-Slip(s)“

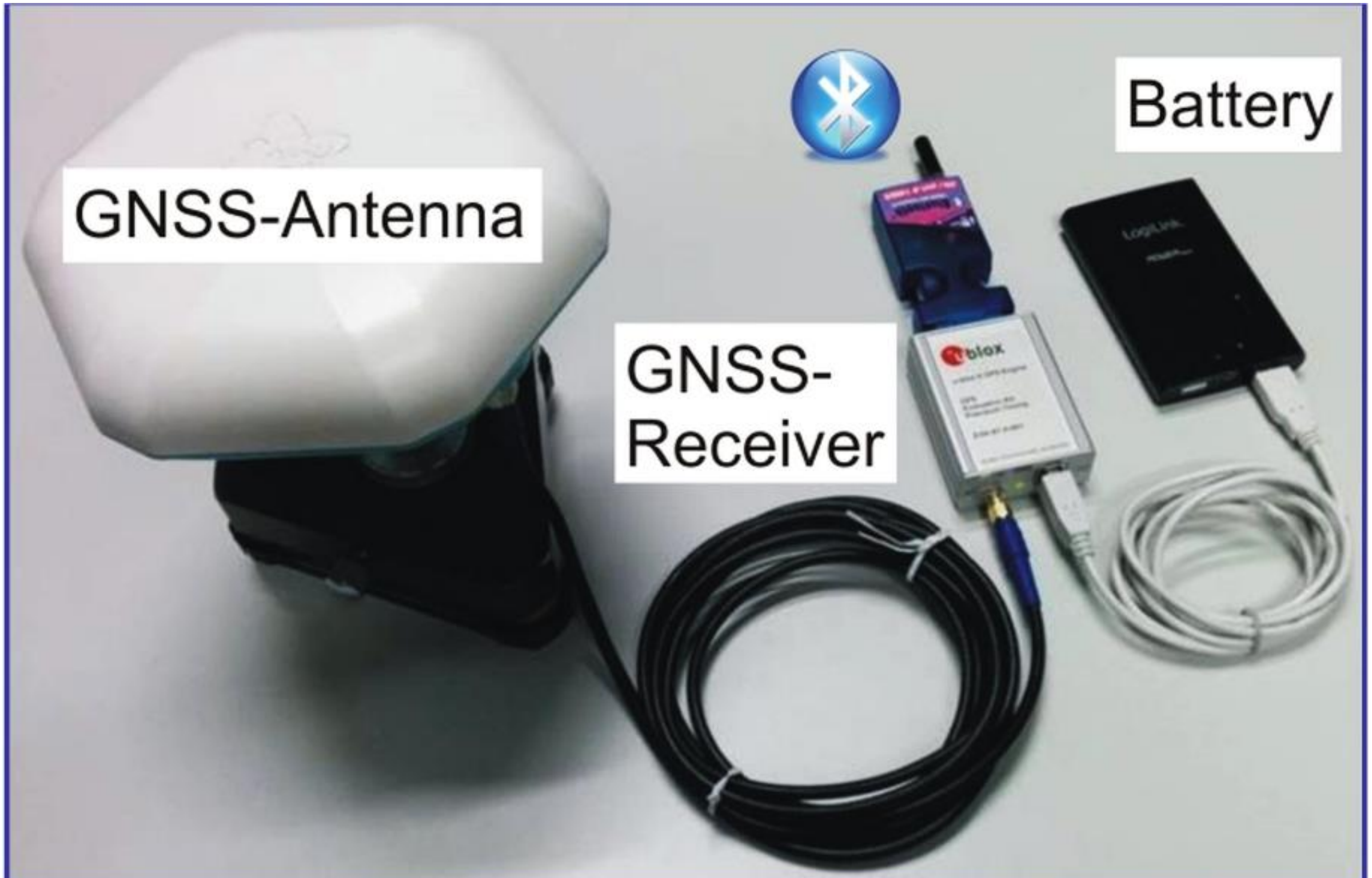
2.) General Measurment for Positioning and Navigation

$$f = f_S{}^t - f_R{}^t = \frac{f_S{}^t}{c} \cdot \frac{\mathbf{r}_S - \mathbf{r}_R}{|\mathbf{r}_S - \mathbf{r}_R|} \cdot (\dot{\mathbf{r}}_S - \dot{\mathbf{r}}_R)$$

$$\Delta f = f \cdot \left(\frac{1}{2} \cdot \left(\frac{v}{c}\right)^2 + \frac{\Delta U}{c^2}\right)$$

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Variants 1.1

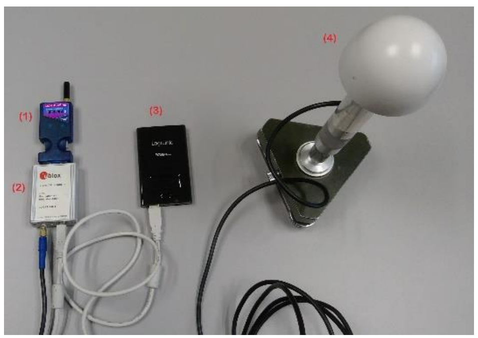
NAVKA „DGNSS/PPP-K Smartphone RTK“



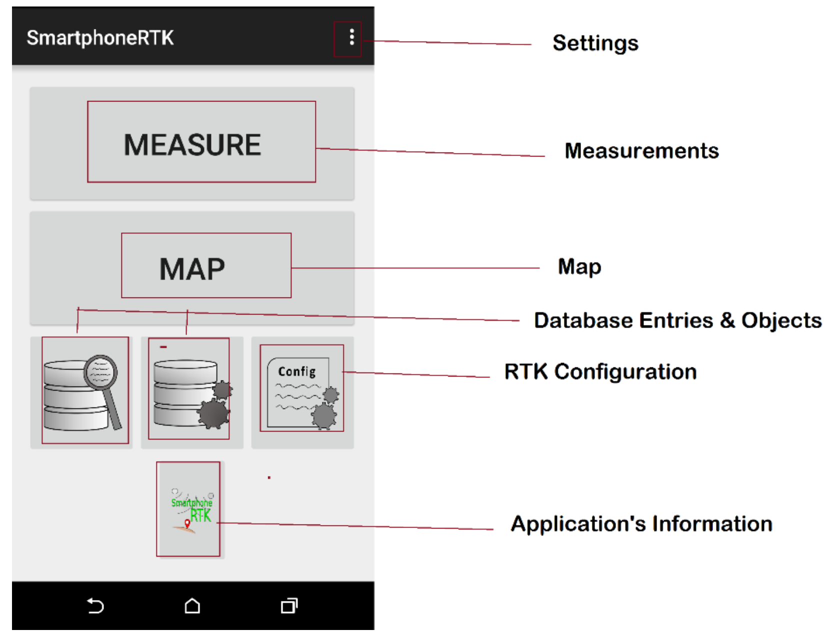
http://www.navka.de/images/files/NAVKA_smartphoneRtk.pdf

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1   Pure DGNSS/PPP-K

- Smartphone RTK is an android App which performs DGNSS, Static & Kinematic measurements by using external receiver (raw data), Bluetooth (data transfer) and RTKLIB service for the computations.



Components of the Smartphone RTK system



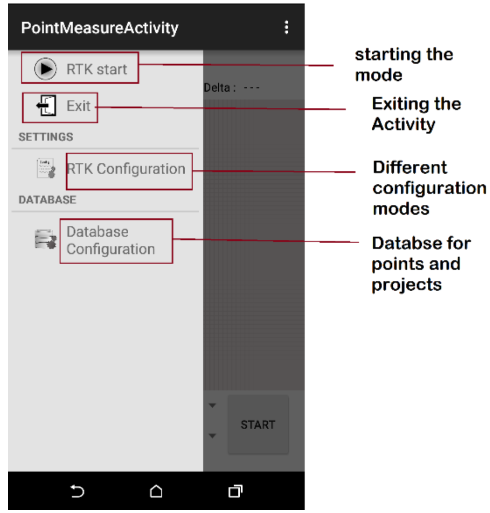
Main Activity of the App

- System Components:
  1. Bluetooth.
  2. GNSS receiver (e.g. Ublox).
  3. Source of power.
  4. Antenna.

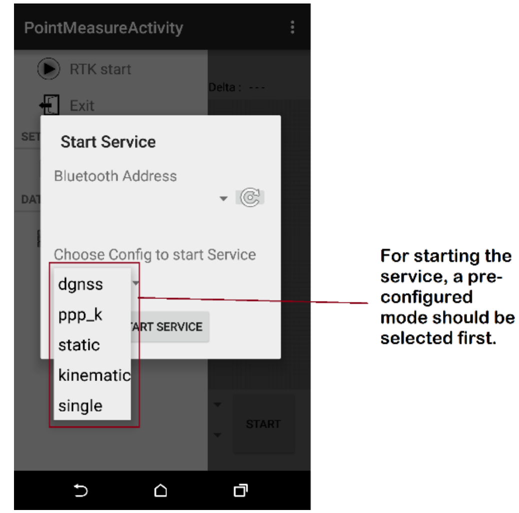
PREGON-X Smartphone for Mobile GIS and Geo-Referencing Variant 1.1 Pure DGNSS/PPP-K

- Measurement Modes:
  - I. Single mode.
  - II. DGNSS (e.g. SAPOS).
  - III. Kinematic.
  - IV. PPP-K.

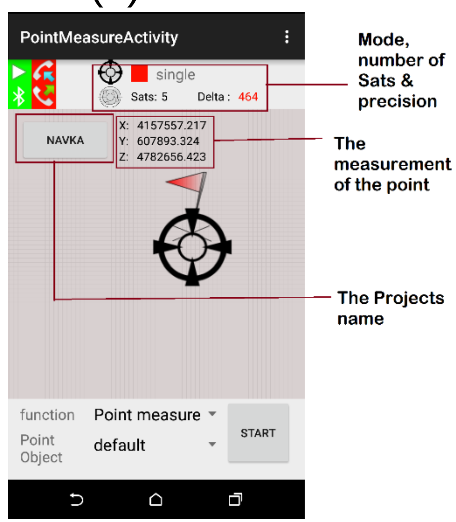
- Raw data/RTCM corrections
- Connection through Bluetooth, TCP/IP & NTRIP client.
- Database for Object management.
- Visualization through a map.
- Geocentric, Geographic & UTM coordinates.
- (a), (b),(c) &(d) shows the process of measuring and visualizing a point in single mode.



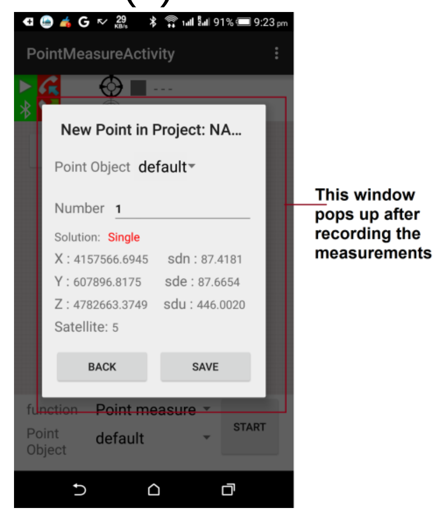
(a)



(b)



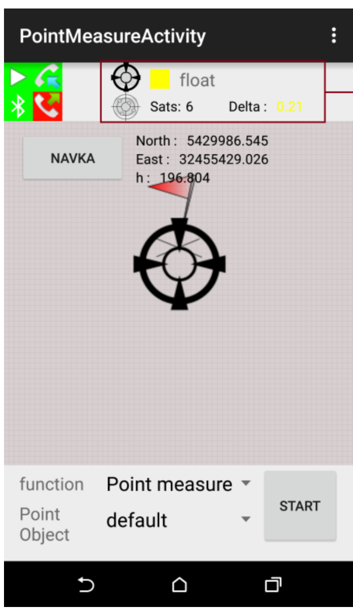
(c)



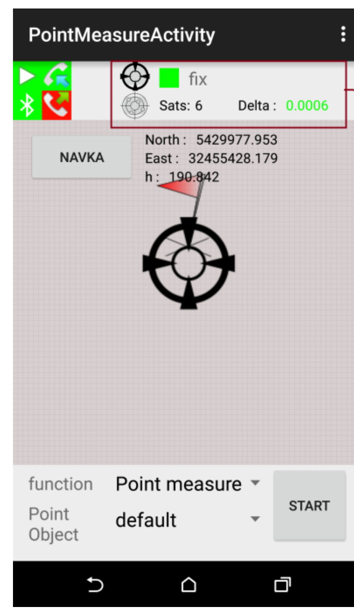
(d)

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1 Pure DGNSS/PPP-K

- A test was carried out using: U-blox receiver(EVK-6T) :
  - I. U-blox receiver (EVK-6T).
  - II. LogiLink Power bank.
  - III. HTC Desire Android 5.1 (Lollipop).
  - IV. Antenna (L1 Trimble Bullet) and Bluetooth (LinTeck mini adapter).
  - V. SAPOS(Satellite Positioning Service of the official German Surveying and Mapping)-DGNSS (static).



shows the float solution in North/East/h



shows the fix solution in North/East/h

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1   Pure GNSS / DGNSS

DGNSS

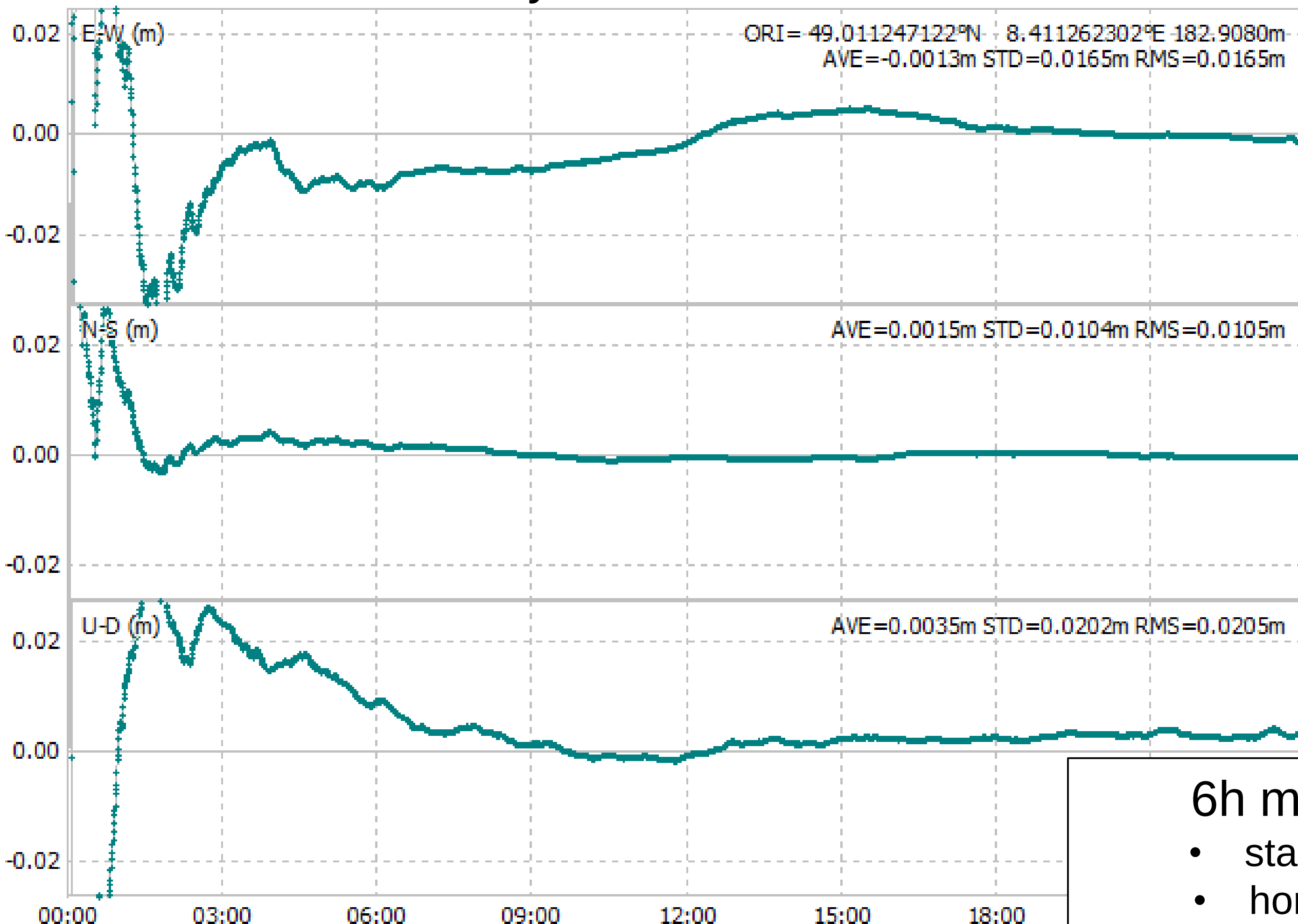
OSR-corrections

1-2 cm for 2 Frequency Receivers,

1-3 cm for 1-Frequency-Receivers. Longer time for fixing the ambiguities

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1 Pure GNSS PPP-K (L1/L2 GPS Receiver)

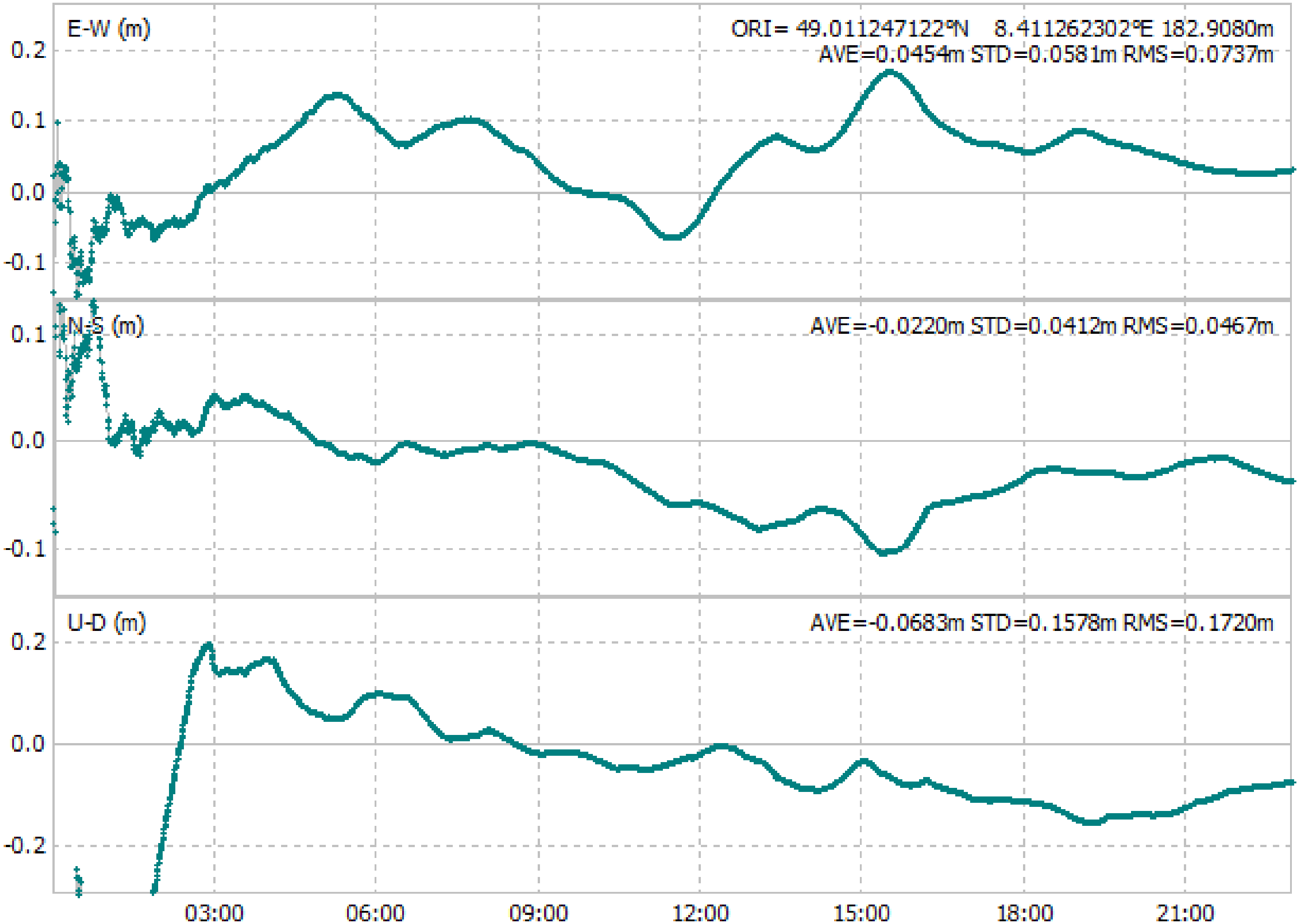
- after 15 min: accuracy is within 20 cm
- after 60 min: accuracy is in the sub-cm level



6h measurement:
- standard deviation:
- horizontal: 4.0 mm
- vertical: 2.0 mm

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1 Pure GNSS PPP-K L1 - Receiver

- after 15 min: accuracy is within 20 cm (horizontal) and 50 cm (height)
- after 60 min: horizontal accuracy is in the cm level



6h measurement:

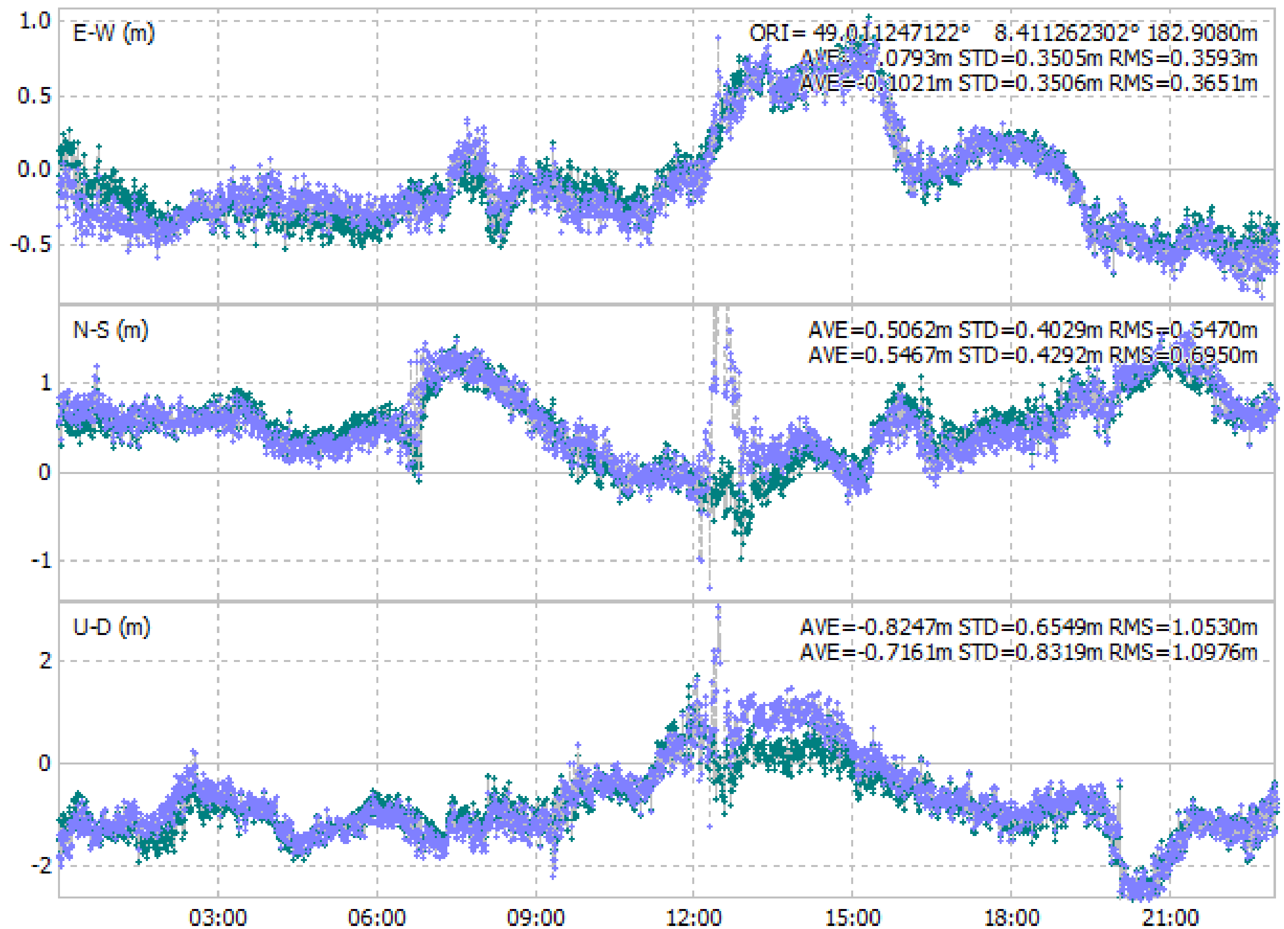
- not including the first 60 min
- standard deviation:
  horizontal: 8 cm vertical: 12 cm

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1   Pure GNSS / PPP-K

Results in PPP: KINEMATIC PPP (REAL TIME – IGS/RTS)

L1 lowcost receiver RTK (**blue**) and Post-processed (**green**)

- Accuracy: Horizontal: 0.7 m, Vertical: 1.0 m

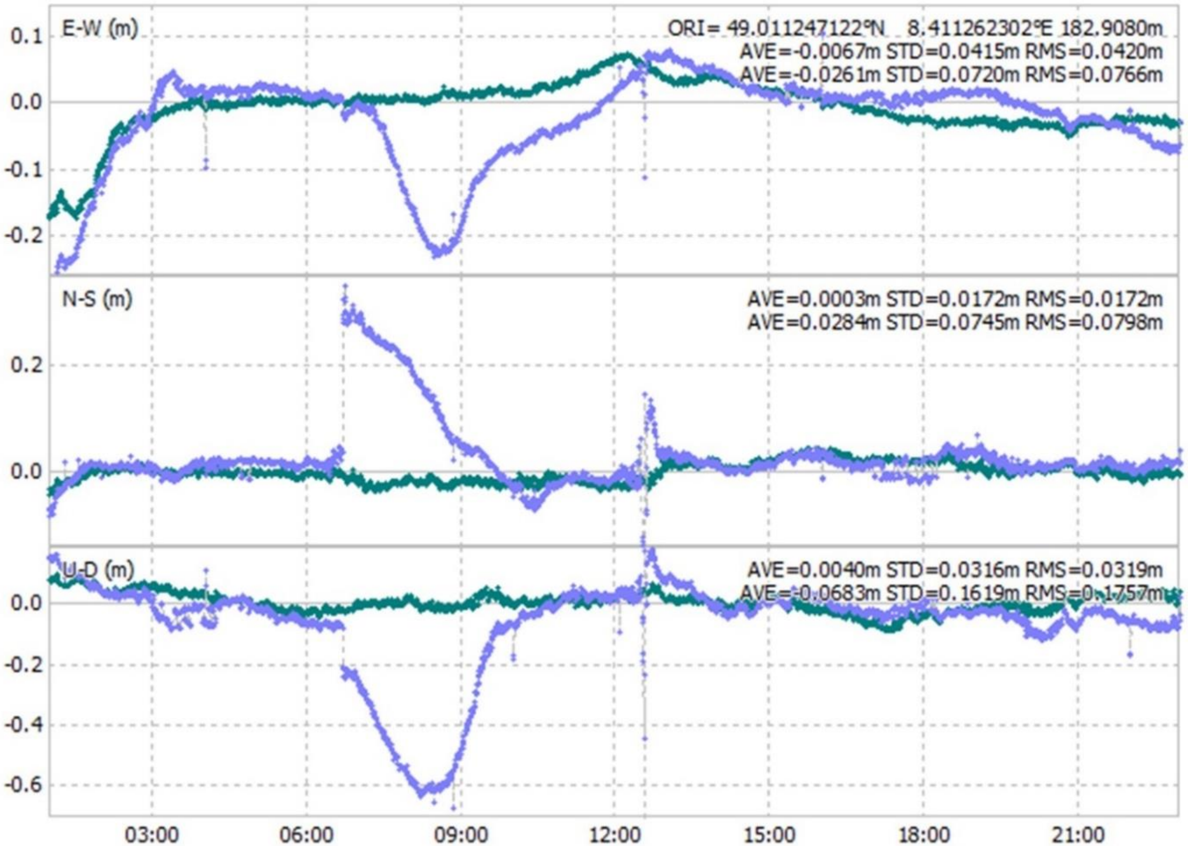


PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variant 1.1 Pure GNSS / PPP-K

First results (L1L2)

PPP Kinematic mode with IGS - RTS

- Realtime service



Results in PPP: KINEMATIC PPP (REAL TIME – IGS/RTS)

L1/L2 receiver (**blue**)

With Outliers!

Post-processed (**green**)

- Accuracy:

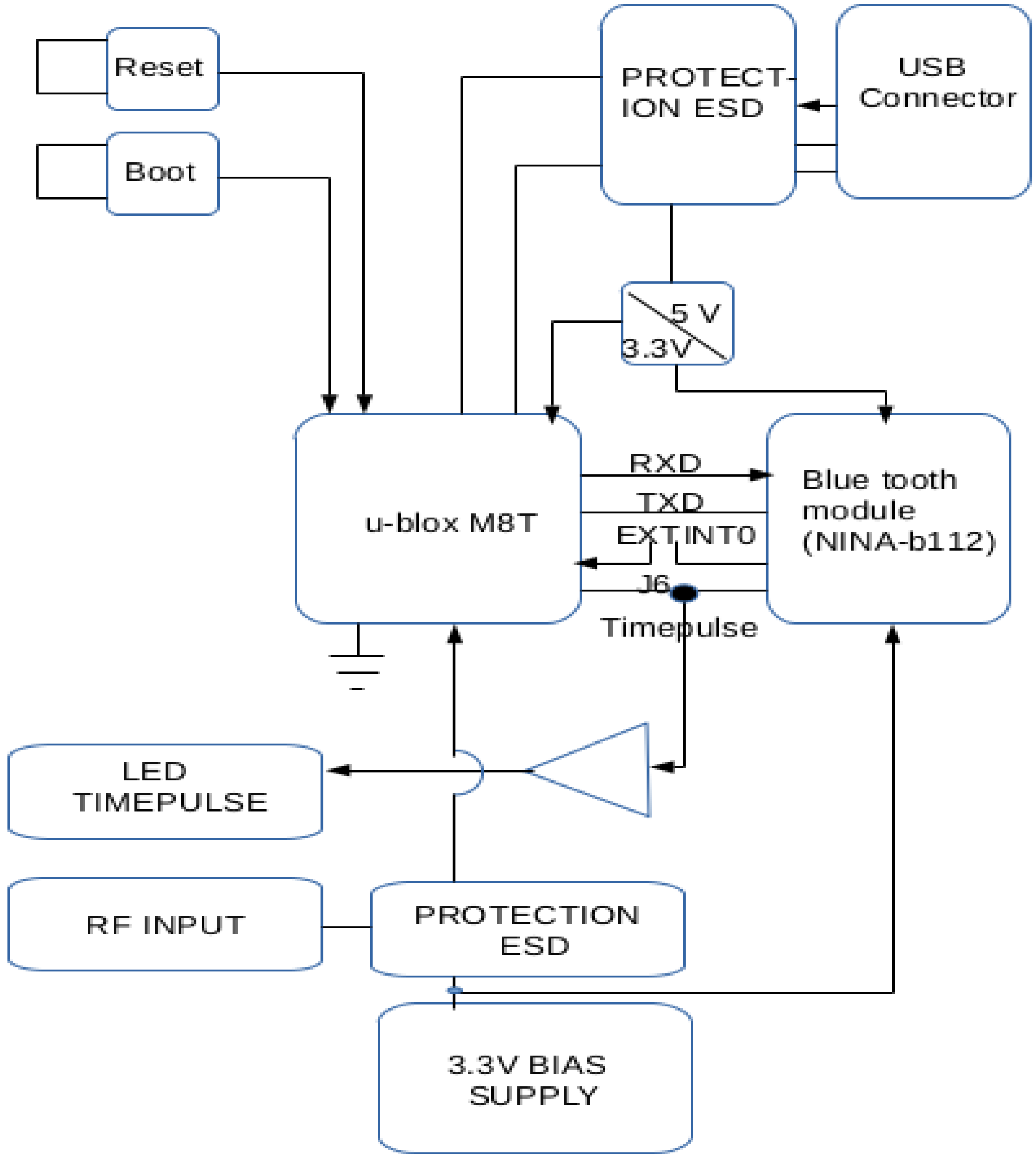
Horizontal: 0.12 m,
Vertical: 0.18 m

At present:

- **Predicted Orbit and Clock File - recomputed at 1 Hz with Bernese Software- In Tests**

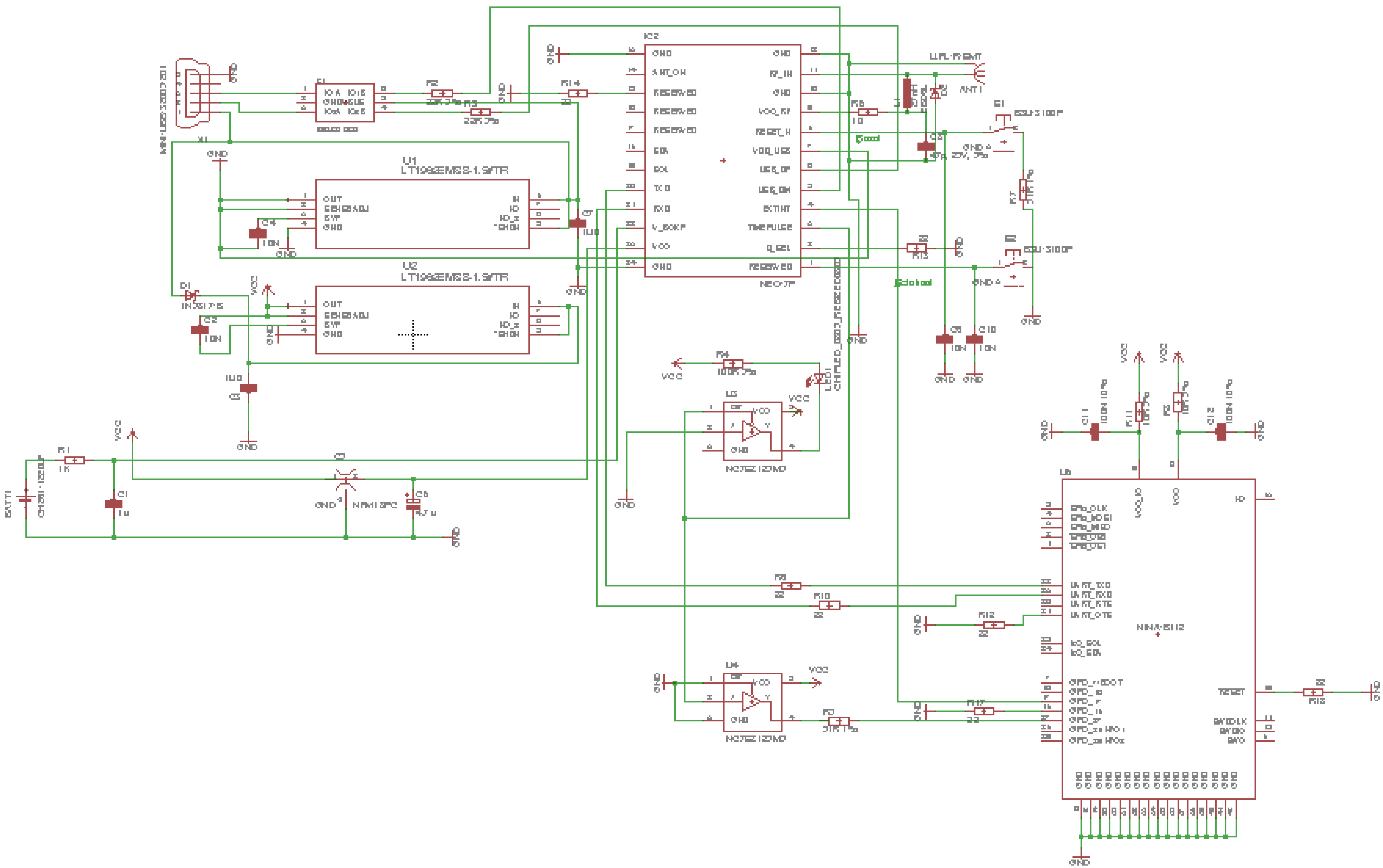
NAVKA
Hardware Developments
in
PREGON-X

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Variant 1.1



As the diagram denotes,the data from the GPS receiver ublox M8T is transmitted to the Bluetooth module NINA - B112. The power supply can be provided through the USB port or through the backup power supply through the battery on board.

PREGON-X Smartphone for Mobile GIS and Geo-Referencing - Variant 1.1 – EAGLE Layout



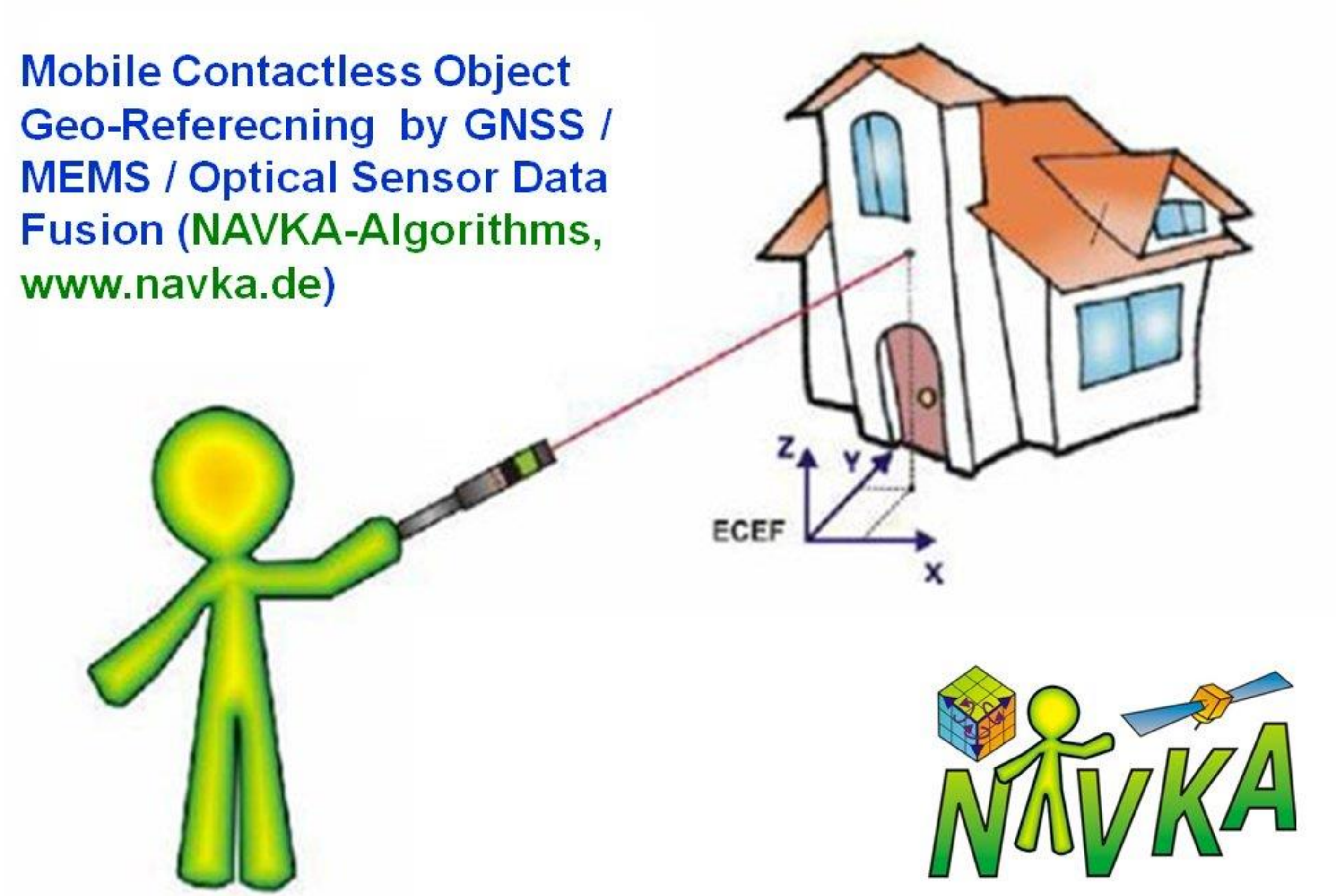
PREGON-X Smartphone for Mobile GIS and Geo-Referencing - Variant 1.1 – Sensors and Electronics

PREGON-X

Contact-free Georeferencing

NAVKA (www.navka.de)

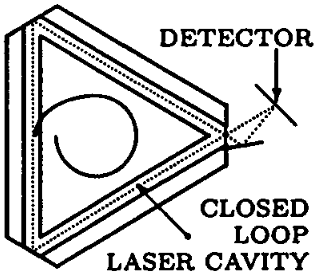
PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Variants 1.2 and 3



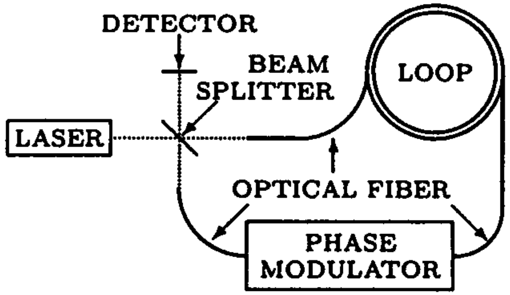
$$\mathbf{y}(t) = \left[x^e \; y^e \; z^e \mid \dot{x}^e \; \dot{y}^e \; \dot{z}^e \mid r^e \; p^e \; y^e \parallel \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \mid \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \mid \dot{\omega}^b_{eb,x} \; \dot{\omega}^b_{eb,y} \; \dot{\omega}^b_{eb,z} \right]$$

2. Autonomous

1.) MEMS-Gyro



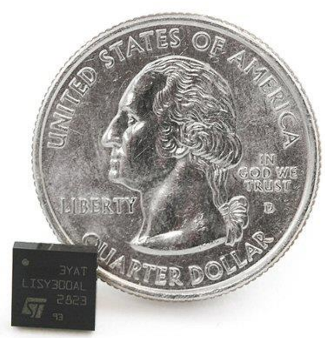
(a) Ring Laser Gyro (RLG)



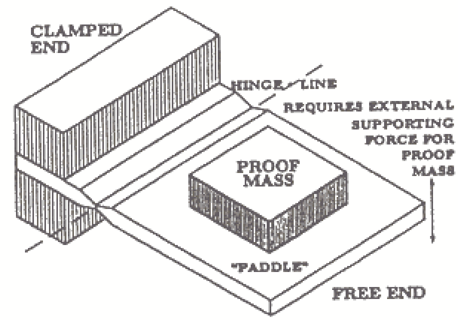
(b) Fiber Optic Gryo (FOG)

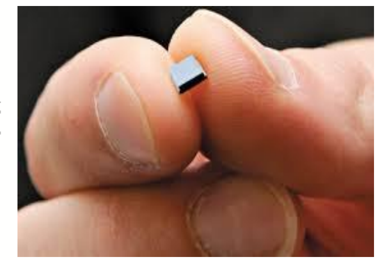
Observation I: $\boldsymbol{\omega}_{ip}^{p}$

$$\boldsymbol{\omega}_{ep}^{p} = \boldsymbol{\omega}_{ip}^{p} - \mathbf{R}_{e}^{p}(r,p,y) \cdot \boldsymbol{\omega}_{ie}^{e}$$



2.) MEMS-Accelerometers





Observation I: $\mathbf{a}^{p}$

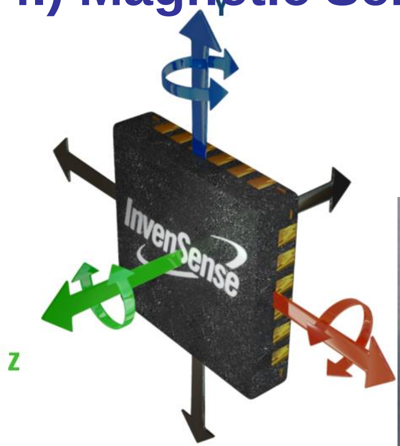
$$\ddot{\mathbf{x}}^{i}(t) = \mathbf{g}^{i}(\mathbf{x}) + \mathbf{R}_{p}^{i}(t) \cdot \mathbf{a}^{p}$$

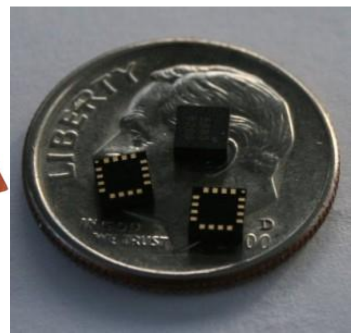
References: Inertial Space (i) and Gravity Field

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smatphone – Variants 1.2 and 3

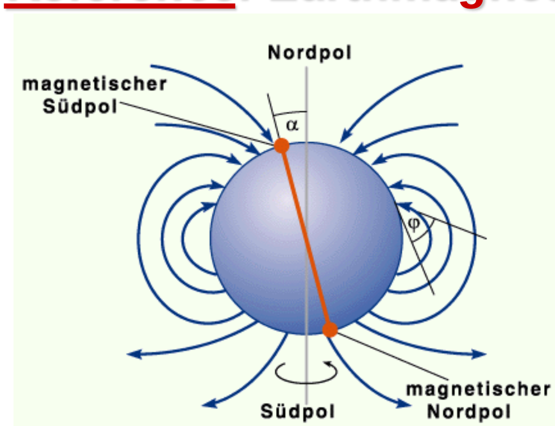
2. Autonomous

4.) Magnetic Sensors





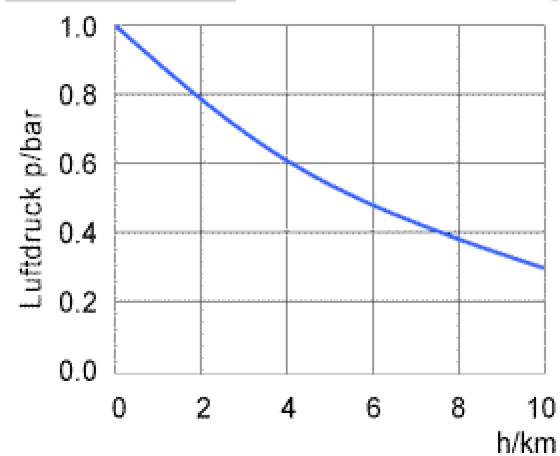
Reference: Earthmagnetic Field M



5.) Barometric Sensors (Height)

Auxiliary Sensor

Reference: Earth Atmosphere



Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smatphone – Variants 1.2 and 3

NAVKASMART-Phone Marker APP (Optical Markers, LED, Infrared)

$$u_i = cx + \left(\frac{\mathrm{r}_{11} * (\mathrm{X_i} - \mathrm{X0}) \ + \ \mathrm{r}_{12} * (\mathrm{Yi} - \mathrm{Y0}) \ + \mathrm{r}_{13} * (\mathrm{Z_i} - \mathrm{Z0})}{\mathrm{r}_{31} * (\mathrm{X_i} - \mathrm{X0}) \ + \ \mathrm{r}_{32} * (\mathrm{Yi} - \mathrm{Y0}) \ + \mathrm{r}_{33} * (\mathrm{Z_i} - \mathrm{Z0})}\right) * f$$

$$v_i = cy + \left(\frac{\mathrm{r}_{21} * (\mathrm{X_i} - \mathrm{X0}) \ + \ \mathrm{r}_{22} * (\mathrm{Yi} - \mathrm{Y0}) \ + \mathrm{r}_{23} * (\mathrm{Z_i} - \mathrm{Z0})}{\mathrm{r}_{31} * (\mathrm{X_i} - \mathrm{X0}) \ + \ \mathrm{r}_{32} * (\mathrm{Yi} - \mathrm{Y0}) \ + \mathrm{r}_{33} * (\mathrm{Z_i} - \mathrm{Z0})}\right) * f$$

Smartphone and Tablets for Mobile GIS and Geo-Referencing
GNSS Raw-Data on Smartphone – Variants 1.2 and 3

1.)

Velocity - Observation from the differentation of subsequent VO-based position-differences

$$\boxed{\mathbf{v}^{VO}(t)}$$

General leverarm-situation for Camera

$$\mathbf{t}^{b}_{VO} \quad \mathbf{R}(r_x, r_y, r_z)^{VO}_{b}$$

Final Observation Equation in Tight Coupling

$$\mathbf{v}^{VO}(t) = \mathbf{R}^{VO}_{b} \cdot \mathbf{R}(r,p,y)^{b}_{e} \cdot (\dot{\mathbf{x}}(t)^{\mathbf{e}} + \mathbf{R}(r,p,y)^{\mathbf{e}}_{\mathbf{b}} \cdot (\boldsymbol{\omega}^{\mathbf{b}}_{\mathbf{eb}} \times \mathbf{t}^{b}_{VO}))$$

GNSS Raw-Data on Smartphone – Variants 1.2 and 3

2.) Orientation-rate observation from the subsequent VO-based orientation change

$$\boxed{\mathbf{\Omega}_{e,VO}^{VO}(t)}$$

General leverarm-situation for Stereo-Camera

$$\mathbf{t}_{VO}^{b} \quad \mathbf{R}(r_x, r_y, r_z)_b^{VO}$$

Final Observation Equation in Tight Coupling

$$\mathbf{\Omega}_{\text{"Object-Frame",VO}}^{VO}(t) = \mathbf{R}_b^{VO} \cdot (\mathbf{\Omega}_{\text{Object-Frame,VO}}^{b}(t)) \cdot (\mathbf{R}_b^{VO})^T$$

$$= \mathbf{R}_b^{VO} \cdot (\underbrace{\mathbf{\Omega}_{\text{Object-Frame},e}^{b}(t)}_{=0} + \mathbf{\Omega}_{e,b}^{b}(t) + \underbrace{\mathbf{\Omega}_{b,VO}^{b}(t)}_{=0}) \cdot (\mathbf{R}_b^{VO})^T$$

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Variants 1.2 and 3

$$\mathbf{y}(t) = \left[x^e \; y^e \; z^e \mid \dot{x}^e \; \dot{y}^e \; \dot{z}^e \mid r^e \; p^e \; y^e \parallel \ddot{x}^e \; \ddot{y}^e \; \ddot{z}^e \mid \omega^b_{eb,x} \; \omega^b_{eb,y} \; \omega^b_{eb,z} \mid \dot{\omega}^b_{eb,x} \; \dot{\omega}^b_{eb,y} \; \dot{\omega}^b_{eb,z} \right]$$

$$\mathbf{x}^e = \mathbf{x}^e_{\substack{GNSS \\ p-Origin}} + \mathbf{R}^e_n(B,L) \cdot \mathbf{R}^n_p(r,p,y) \cdot \mathbf{x}(s,\alpha,\delta,t_x,t_y,t_z)^p$$

with

$$\mathbf{x}^e = \begin{bmatrix} x(B,L,h) \\ y(B,L,h) \\ z(B,L,h) \end{bmatrix}$$

1. Component: GNSS $\mathbf{x}^e_{\substack{GNSS \\ p-Origin}}$

2. Component - Contribution of the Laser

s = Slope Distance of Laser
α = Orientation of Laser relative to x-axis of the Platform (p)
α = Orientation of Laser relative to z-axis of the Platform (p)
t_x = x-Coordinate of the Position of Laser on the Platform (p)
t_y = y-Coordinate of the Position of Laser on the Platform (p)
t_z = z-Coordinate of the Position of Laser on the Platform (p)

$$\mathbf{x}^p = s \cdot \begin{bmatrix} \cos\alpha \cdot \cos\delta \\ \sin\alpha \cdot \cos\delta \\ \sin\delta \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

3. Component - Contribution of the Deep Coupled MEMS-Multisensorsystem

Orientation of Platform (p) in the Local Navigation Frame (n-frame) in terms of the Attitude Matrix

$$\mathbf{R}^n_p = \begin{pmatrix} \cos p \cos y & \cos p \sin y & -\sin p \\ \sin r \sin p \cos y - \cos r \sin y & \sin r \sin p \sin y + \cos r \cos y & \sin r \cos p \\ \cos r \sin p \cos y + \sin r \sin y & \cos r \sin p \sin y - \sin r \cos y & \cos r \cos p \end{pmatrix}^T \qquad \mathbf{R}(Roll, Pitch, Yaw)^n_p$$

General Georeferencing Questions

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts

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Title and reference

Verordnung (EG) Nr. 1089/2010 der Kommission vom 23. Novemb
und des Rates hinsichtlich der Interoperabilität von Geodatensätze

Languages and formats available

BG ES CS DA DE ET EL EN FR G

HTML

Georeferencing and Interoperability ITRF/ETRF89 http://inspire.ec.europa.eu/index.cfm/pageid/3

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INSPIRE
Infrastructure for Spatial Information in Europe

D2.8.III.2 Data Specification on Buildings – Draft Guidelines

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Creator	INSPIRE Thematic Working Group *Buildings*
Date	2012-04-20
Subject	INSPIRE Data Specification for the spatial data theme *Buildings*
Publisher	INSPIRE Thematic Working Group *Buildings*
Type	Text
Description	This document describes the INSPIRE Data Specification for the spatial data theme *Buildings*

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts

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BAnz AT 14.11.2013 B1
Seite 1 von 17

Bundesministerium des Innern

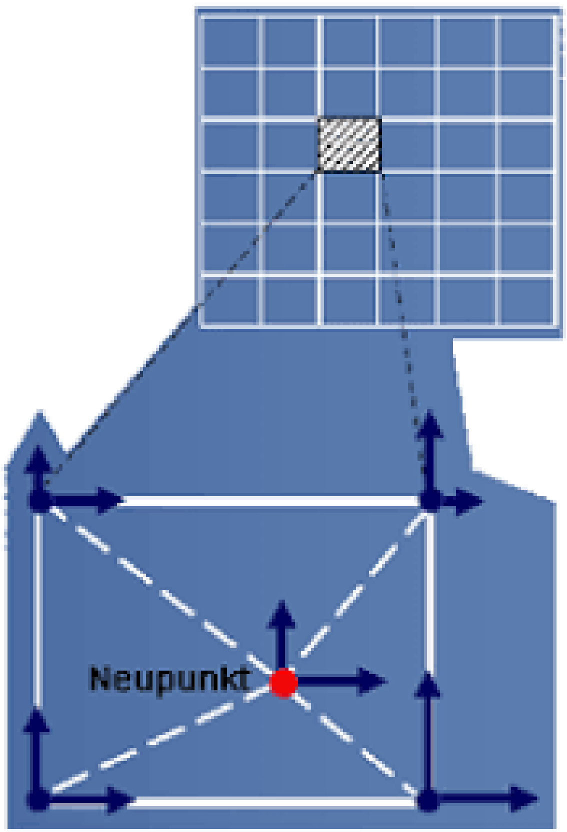
Bekanntmachung
der Neufassung der Technischen Richtlinie zum Gesetz
über die geodätischen Referenzsysteme, -netze
und geotopographischen Referenzdaten des Bundes
(Technische Richtlinie Bundesgeoreferenzdatengesetz – TR BGeoRG)

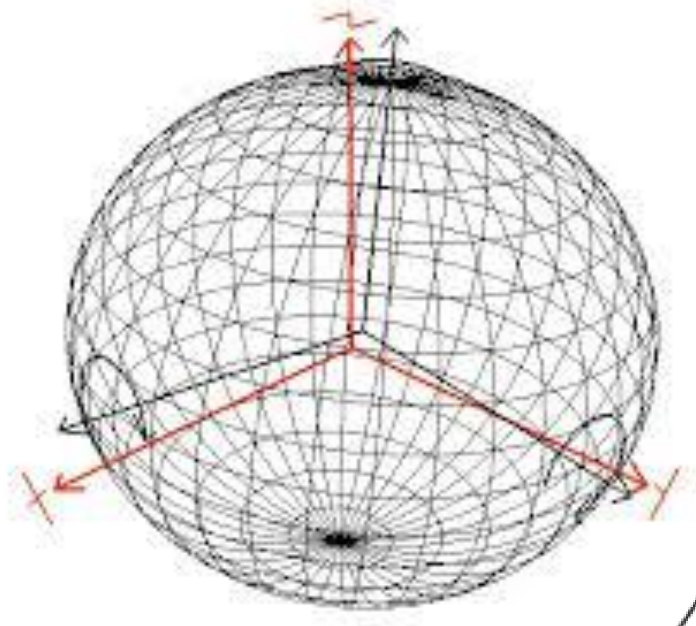
Vom 28. Oktober 2013

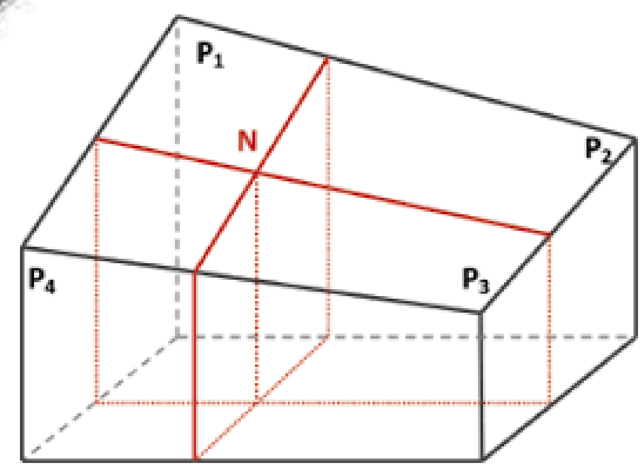
http://inspire-geoportal.ec.europa.eu/

Seamless Out-/Indoor Georeferencing and Interoperability based on ITRF/ETRF89

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts
- NTV2 Stanard for Transformation form ITRF to Classical Datum Systems covers only (B,L)_2D -

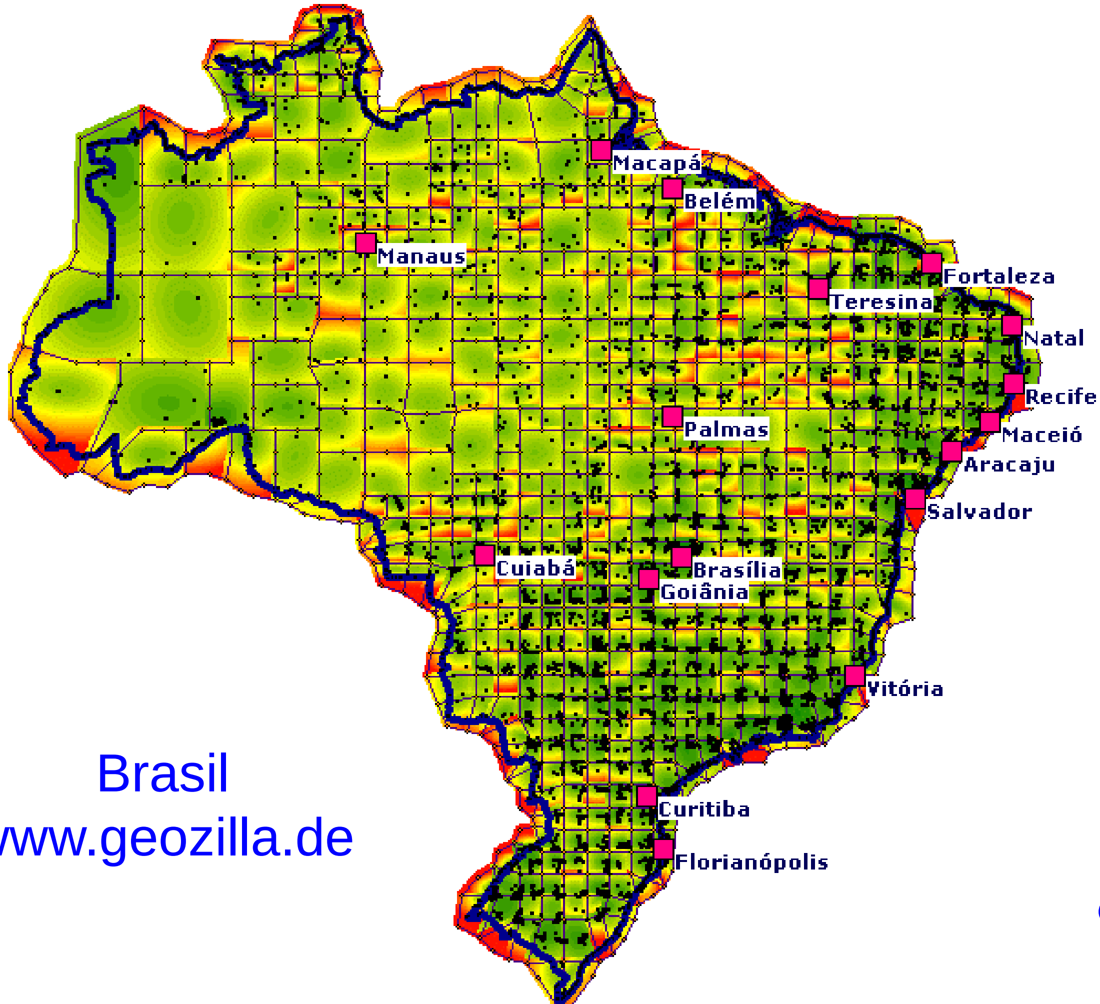






PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation -

3D-Datumtransformationsproblem - Solution following Molodenski



Brasil
www.geozilla.de

Accuracy_SAD96

0.0000 - 0.0080
0.0080 - 0.0160
0.0160 - 0.0240
0.0240 - 0.0320
0.0320 - 0.0400
0.0400 - 0.0480
0.0480 - 0.0560
0.0560 - 0.0640
0.0640 - 0.0720
0.0720 - 0.0800
0.0800 - 0.0880
0.0880 - 0.0960
0.0960 - 0.1040
0.1040 - 0.1120
0.1120 - 0.1200
0.1200 - 0.1280
0.1280 - 0.1360
0.1360 - 0.1440
0.1440 - 0.1520
0.1520 - 0.1600
0.1600 - 0.1680
0.1680 - 0.1760
0.1760 - 0.1840
0.1840 - 0.1920
0.1920 - 0.2000
0.2000 - 100000.0000

Genauigkeitsfläche

COPAG_DB
DFLBF_DB

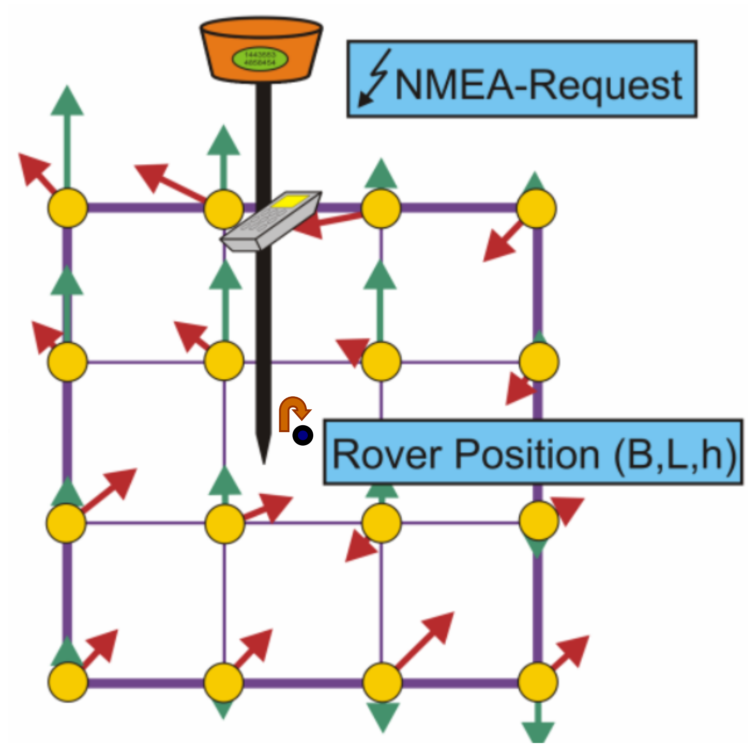
1.) Transforma-tions-Para-meters
&
2.) Residuals

FEM-Meshes - Regional 7/8 Parametersets. Coninuity Conditions)

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts

RTCM 3.x Transformationmessages Horizontal Transformation

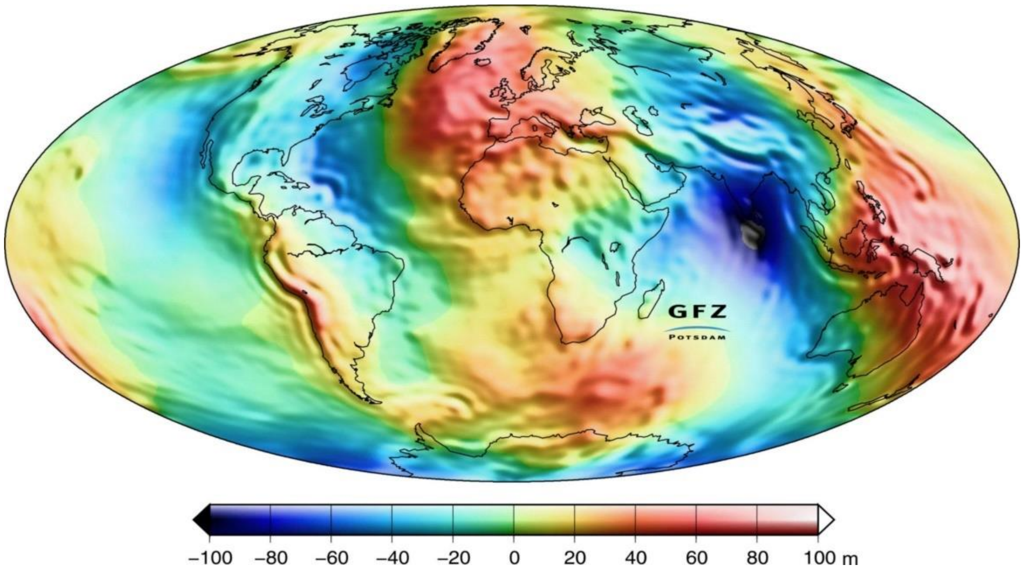
„Dynamic Grid“

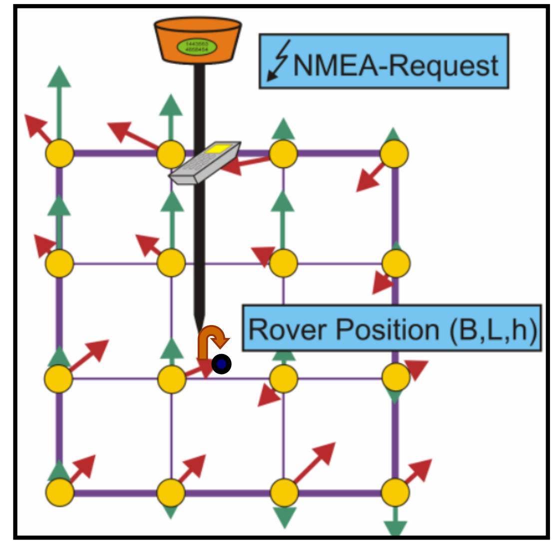


Using Reference Transformations to compute country-wide grids dynamically online on NMEA-request by virtual fitting points

PREGON-X Smartphone for Mobile GIS and Geo-Referencing
Transformation Concepts
GZTraS - RTCM Server for Static and Dynamic Grids

Height: Direct use of Original Reference Transformations





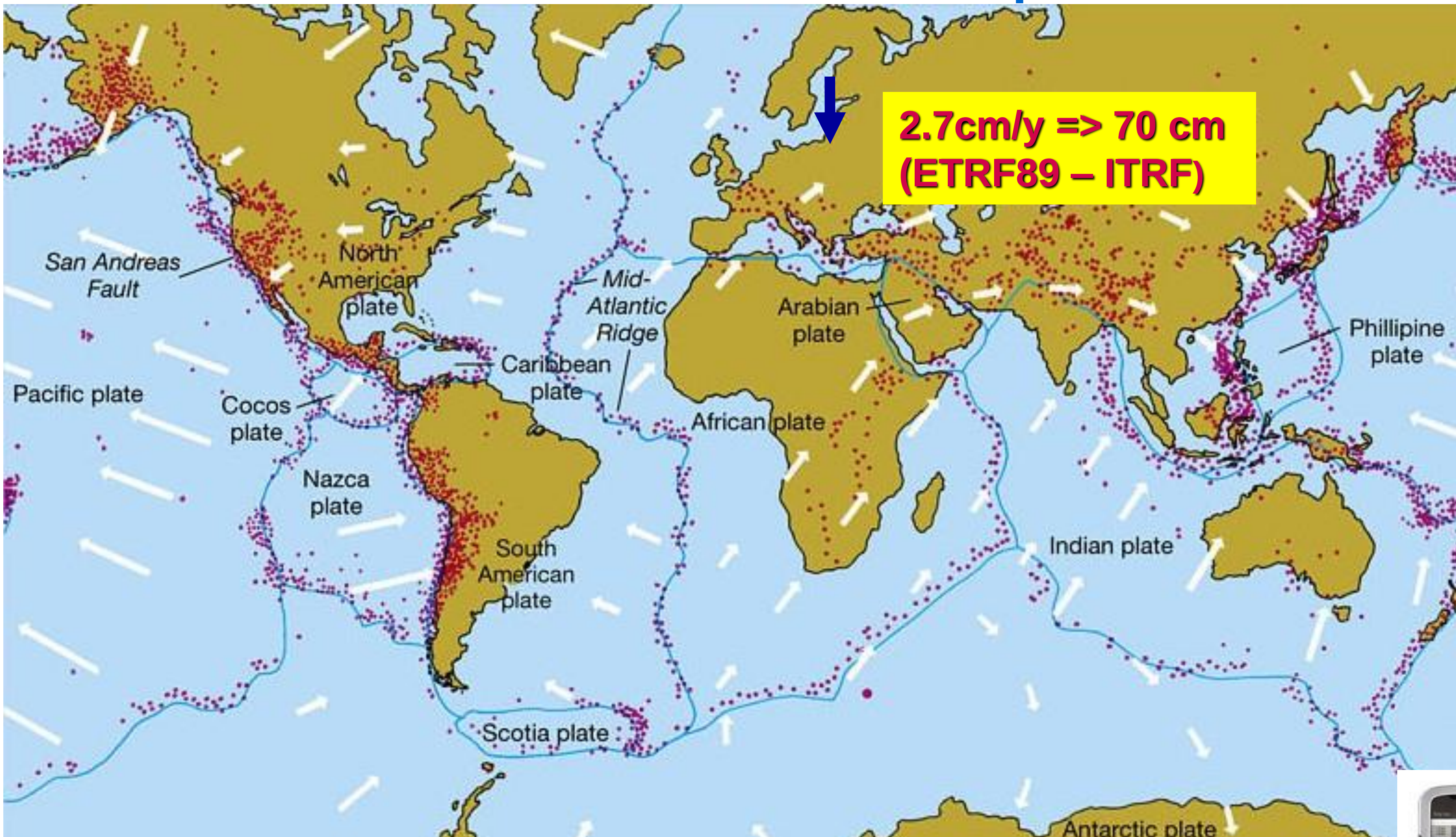
$$W(r,\vartheta,\lambda)=\left\{\frac{GM}{r}\cdot\left(1+\sum_{n=2}^{\infty}\sum_{m=0}^{n}\left(\frac{a_{GRS80}}{r}\right)^{n}\cdot\left(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda\right)\cdot P_{nm}(\cos\vartheta)\right\}$$

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}=\begin{bmatrix} u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos\text{ß}\cdot\cos\lambda \\ u_i\cdot\sqrt{1+\varepsilon^2/u^2}\cdot\cos\beta\cdot\sin\lambda \\ u\cdot\sin\beta \end{bmatrix}$$

$$U=U(a,\varepsilon,\omega,M)_{REF}\,|\,(\text{ß},\lambda,u))$$

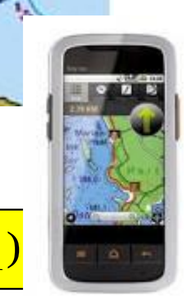
$$\boxed{N((x,y,z)_{GNSS})=\frac{W-U}{\gamma_{h-N}}}$$

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts



$$\mathrm{x}(\mathrm{t}_1)_{\mathrm{ITRF}_{zz,t_1}} = (1+\Delta \mathrm{m}) \cdot \mathbf{R}(\varepsilon_x, \varepsilon_y, \varepsilon_z) \cdot \mathbf{x}(\mathrm{t}_1)_{\mathrm{ITRFyy},t_1} + \mathbf{t}$$

$$\mathbf{x}(\mathrm{t}_2)_{\mathrm{ITRFzzt}_2} = \mathbf{x}(\mathrm{t}_1)_{\mathrm{ITRFzzt}_1} + \Big(\big((\dot{\mathbf{R}} + \Delta\dot{\mathrm{m}}) \cdot \mathbf{x}(\mathrm{t}_1)_{\mathrm{ITRFzzt}_1} + \dot{\mathbf{t}}\big) + \big(\dot{\mathbf{R}}_{\mathrm{P(j)}} \cdot \mathbf{x}(\mathrm{t}_1)_{\mathrm{ITRFzzt}_1}\big)\Big) \cdot (\mathrm{t}_2 - \mathrm{t}_1)$$



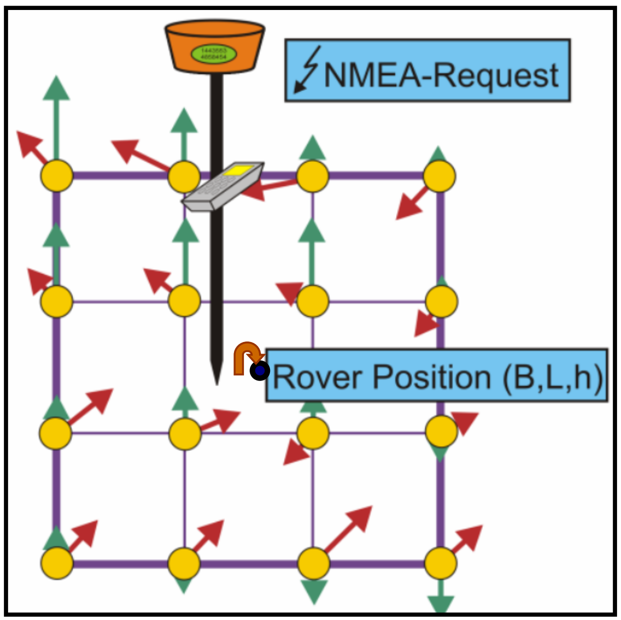
PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts

RTCM 3.x Transformationmessages (2D and 1D)

Using Reference Tranformations to compute grids dynamically

„Dynamic Grid“

„Combined Message Generation“



Part 1 - ***Plate Models***

$[(B,L,h)_{ITRF\text{-}related}]_i \Rightarrow [(B,L,h)_{GNSS,ITRF}]_i$

Virtual Fitting-Points

Part 2 - ***Standard Reference Transformations***

$[(B,L,h)_{ITRF\text{-}related}]_i \Rightarrow [(B,L)_T\ ,\ H_T \text{ or } N)]_i$

Virtual Fitting Points

Dynamic Message Set up by local 7PT Gridding

PREGON-X Smartphone for Mobile GIS and Geo-Referencing Transformation Concepts

1.) Use of RTCM Server, e.g. GZTRaS, enabling Dynamic Grid Generation for 2D and 1D

2.) Extension of NTV2 (2D only) to NT3D) – 2.1) 2 Steps with Smartphone Databases for both steps or a Dynamic NT3D-Grid as an Online Service

Further Information: www.navka.de

Book on Parameter-Estimation including Navigation 05/2018

https://www.amazon.de/Klassische-robuste-Ausgleichungsverfahren-Ausbildung-Geoinformatikern/dp/3879076154