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GNSS

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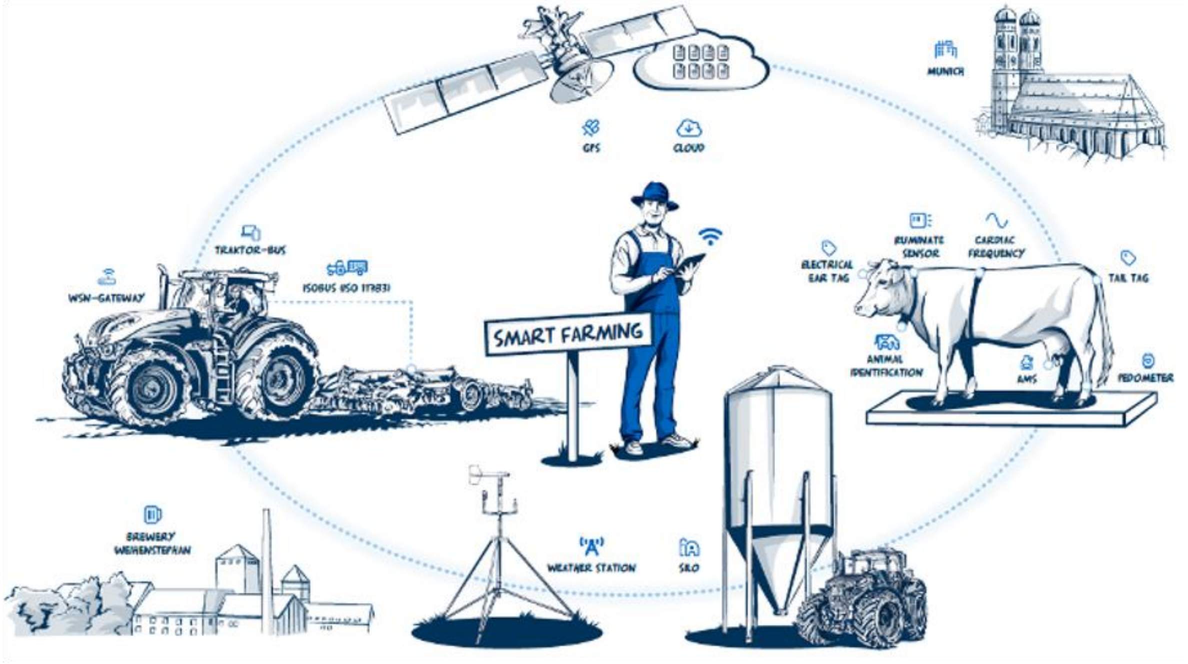

What is GNSS?

GNSS = **G**lobal **N**avigation **S**attelite **S**ystem

GPS

Glonass

Galileo

BeiDou

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Introduction Exercise

48.405969496 11.688836788

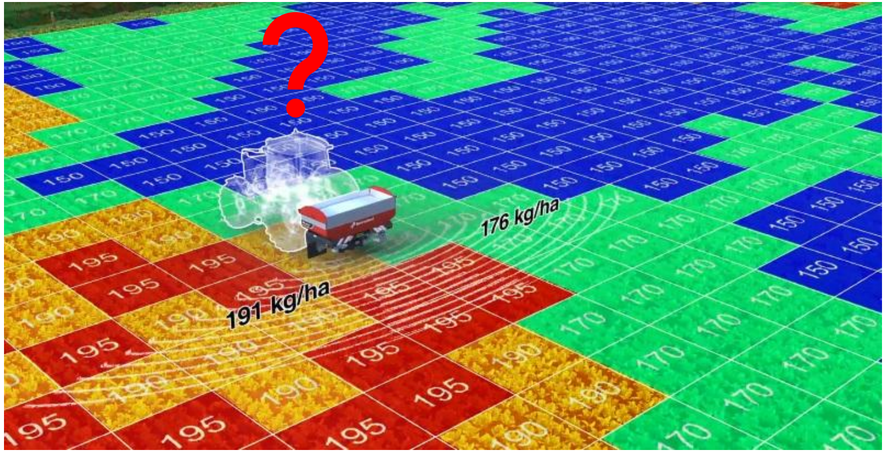
Why are GNSS Systems relevant for Agriculture?

Position is the Core Information for Precision Farming!

- Tractor-Implement Combinations can only use
  - **Automated Steering Systems**,
  - **Section Control** and
  - **Variable Rate Technology**,

  if they know, where they are and how they move

- Therefore, GNSS Systems are a **core enabling technology** for Precision Farming

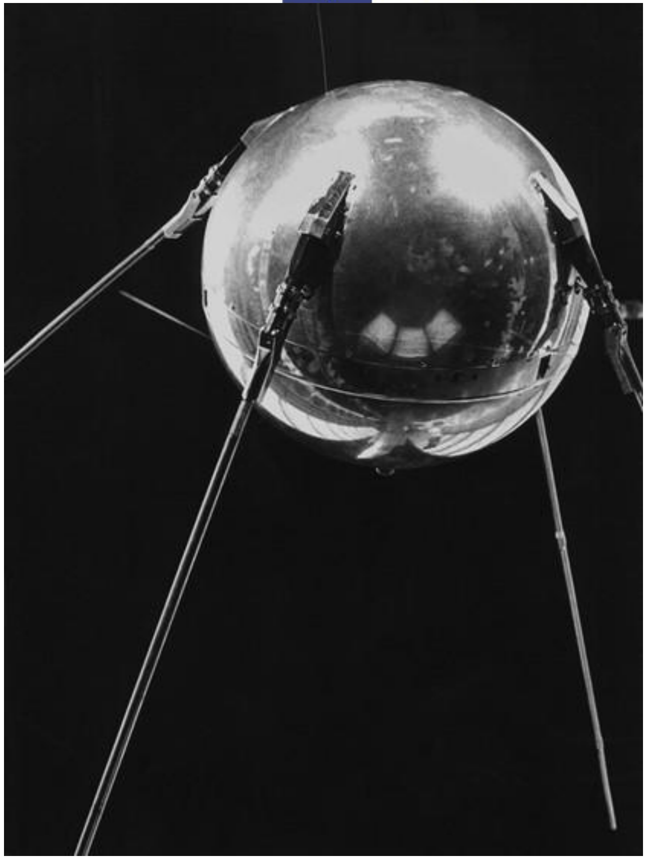


History of GNS-Systems

History of GNS-Systems

04. October 1957

Sputnik 1 (Russia) is the first sattellite to orbit earth and send data



History of GNS-Systems

1958

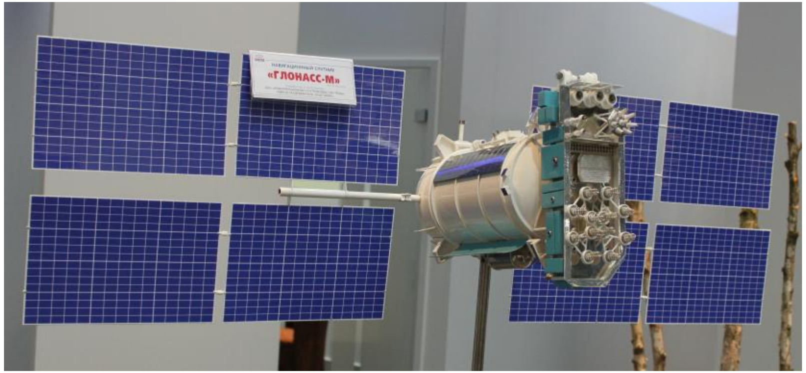
Start of the Development of „TRANSIT“ in the USA
-> Guidance for ballistic rockets

Accuracy between 15 and 500m

In full operational service between 1964 and 1996

History of GNS-Systems

1972



Start of the Development of „GLONASS“ in Russia

In full operational service since 1993, with interuptions
(after 1996 the number of sattelites decreased, rebuild started in 2008)

History of GNS-Systems

1973

Start of the Development of „NAVSTAR-GPS“ in the USA
-> Developed for military puropses only

Aim for accuracy <30m

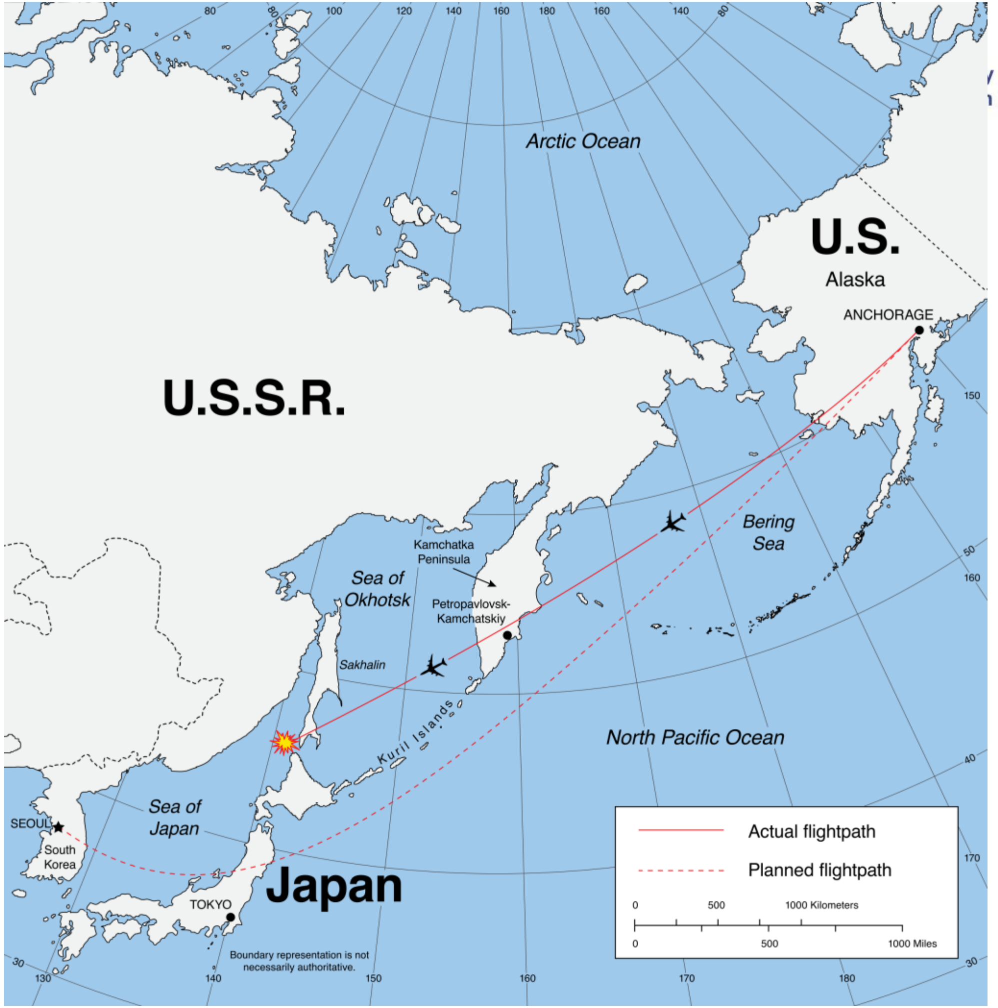
In full operational service since 1995

History of GNS-Systems

01. September 1983

Korean airlines flight 007
was shot down because it entered
russian airspace

-> Ronald Regan opened GPS for civilian use



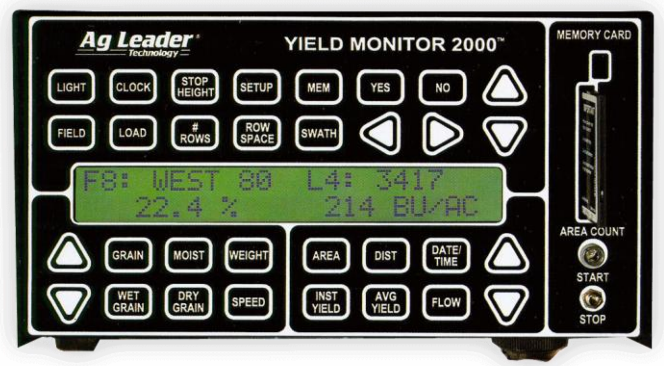
Arctic Ocean
U.S.
Alaska
ANCHORAGE
U.S.S.R.
Kamchatka
Peninsula
Sea of
Okhotsk
Petropavlovsk-
Kamchatskiy
Sakhalin
Bering
Sea
Kuril Islands
North Pacific Ocean
Sea of
Japan
SEOUL
South
Korea
Japan
TOKYO
Boundary representation is not
necessarily authoritative.
Actual flightpath
Planned flightpath
0 500 1000 Kilometers
0 500 1000 Miles

History of GNS-Systems

1992

First commercially available yield mapper

Including GPS (1997)



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History of GNS-Systems

2003

Planning for GALILEO started

Aim for accuracy in the range of multiple cm

First open for public in 2016

28 satellites in space, 21 usable (as of 26. April 2023)

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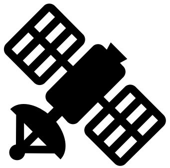
GNSS Segments

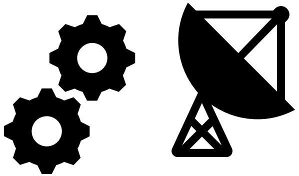
Basic Components of GNSS

Space Segment
Satellites transmitting radio signals to users



Control Segment
global network of ground facilities

- track the GPS satellites
- monitor transmissions
- perform analyses
- send commands and data to the constellation



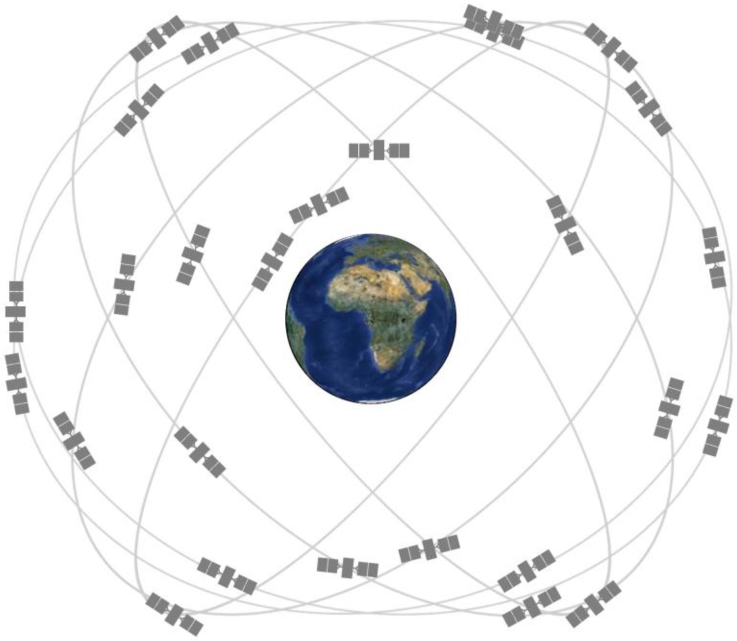
User Segment
GPS receiver equipment

- Receives signals
- Calculates position and time

Space Segment

Aim: minimum of 4 satellites visible from every place on earth

GPS: 6 orbitals

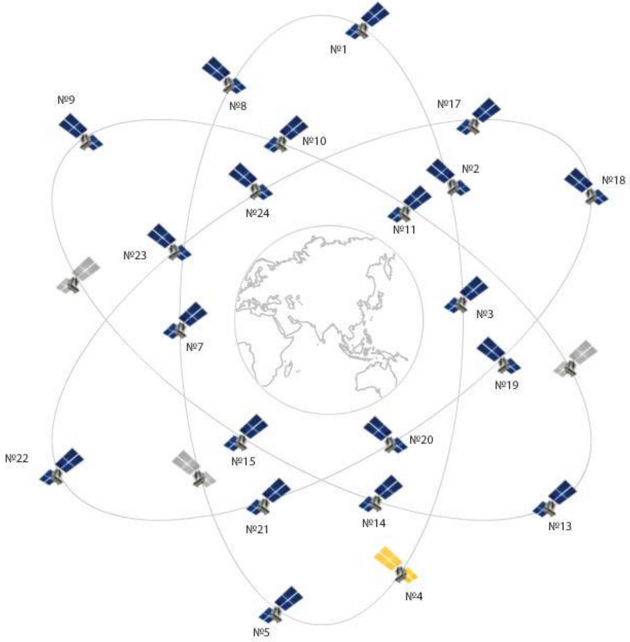


Space Segment

Aim: minimum of 4 satellites visible from every place on earth

GPS: 6 orbitals

GLONASS: 3 Orbitals



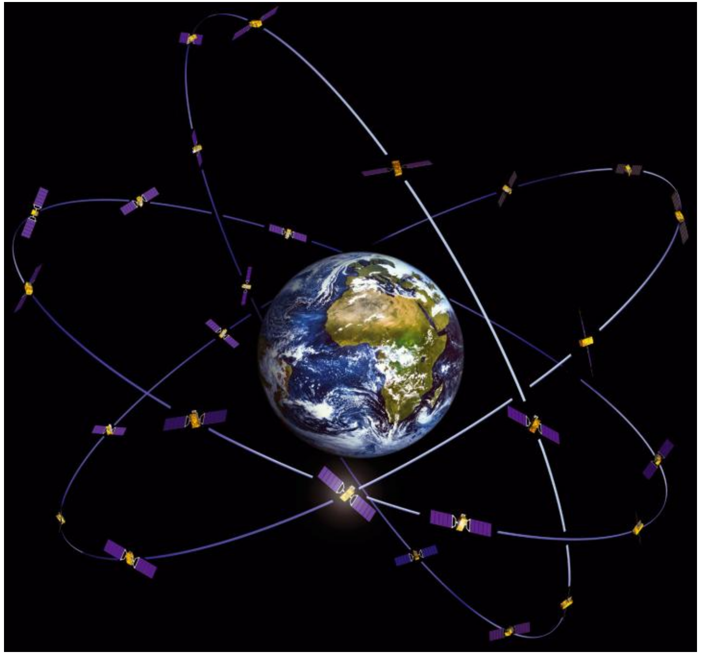
Space Segment

Aim: minimum of 4 satellites visible from every place on earth

GPS: 6 orbitals

GLONASS: 3 orbitals

Galileo: 3 orbitals



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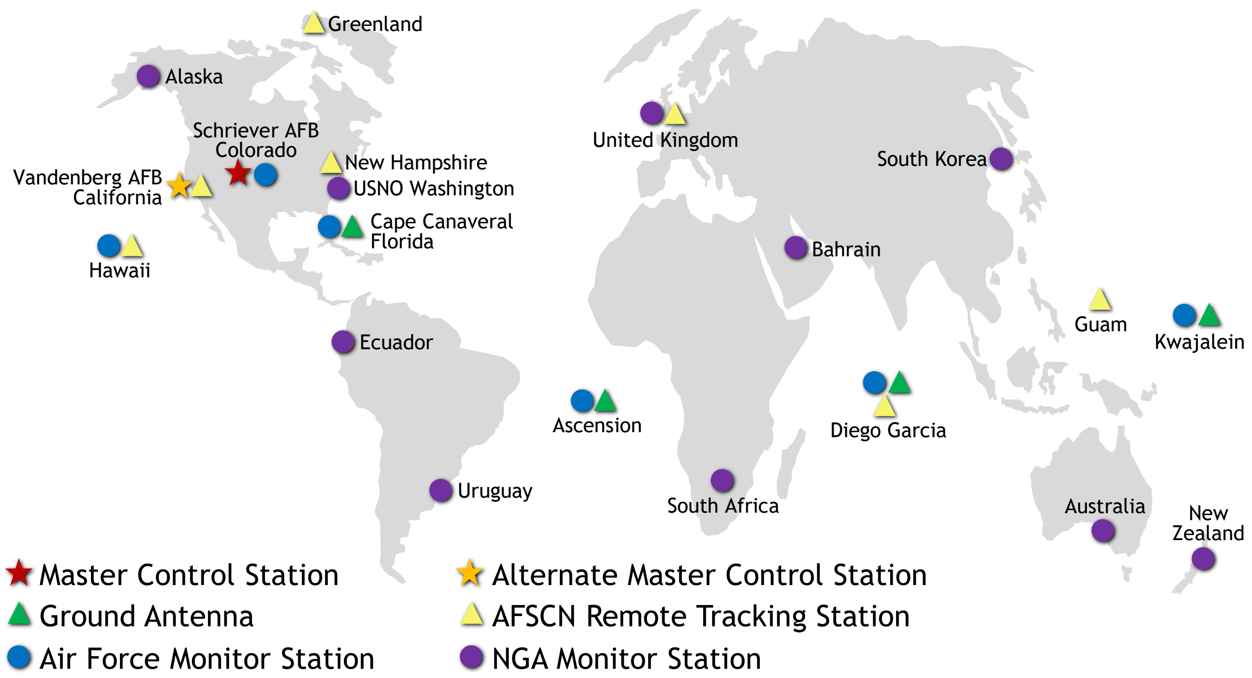
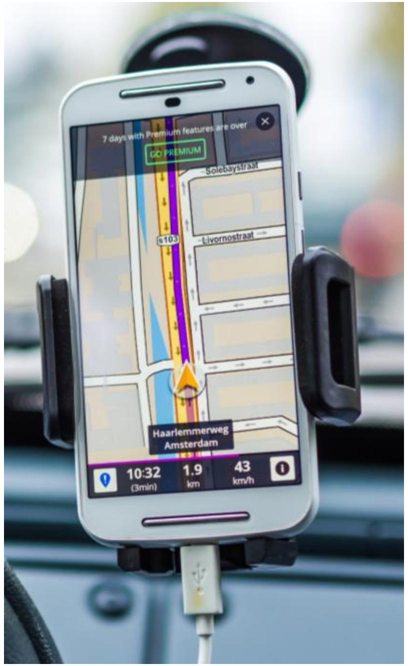
Ground Segment



User Segment



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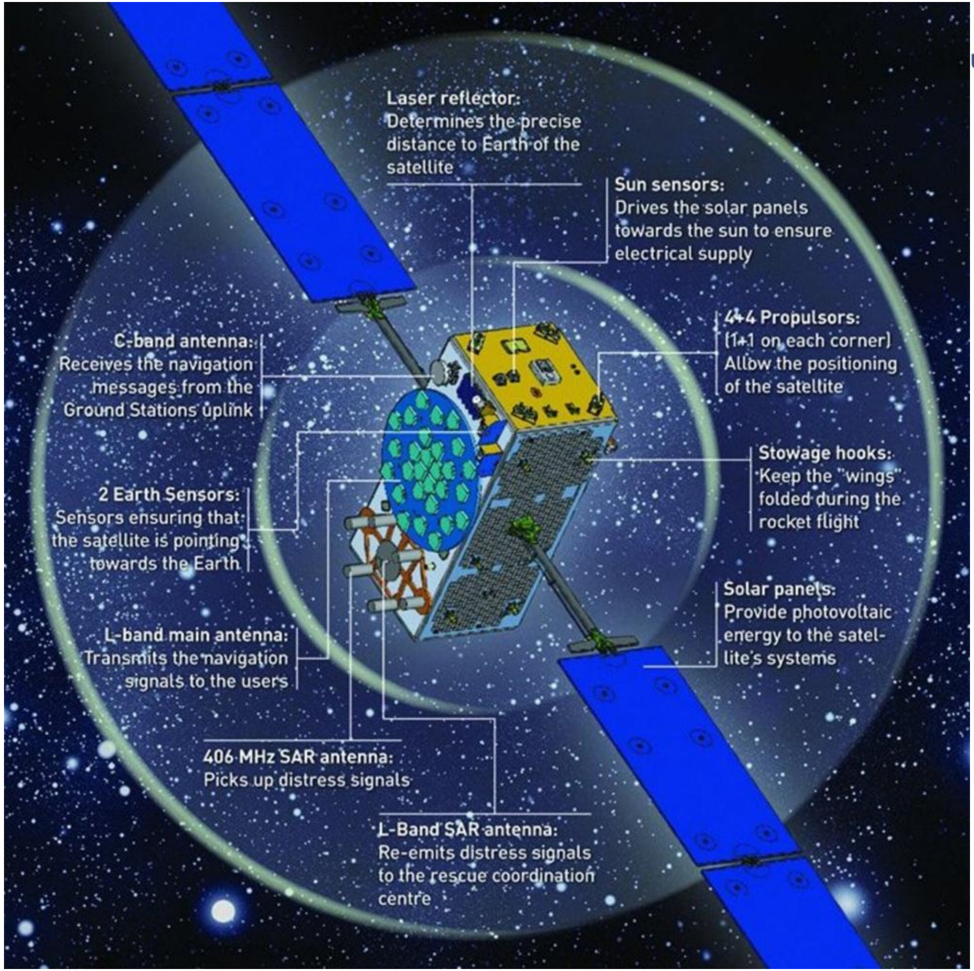
Positioning – How does it work?


Laser reflector:
Determines the precise distance to Earth of the satellite
Sun sensors:
Drives the solar panels towards the sun to ensure electrical supply
4+4 Propulsors:
(1+1 on each corner)
Allow the positioning of the satellite
C-band antenna:
Receives the navigation messages from the Ground Stations uplink
Stowage hooks:
Keep the "wings" folded during the rocket flight
2 Earth Sensors:
Sensors ensuring that the satellite is pointing towards the Earth
Solar panels:
Provide photovoltaic energy to the satellite's systems
L-band main antenna:
Transmits the navigation signals to the users
406 MHz SAR antenna:
Picks up distress signals
L-Band SAR antenna:
Re-emits distress signals to the rescue coordination centre

What is transmitted by a satellite?

L1 Frequency (1575,42MHz)

- Navigation message
  - GPS date, time and the satellites status
  - Ephemeris: precise position information for the transmitting satellite
  - Almanac: status and low resolution position information for all satellites
  - 50 bits per second (bps or b/s)

- C/A Code
  - Pseudo Random Noise (PRN)
  - doesn‘t contain any information
  - 1 transmission of this code takes 1 ms
  - 1 Megabit per second (Mbps oder Mb/s)

What is transmitted by a satellite?

L2 Frequency (1227,50MHz)

- Navigation message
  - GPS date, time and the satellites status
  - Ephemeris: precise position information for the transmitting satellite
  - Almanac: status and low resolution position information for all satellites
  - 50 bits per second (bps or b/s)

- P Code encrypted (military use)
  - Pseudo Random Noise (PRN)
  - doesn‘t contain any information
  - 1 transmission of this code takes 1 week
  - 10,23 Megabits per second (Mbps oder Mb/s)

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What is transmitted by a satellite?

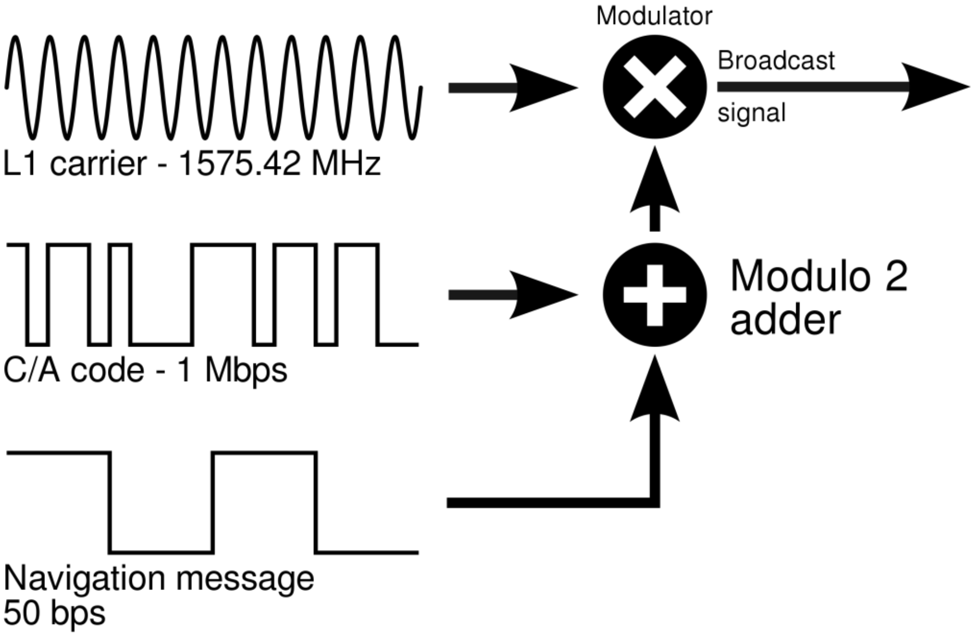
Other frequencies

There are plans to use several other frequencies to increase accuracy

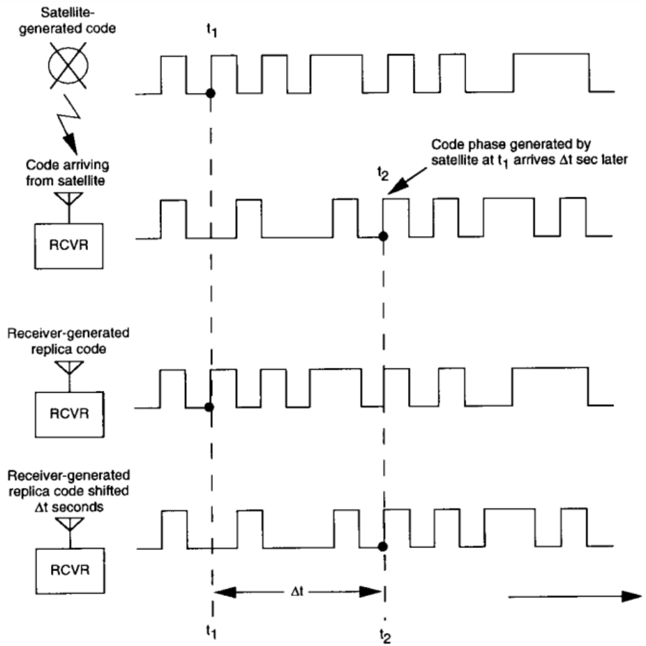
More info on the official GPS website

https://www.gps.gov/systems/gps/modernization/civilsignals/

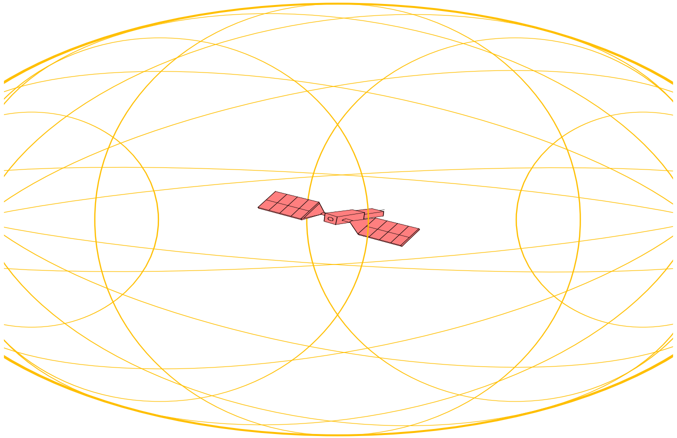
Digression: How to add up multiple data streams



Basics of GNSS: Timing



Basics of GNSS: Trilateration



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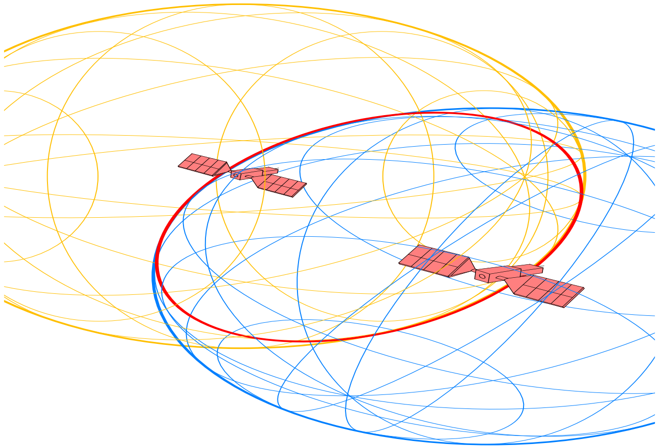
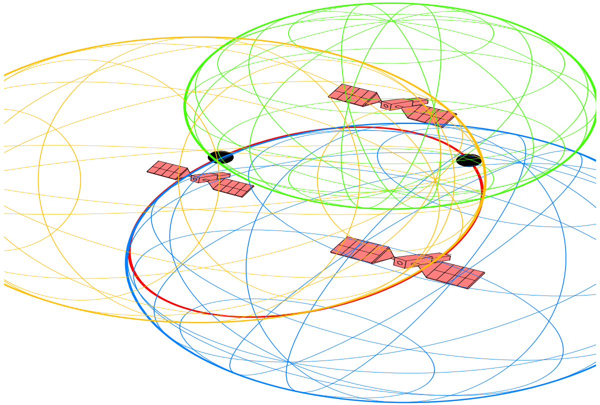
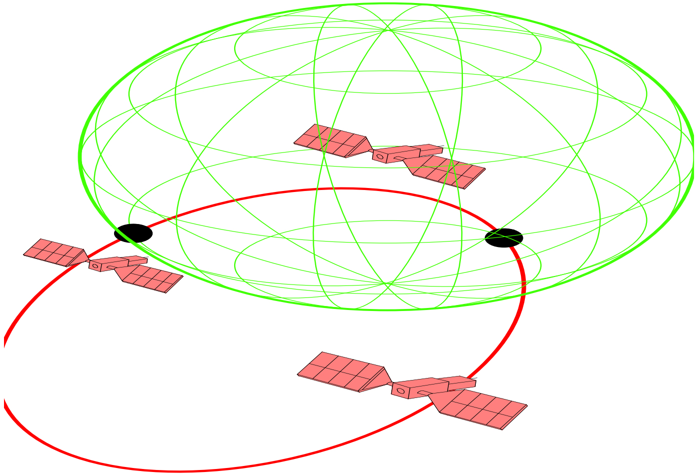
Basics of GNSS: Trilateration



Basics of GNSS: Trilateration





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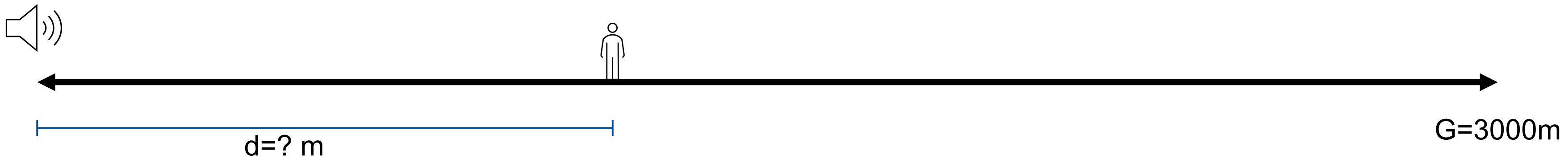
Basics of GNSS: timing error

Speed of Sound = $V_S \approx 300$ m/s



Example with two exactly precise clocks:

Signal sent at 06:00:00

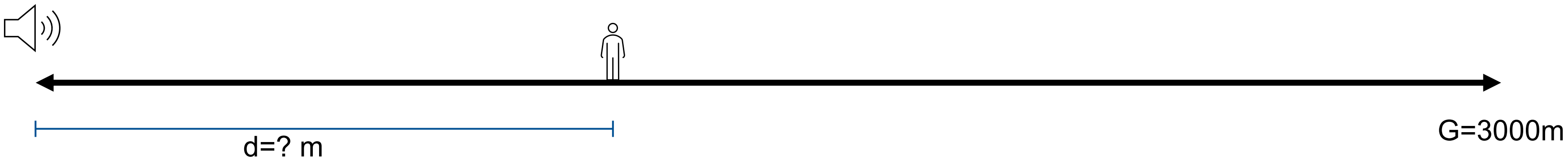
Signal received at 06:00:03

t_1 = 06:00:03 – 06:00:00 = 3s

$d = V_S * t_1$ = 300m/s * 3s = 900m

Basics of GNSS: timing error

Speed of Sound = $V_S \approx 300$ m/s



Example with unprecise clock (2s):

+2s error

Signal sent at 06:00:00

Signal received at 06:00:~~03~~ 05

t_1 = 06:00:~~03~~ 05 – 06:00:00 = ~~3s~~ 5s

$d = V_S * t_1$ = 300m/s * ~~3s~~ 5s = ~~900m~~ 1500m

Solution: second horn

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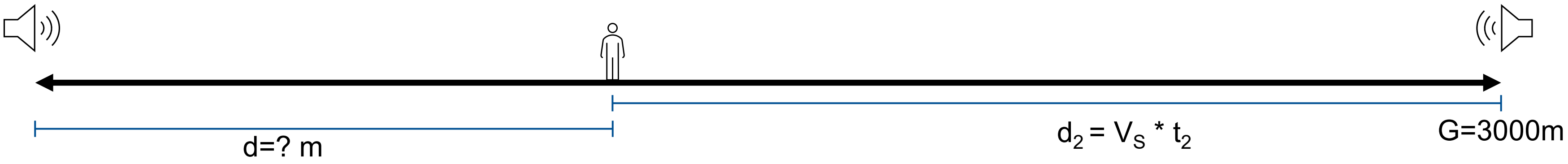
Basics of GNSS: timing error

Speed of Sound = $V_S \approx 300$ m/s



$d = V_S * t_1$

$d = G - V_S * t_2$

adding the equations:

$$2d = V_S * t_1 + G - V_S * t_2$$

$$2d = (t_1 - t_2) * V_S + G$$

$$d = \frac{(t_1 - t_2) * V_S + G}{2}$$

Here the error in time gets eliminated

Accuracy & Errors

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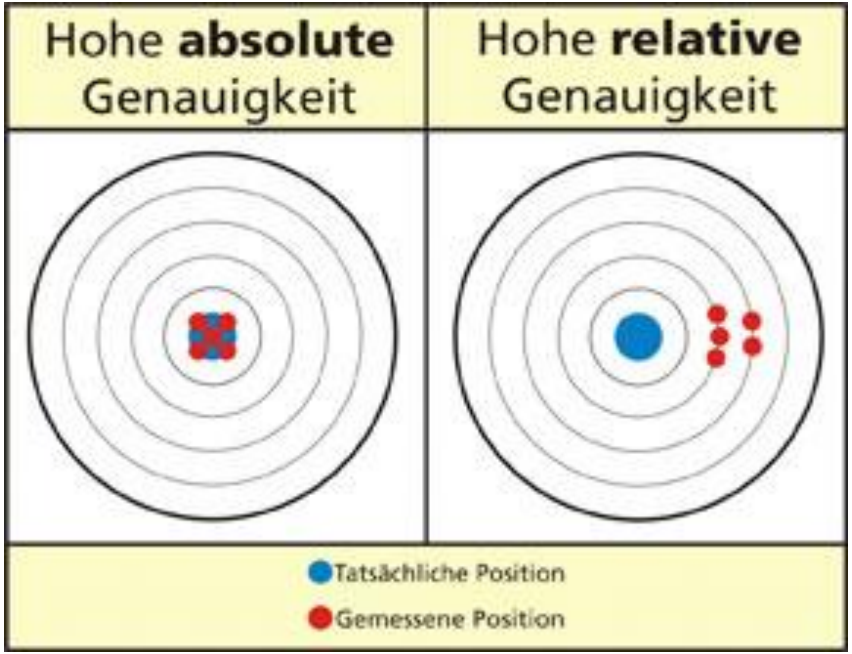
Absolute vs. Relative Accuracy

Absolute Accuracy:

- Locate position in absolute terms (same position even after month/years)

Relative Accuracy:

- Positioning in a defined timeframe
- Not neccessarily the correct geographical coordinates
- Enough for parallel lines with steering system, not enough for CTF (controlled traffic farming)
- Good enough for measuring areas



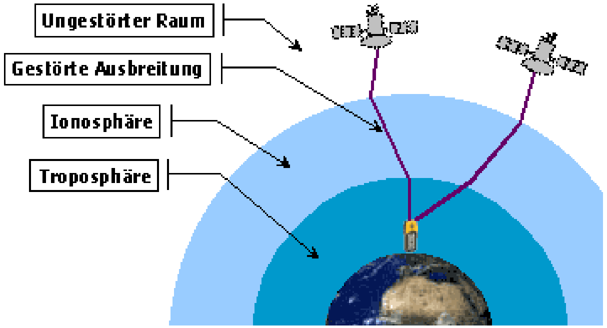
Error & Interference

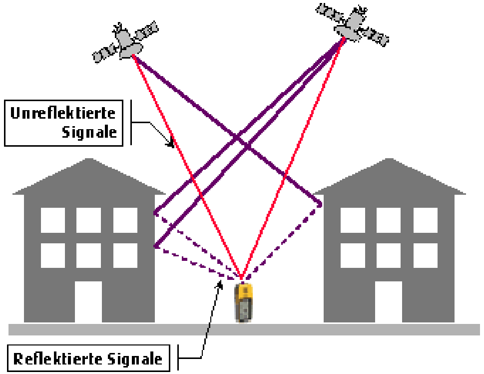
Common Causes for losses in signal quality:

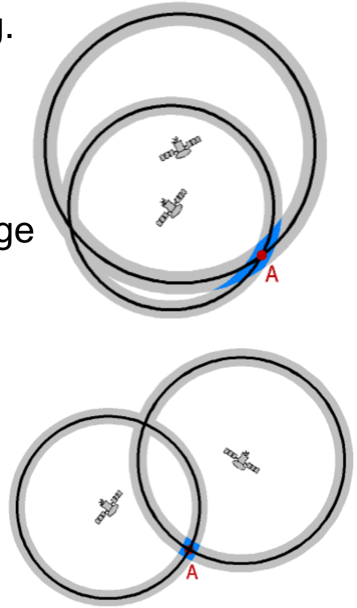
- Athmospheric effects
- Multipath error
- Satellite constellation

Less common causes:

- Radio interference or jamming (e.g. military)
- Major solar storms
- Satellite maintenance/maneuvers creating temporary gaps in coverage







Quelle: Agrocom, 2007

Errors add up

Ionospherical Interference	+/- 5 m
Satellite constellation	+/- 2,5 m
Satellite clock error	+/- 2 m
Tropospherical Interference	+/- 0,5 m
Multipath Error	+/- 1 m
Calculation Errors	+/- 1 m

Makes for a theoretical combined Accuracy of +- 15 metres.

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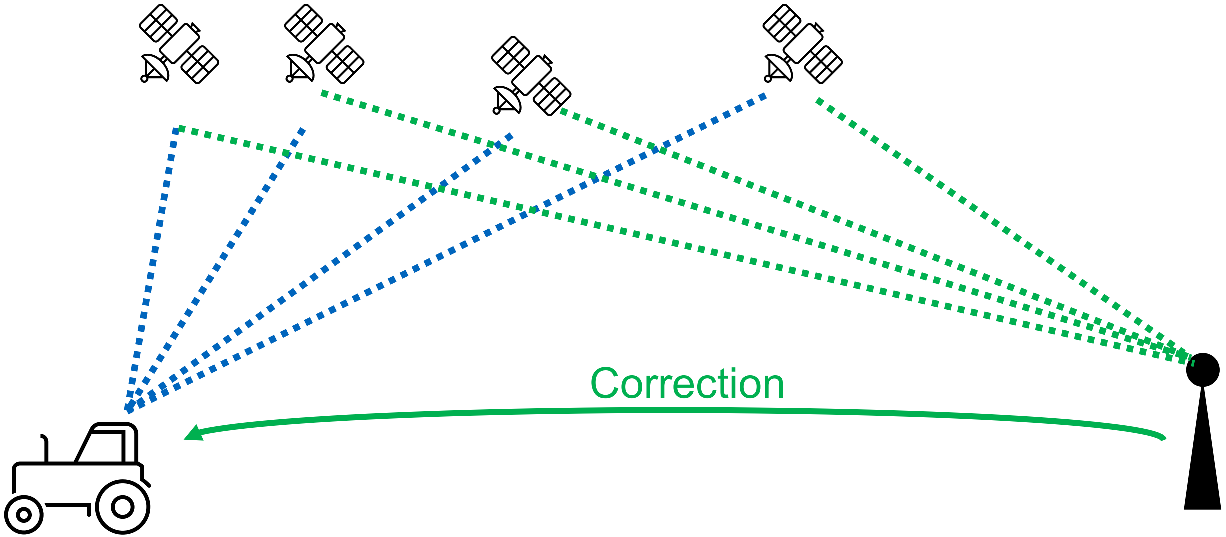
How to improve accuracy?

GNSS augmentation – Differential GPS

Basic idea of Differential GNSS



Measured position = error + actual position

Measured position = error + actual position

Basic idea of Differential GNSS

Augmentation of a GNSSystem is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process.

This calculation can be done in 2 ways:

- **Post processing** - data is collected and precise georeferencing is done @home, e.g. post-processing of yield maps (relevant during the early stages of Precision Farming)
- **Real Time** - correction signals are transmitted directly to the Operator (e.g. tractor/harvester receiver) and correction takes place near real-time

3 Methods are common:

- **Satellite-based** augmentation systems
- **Ground-based** augmentation systems
  - **RTK** (real-time-kinematics)

Post Processing vs. Real Time

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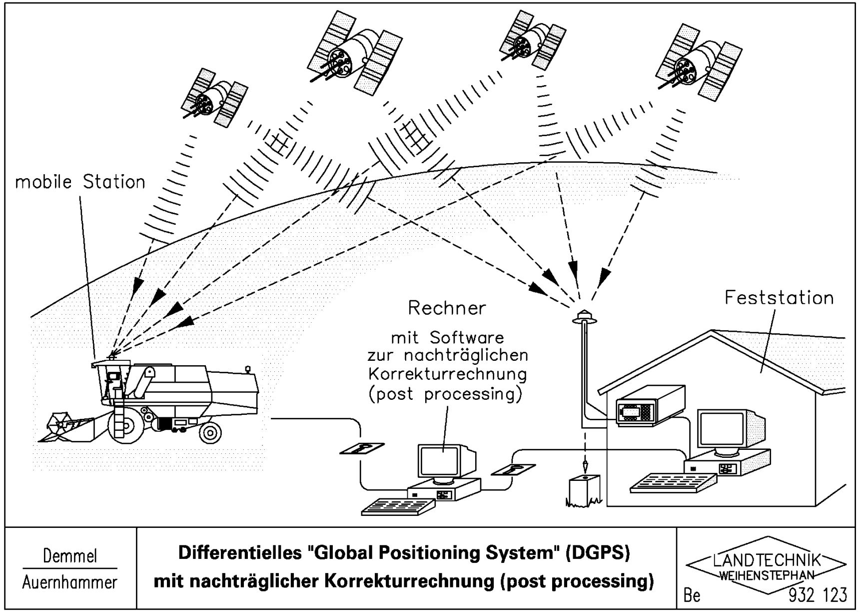
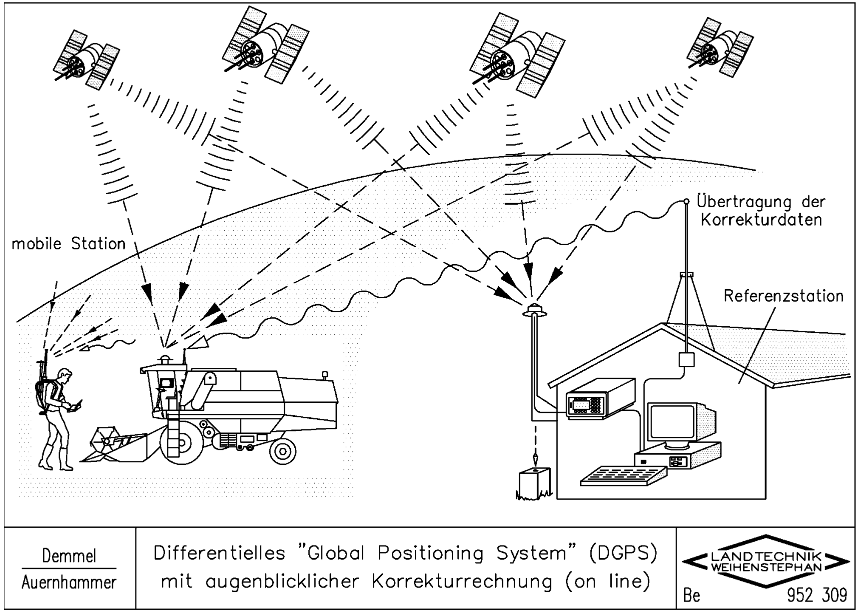
Post Processing vs. Real Time





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Post Processing

Base Station and mobile receiver are logging Positions, data can be matched via timestamps and used for calculation of corrected position.

- No telemetry neccessary on mobile machine
- Accuracy can be improved
- Data storage on mobile machine required
- Accurate position not available to machine operator

→ **Only suitable for documentation purpose!**

Real Time

Correction signal of the base station is directly transmitted to the mobile receiver.

- Telemetry System required on mobile machinery
- Low requirements for data storage on machine
- Accurate Position available for Operator & Machine control (e.g. steering system)

→ **Suitable for positioning & navigation!**

Satellite-based augmentation

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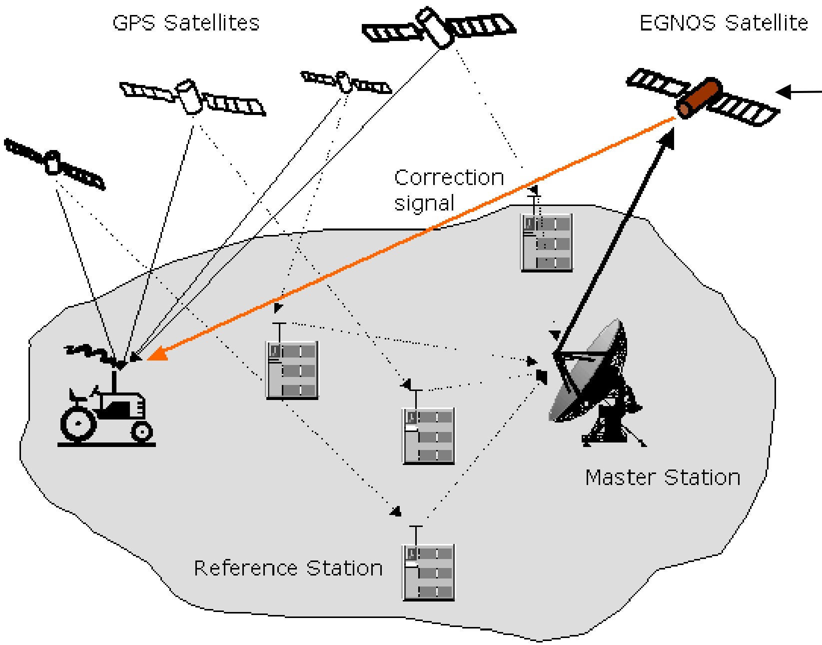
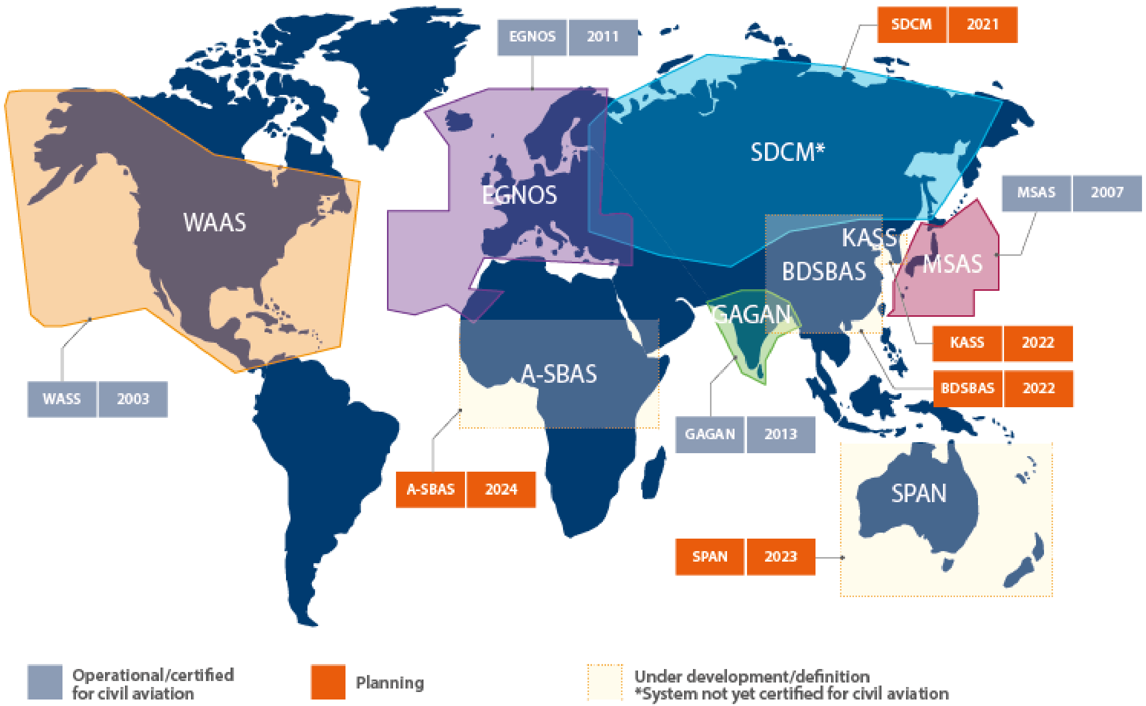
SBAS (sattelite based augmentation system)



Geostationary satelllite

Source: Agrocom (2007)

Satellite-based Augmentation Systems (SBAS)



Source: European Global Navigation Satellit Systems Agency

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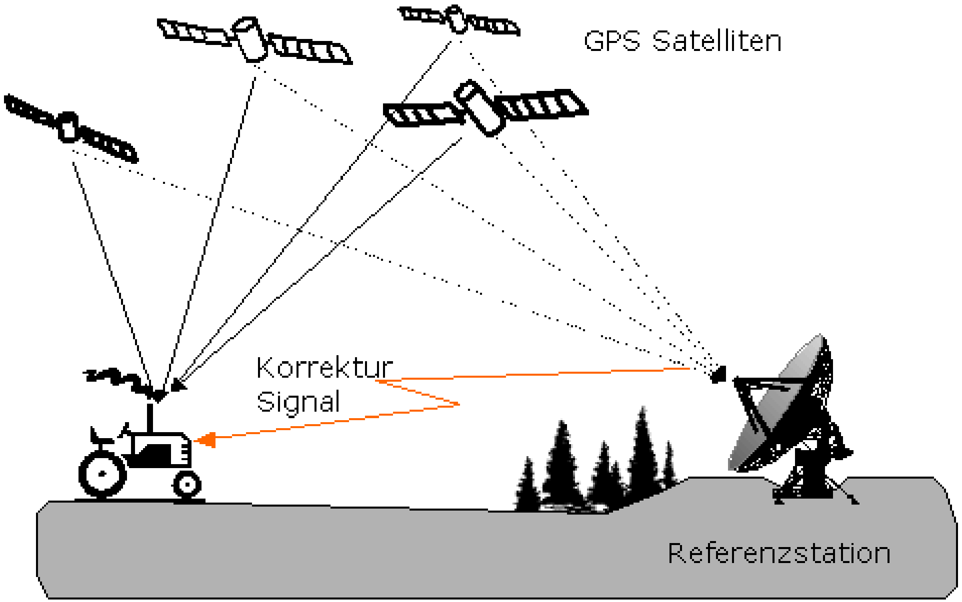
Ground-based augmentation

Ground-based Augmentation System



Source: Agrocom (2007)

Example for ground based augmentation – nautical beacons

- Network of ground-based reference stations transmit their position via VHF-/ or long wave radio
- Range ~70-200 km
- The closer a reference station – the higher the accuracy

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Example for ground based augmentation – own reference station

- Farmer buys ground-based reference station
- Reference station transmits its position to Tractors/Harvesters via 434 MHz frequency band (free)
- Whole fleet of the farmer‘s/contractor‘s operation can use the signal
- Range:
  - 3-5 km for mobile reference station
  - 20 km for stationary reference station

Real-time Kinematic (RTK)

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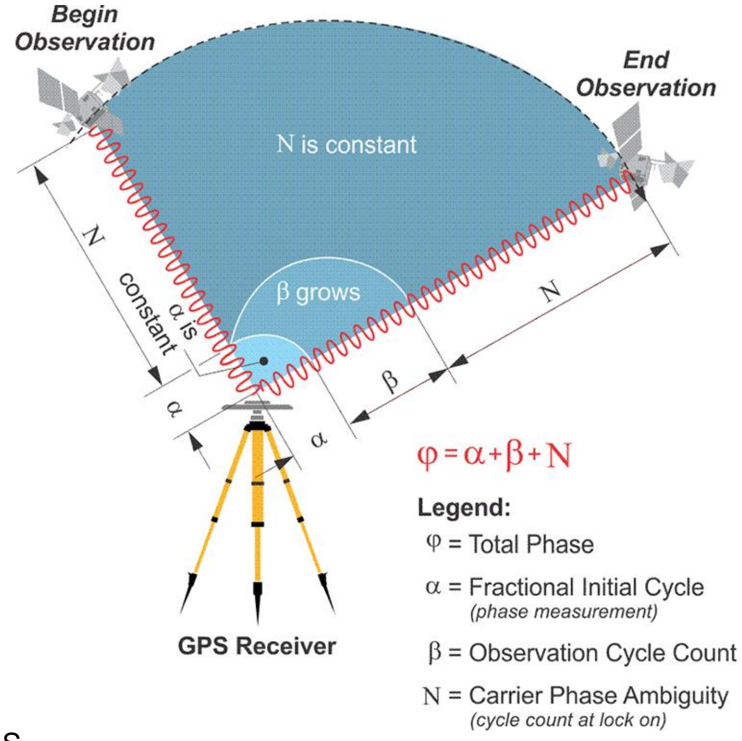
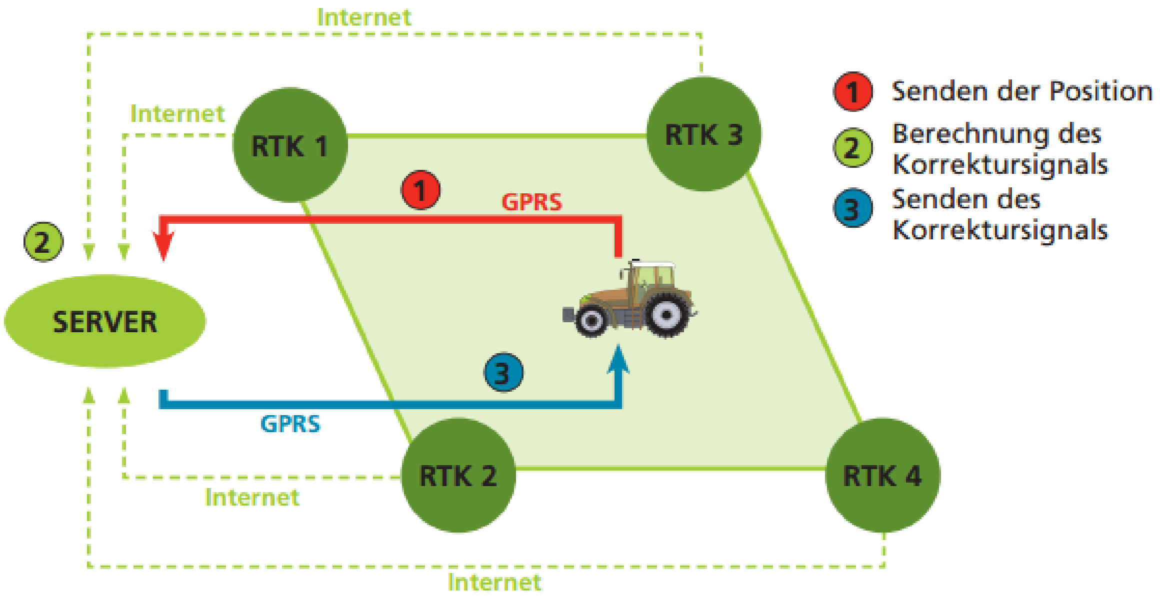
Phase Measurement



VRS

- Real time kinematics uses the **satellite signal's carrier wave** as its signal, ignoring the information contained within
- A reference station transmits correction data to the tractor
- RTK uses a fixed base station or virtual base station from a network to reduce the tractor's position error



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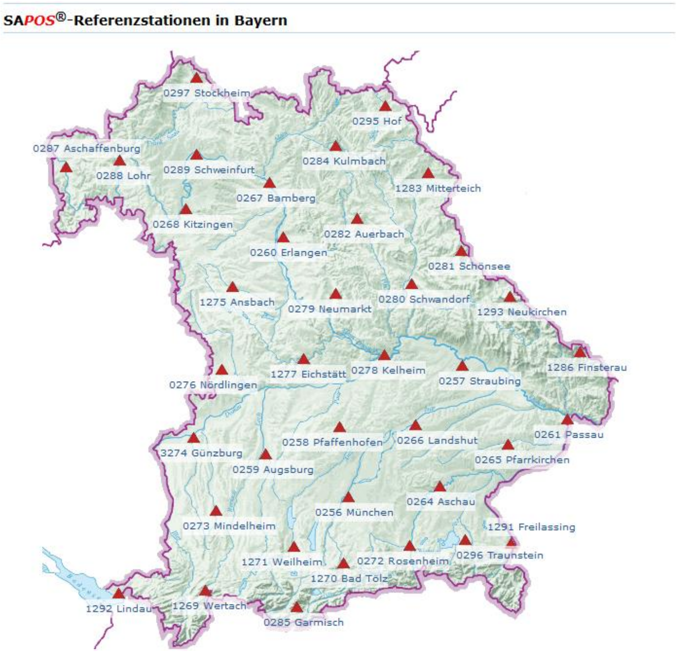
Different Signals for different Applications in Agriculture

SAPOS HEPS

“Free” RTK Signal for Farmer:

- 150 € registration fee
- SAPOS compatible receiver
- Mobile Internet Connection for receiving the correction signal



Differential Providers for correction in Europe

Signal	Provider	Accuracy	Cost
WAAS/EGNOS	public	50 cm	free
StarFire I	John Deere	25 cm	free (StarFire 3000 Receiver)
Range Point RTX	Trimble	15 cm	250 €/a
StarFire II	John Deere	5-10 cm	600 €/a
OmniSTAR XP/HP/G2	OmniSTAR	5-10 cm	1000 €/a
Center Point RTX	Trimble	3,8 cm	1.090 €/a
RTK	VRS Now, Farm-RTK, AgCellent, Agravis-Net, LU-Net, MR-Net	2,5 cm	350-1500 €/a
SAPOS-RTK	Every German State	2,5cm	For agriculture: basically free*

* Some states charge a adminstration fee