# Welcome to the RNN-seminar on:

# New GNSS signals - opportunities for new PNT applications and improved robustness

2018-11-29

| | | |
|---|---|---|
| 9.00 | Registration and breakfast | |
| 10.00 | Welcome | ÅF |
| 10.10 | Opening | Jan Johansson, chairman of the Swedish Radio Navigation Board |
| 10.20 | Uncertainty in GNSS-positions from meters to centimetres - a short overview of observation methods | TBD |
| 10.35 | New GNSS-signals create opportunities for new applications and improved robustness | Jan Johansson, Chalmers University of Technology |
| 11.05 | Experiences from test measurements with Galileo-signals and SWEPOS™ | Stefan Öberg, Lantmäteriet |
| 11.25 | Break | |
| 11.50 | Android Raw Measurements (Task Force) and Galileo High Accuracy Service | Martin Sunkevic, European GNSS Agency (GSA) |
| 12.20 | Discussion | Jan Johansson |
| 12.30 | Lunch | |
| 13.30 | High accuracy GNSS positioning – compatibility and the future mass market | Martin Håkansson, Lantmäteriet |
| 13.50 | Autonomous shuttles in the countryside of northern Sweden | Petra Bassioukas Hanseklint, Skellefteå kommun |
| 14.10 | Development platform for autonomous forestry machines | Håkan Lideskog, Luleå University of Technology |
| 14.30 | Unmanned Traffic Management for Future Drone Traffic in Cities, results from a two-year project | Jonas Lundberg, Linköpings Universitet<br>Billy Josefsson, LFV |
| 14.50 | Coffee break | |
| 15.10 | Status for the projects NPAD (Network-RTK for Automated Driving) and PRoPART (Precise and Robust Positioning for Automated Road Transports) | James Tidd, Waysure |
| 15.30 | The RTCM-committee as a forum for development of formats for teal-time and postprocessing applications | Gunnar Hedling, Lantmäteriet |
| 15.50 | The effect of dynamic reference system on formats for real-time data distribution | Martin Lidberg, Lantmäteriet |
| 16.10 | Design of the next generation of the Galileo satellites | Peter Wiklund, Lantmäteriet |
| -16.35 | General discussion and closing | Jan Johansson |

# New GNSS Signals – applications & robustness

Jan Johansson

Chalmers University of Technology
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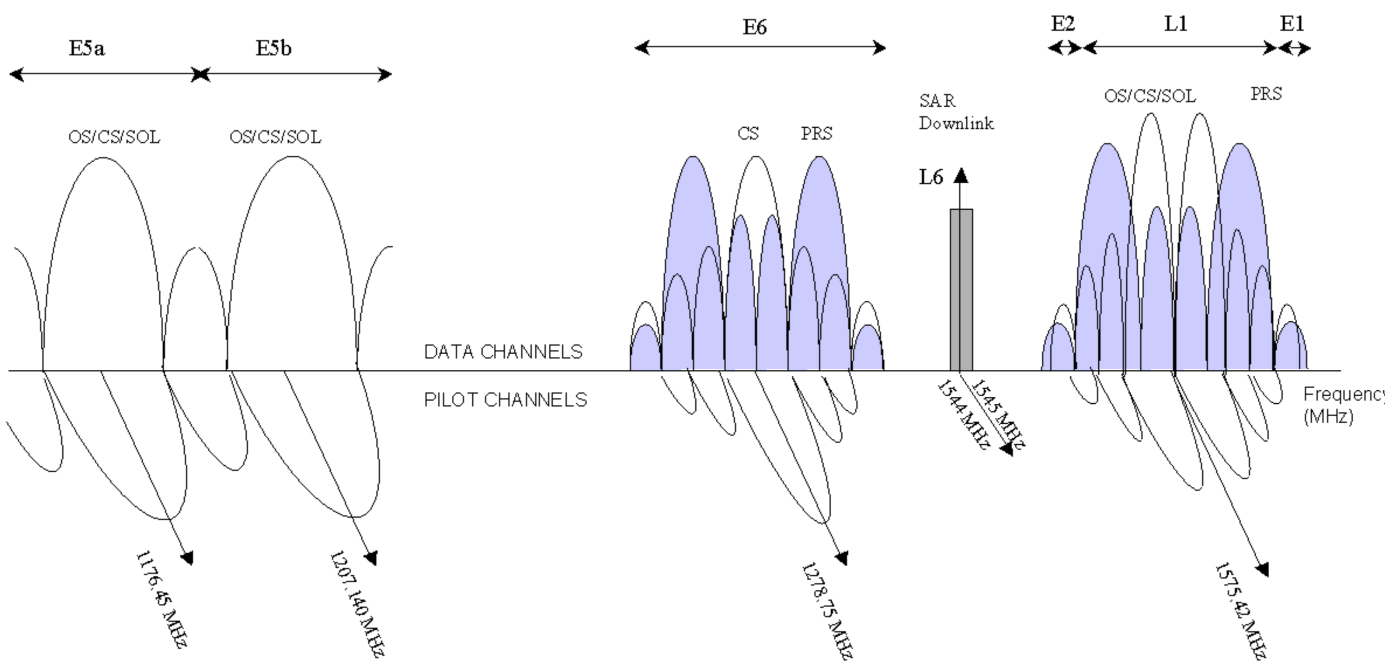
**RNN Seminar, 29 November 2018**

# Galileo Signals

10 navigation signals are transmitted

OS : Open Service
CS: Commercial service
PRS: Public Regulated Service
~~SoL: Safety of Life~~ Descoped

| Signal | Modulation | Carrier frequency (MHz) | Data /Pilot | OS | SoL | CS | PRS |
|---|---|---|---|---|---|---|---|
| E5a-I | BPSK(10) | 1176.45 | Data | | | | |
| E5a-Q | BPSK(10) | 1176.45 | Pilot | | | | |
| E5b-I | BPSK(10) | 1207.14 | Data | | | | |
| E5b-Q | BPSK(10) | 1207.14 | Pilot | | | | |
| E6-A | BOC(10,5) | 1278.75 | Classified | | | | |
| E6-B | BPSK(5) | 1278.75 | Data | | | | |
| E6-C | BPSK(5) | 1278.75 | Pilot | | | | |
| L1-A | BOC(15,2.5) | 1575.42 | Classified | | | | |
| L1-B | BOC(1,1) | 1575.42 | Data | | | | |
| L1-C | BOC(1,1) | 1575.42 | Pilot | | | | |



# GNSS Applications (High-precision)

## Full GNSS signal package => codes and carriers

### Real-time positioning and navigation

- Surveying, Machine guidance, Agriculture
- Space missions, Remote sensing

### Time and frequency

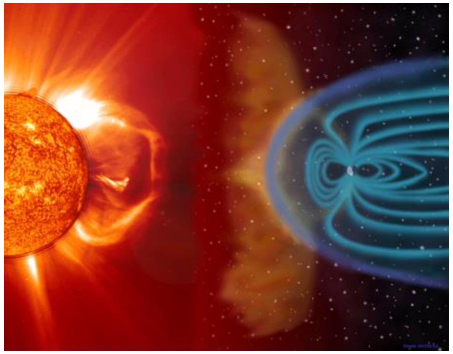
- Communication networks
- Electrical power grids

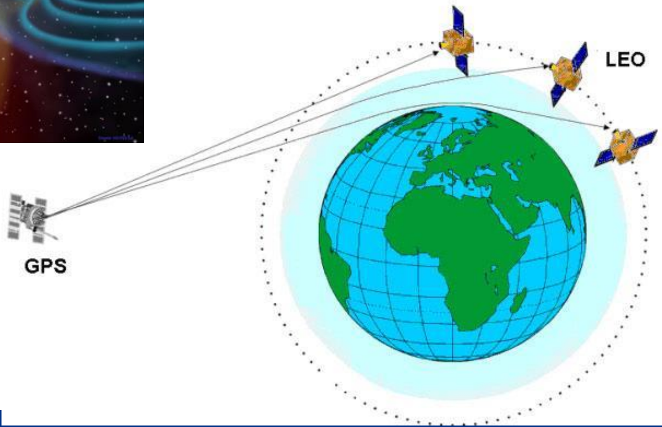
### Atmospheric remote sensing

- Ionosphere TEC, Troposphere

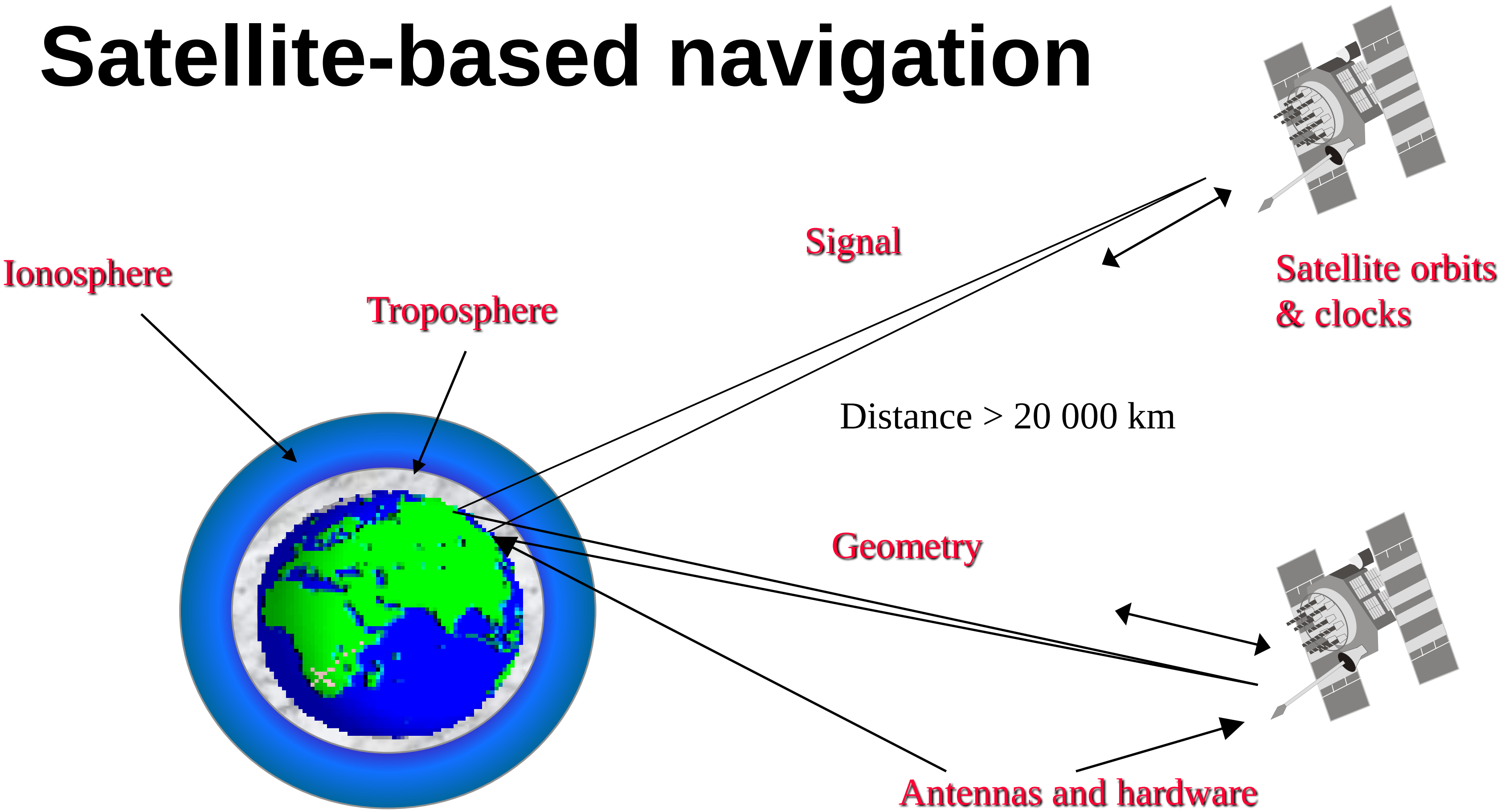
### Monitoring, Geodesy and Geophysics

- Important infrastructure e.g. bridges
- Tectonic plate motion, Sea level



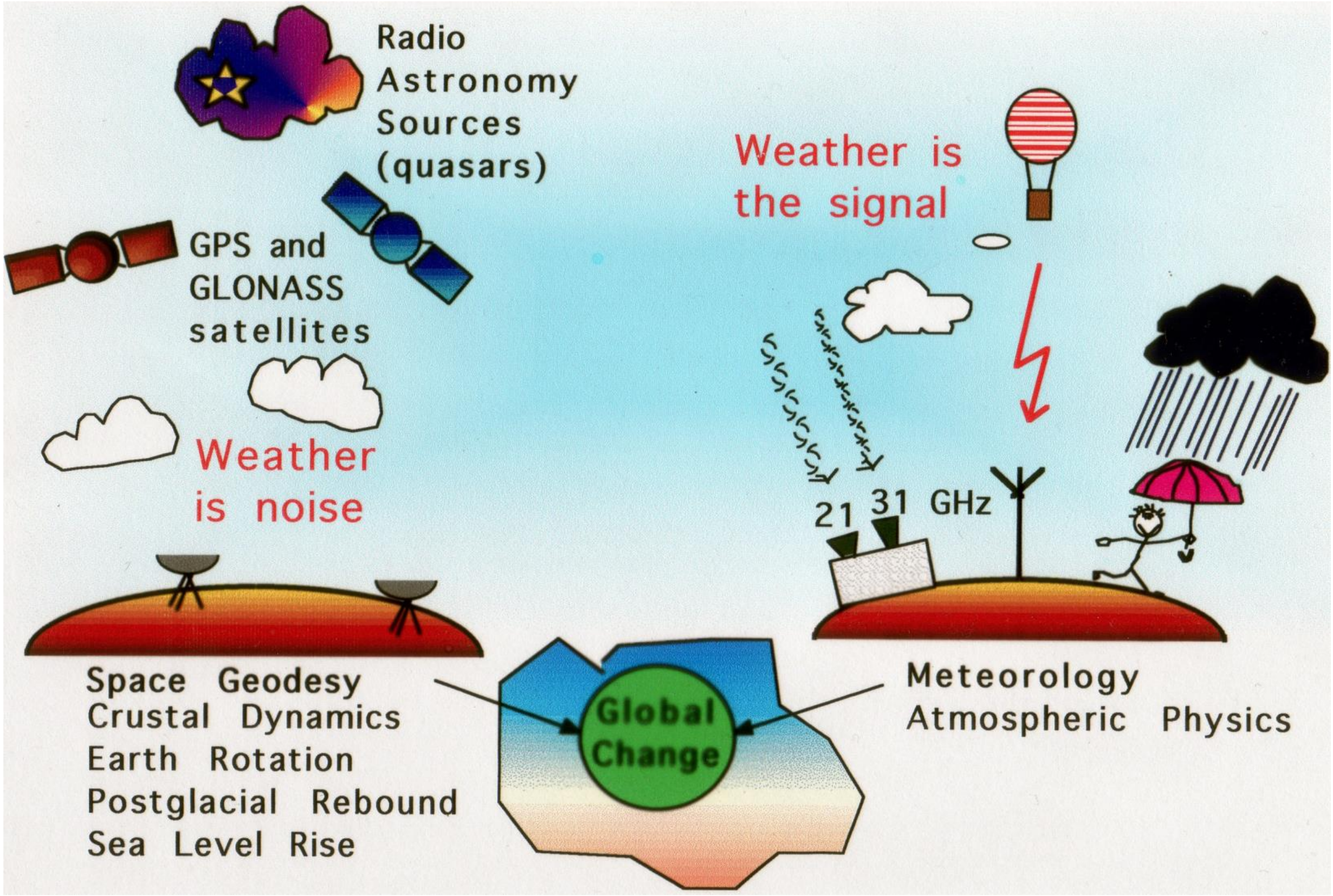
# Satellite-based navigation



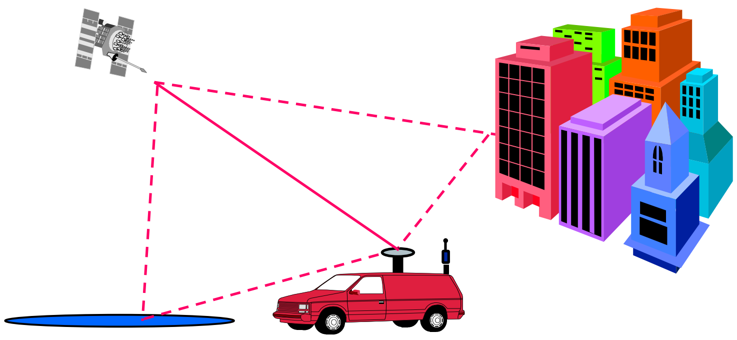

Received power (minimum):
$P_R = 10^{-16}$ W = - 130 dBm = - 160 dBW

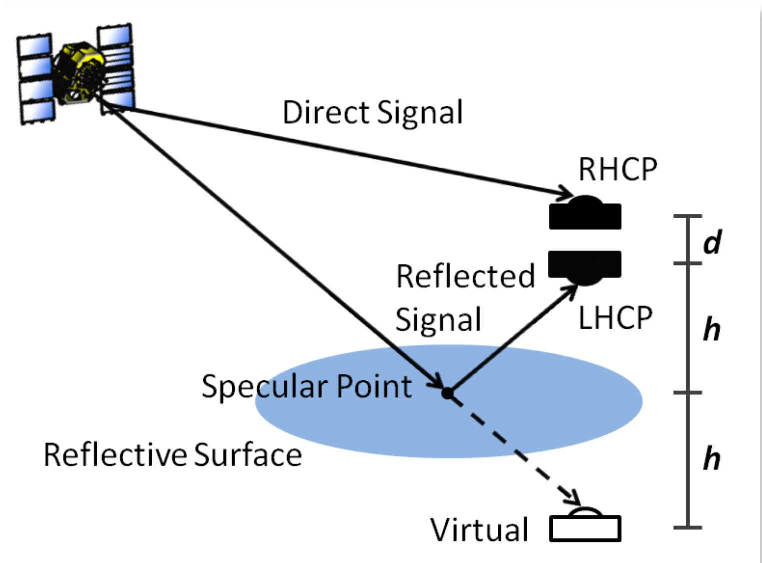
Satellite power: $P_T$ = 27 W
Antenna Gain: $G_T$ ~ 10 dBi
Transmitted power ~ 250 W

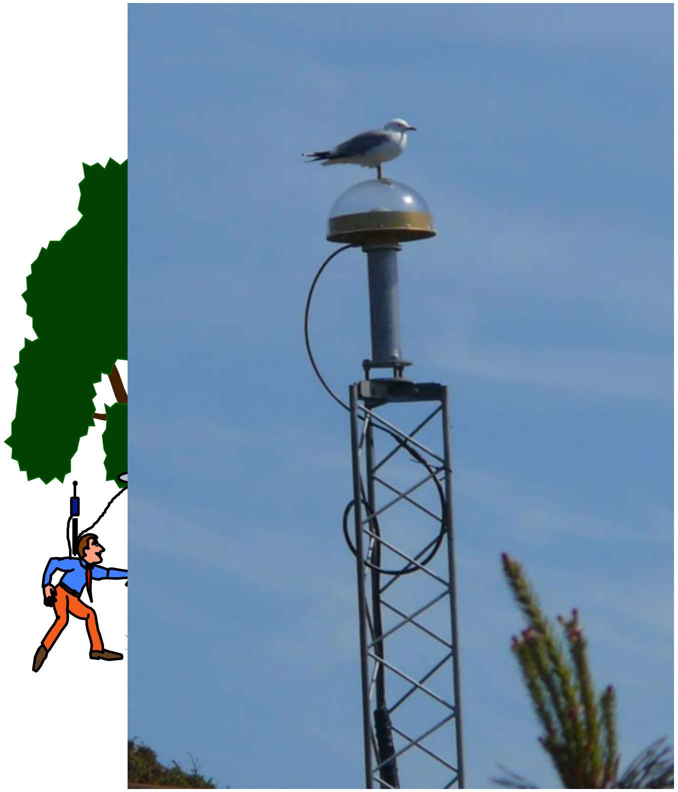

5

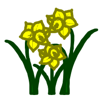

Radio
Astronomy
Sources
(quasars)
GPS and
GLONASS
satellites
Weather
is noise
Weather is
the signal
21
31
GHz
Space Geodesy
Crustal Dynamics
Earth Rotation
Postglacial Rebound
Sea Level Rise
Global
Change
Meteorology
Atmospheric Physics

# Multipath and Blockage







Other possible interference problems …

- Atmosphere
- Intentional interference
- Seagulls

# Signal requirements and robustness

**A "scientific" view on GNSS development:**

- Always expect new systems, satellites and signals to become available
- Trusts that all signals eventually will be possible to use => new applications
- Research on new ideas for signal generation (code and carrier)

**A "conventional" GNSS user (positioning and navigation) require:**

- Reliability, Robustness and achieving declared Precision
- Augmentation possibilities, Interoperability, Sensor fusion
- Often have access to other techniques for redundancy

**The GNSS Time and frequency community:**

- GNSS used in communication networks (e.g. Internet, Cellular phone networks)
- Permanently installed GNSS equipment in critical infrastructure for society
- Often without redundancy - Identified as a risk e.g. by authorities in Sweden

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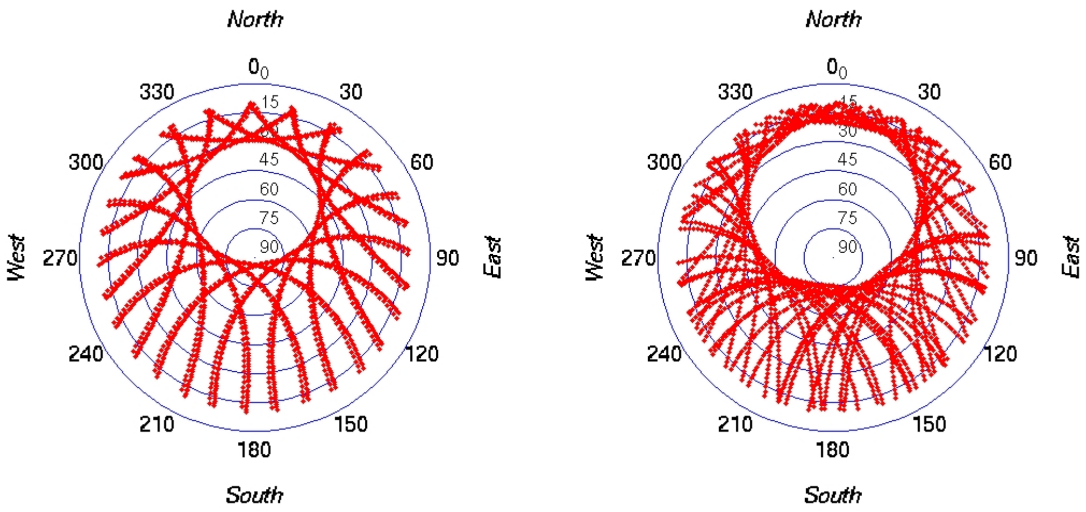
# GLONASS & GPS coverage in Kiruna




**High-latitude regions**

- Different satellite geometry
- No (few) satellites in Zenith
- More observations at low elevation
- Augmentation systems based on Geostationary satellites e.g. EGNOS/WAAS less useful

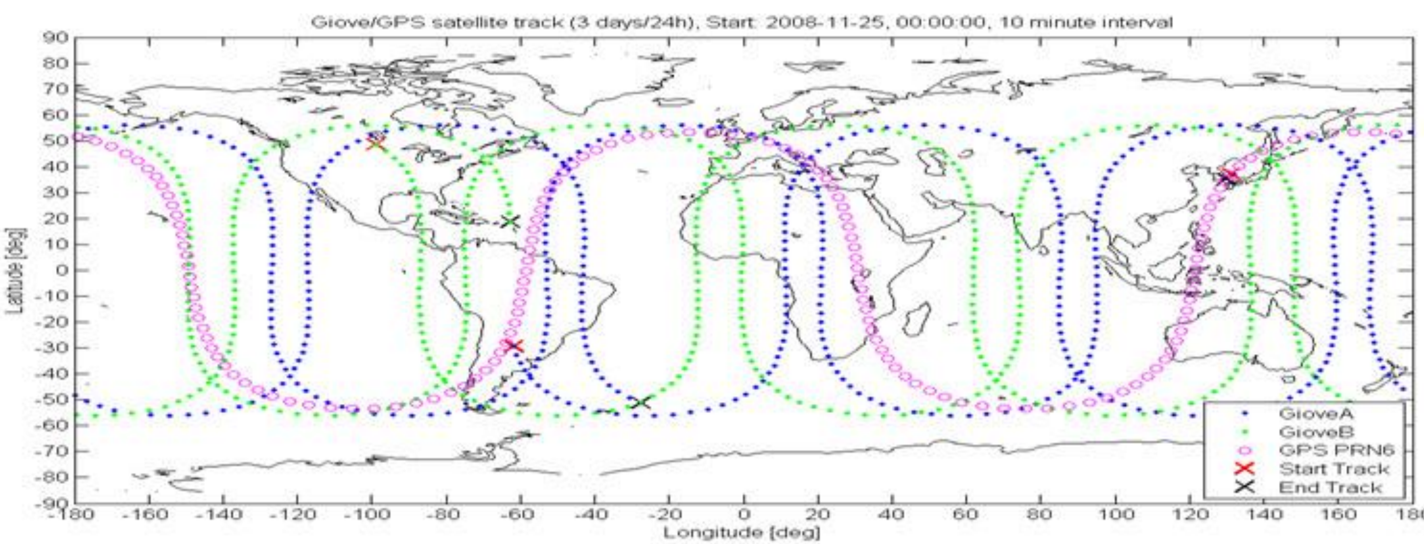
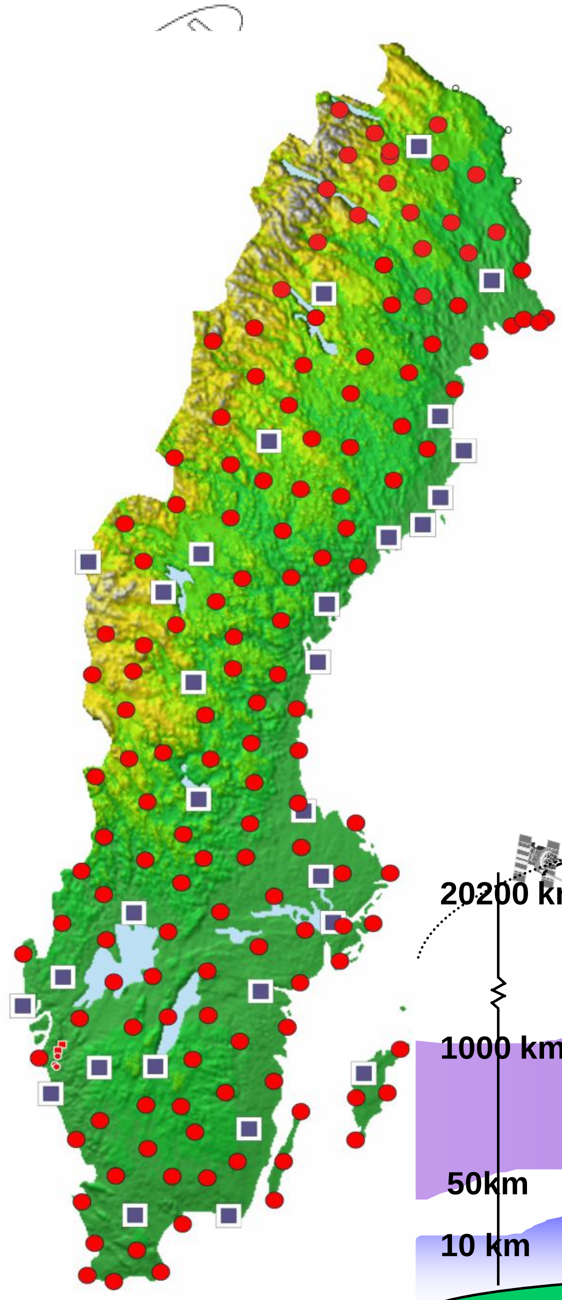



**Figure 6 – Ground Tracks of GIOVE-A and GPS Satellite Orbits**

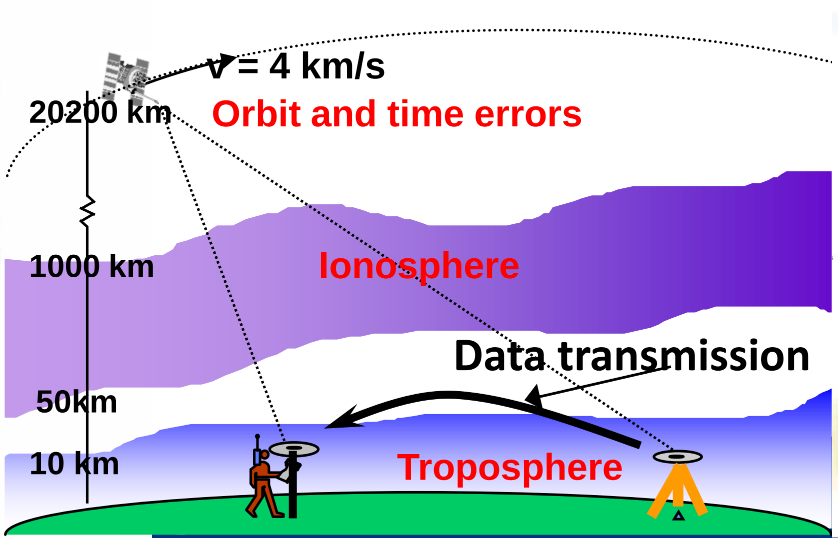
From:
Su & Zimmermann
2010

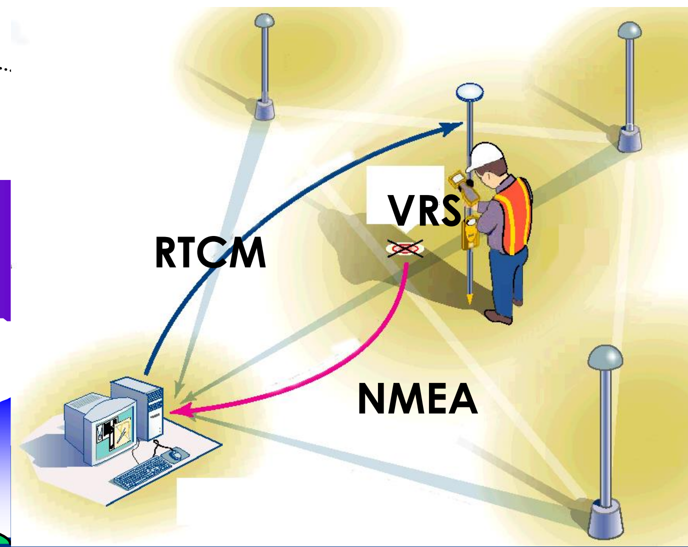
# SWEPOS – GNSS Augmentation and Monitoring



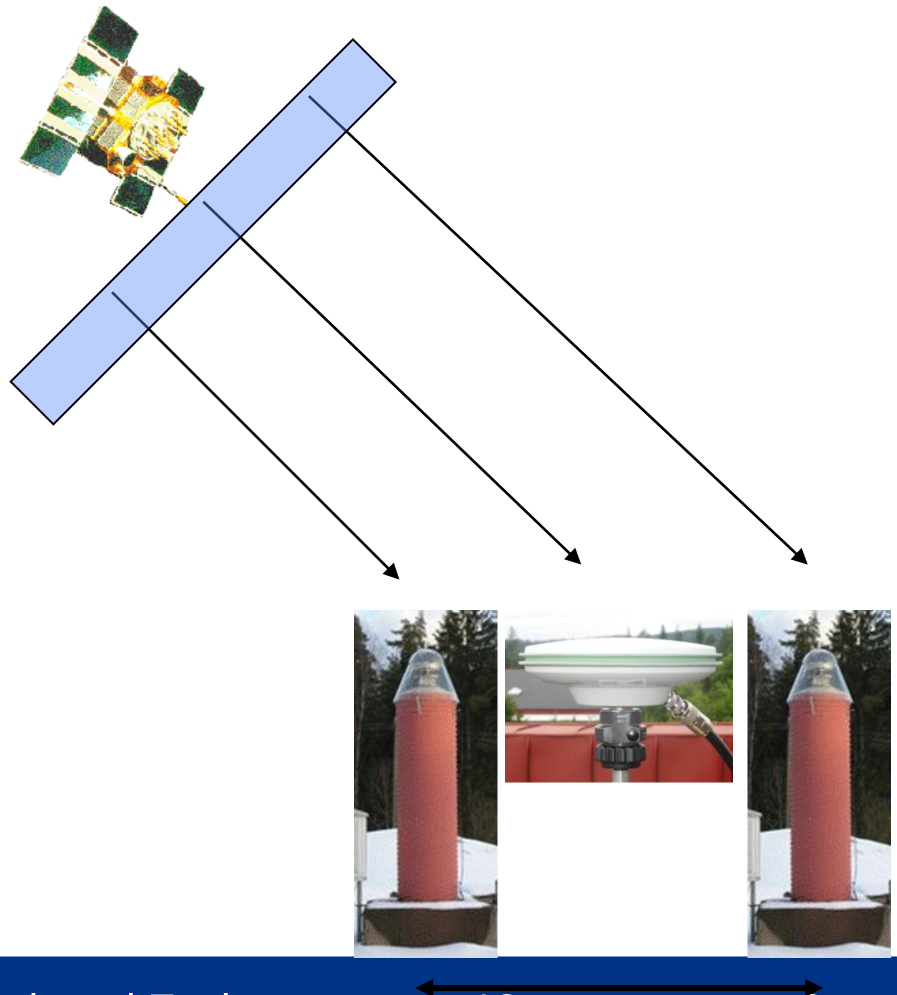
National network of 400 permanent reference stations:

- Providing real-time corrections for DGPS and RTK using RTCM-format
- GPS/GLONASS-receivers (soon also Galileo/Beidou)

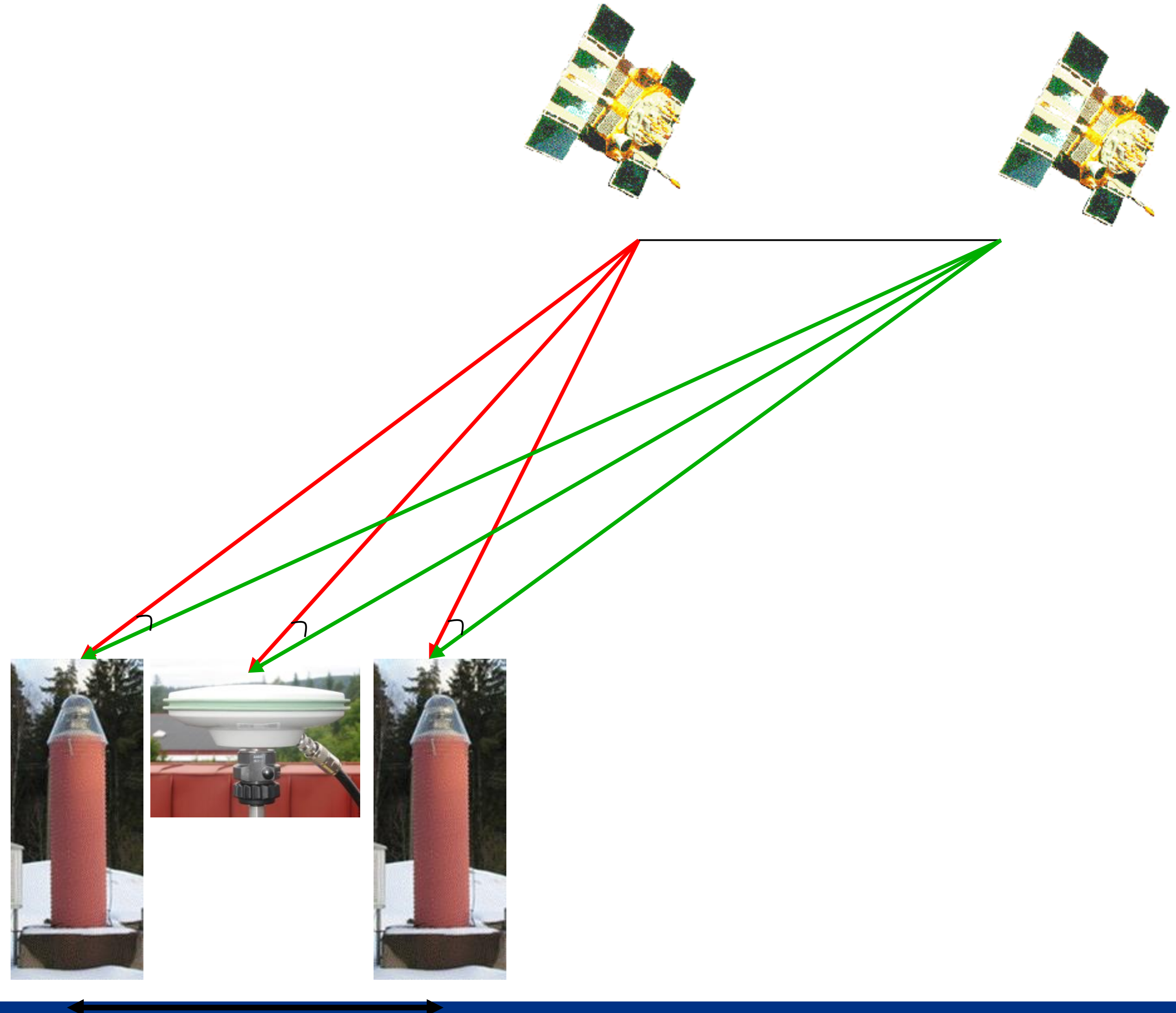


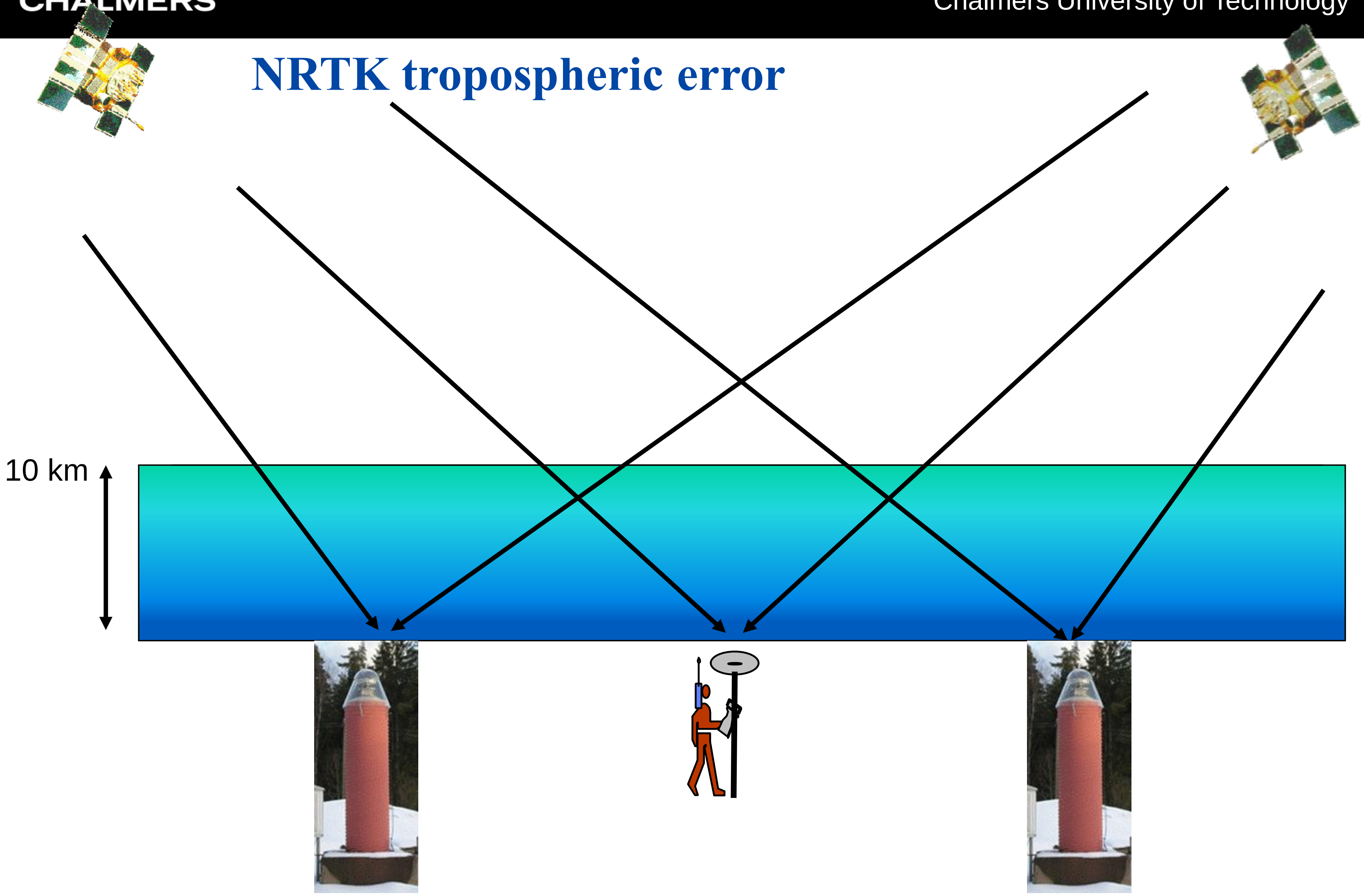
# Satellite clocks



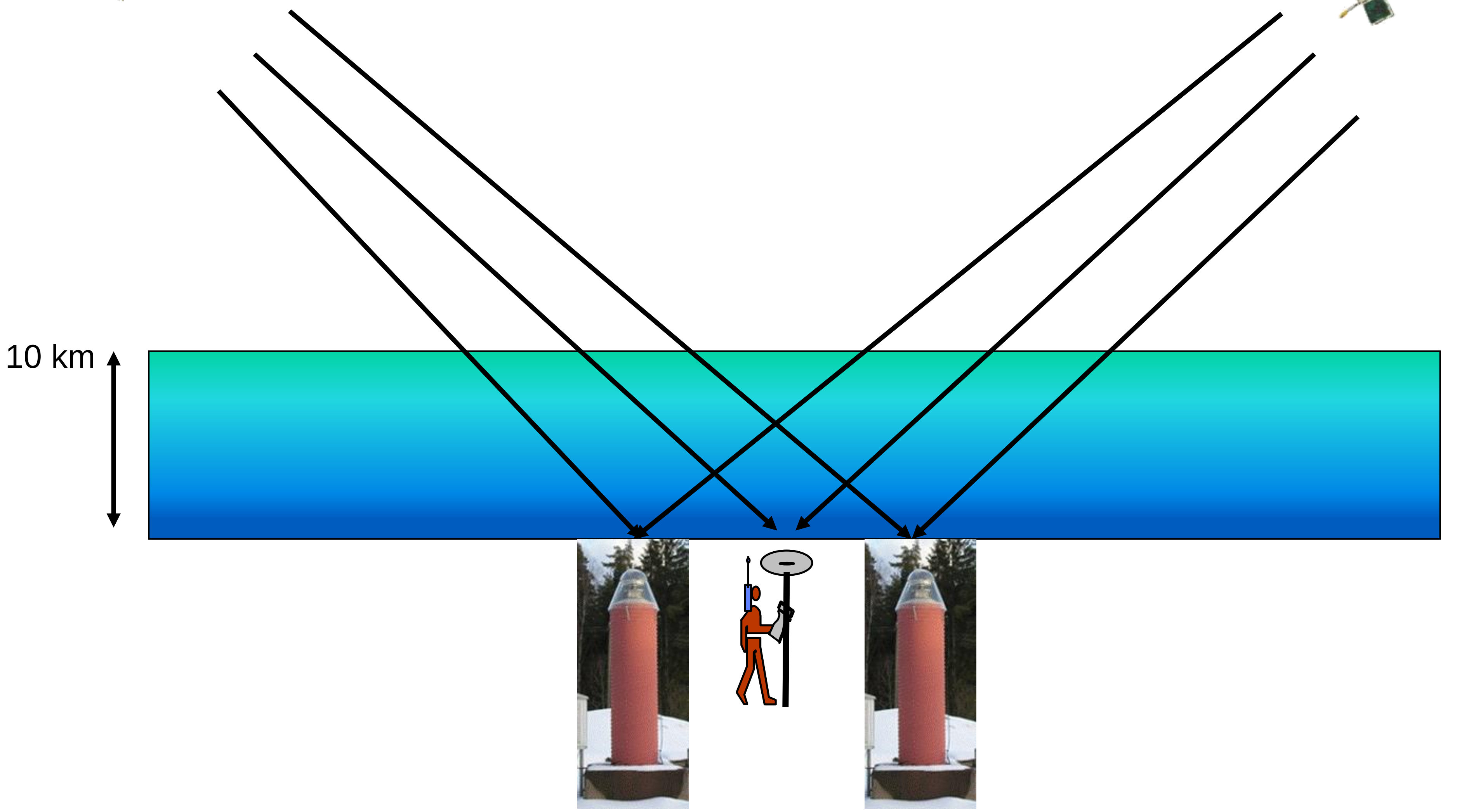
# Satellite orbits



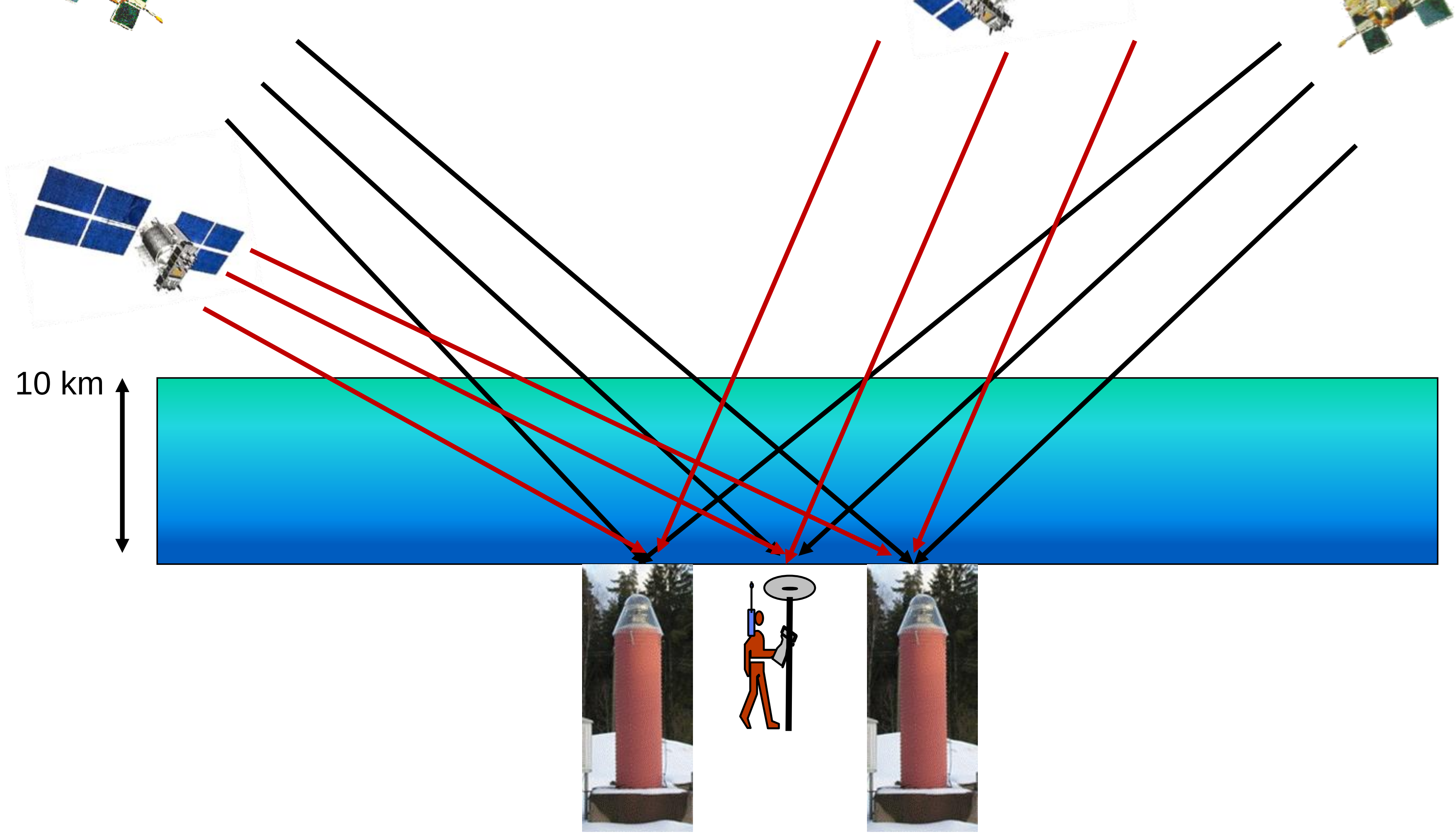
# NRTK tropospheric error



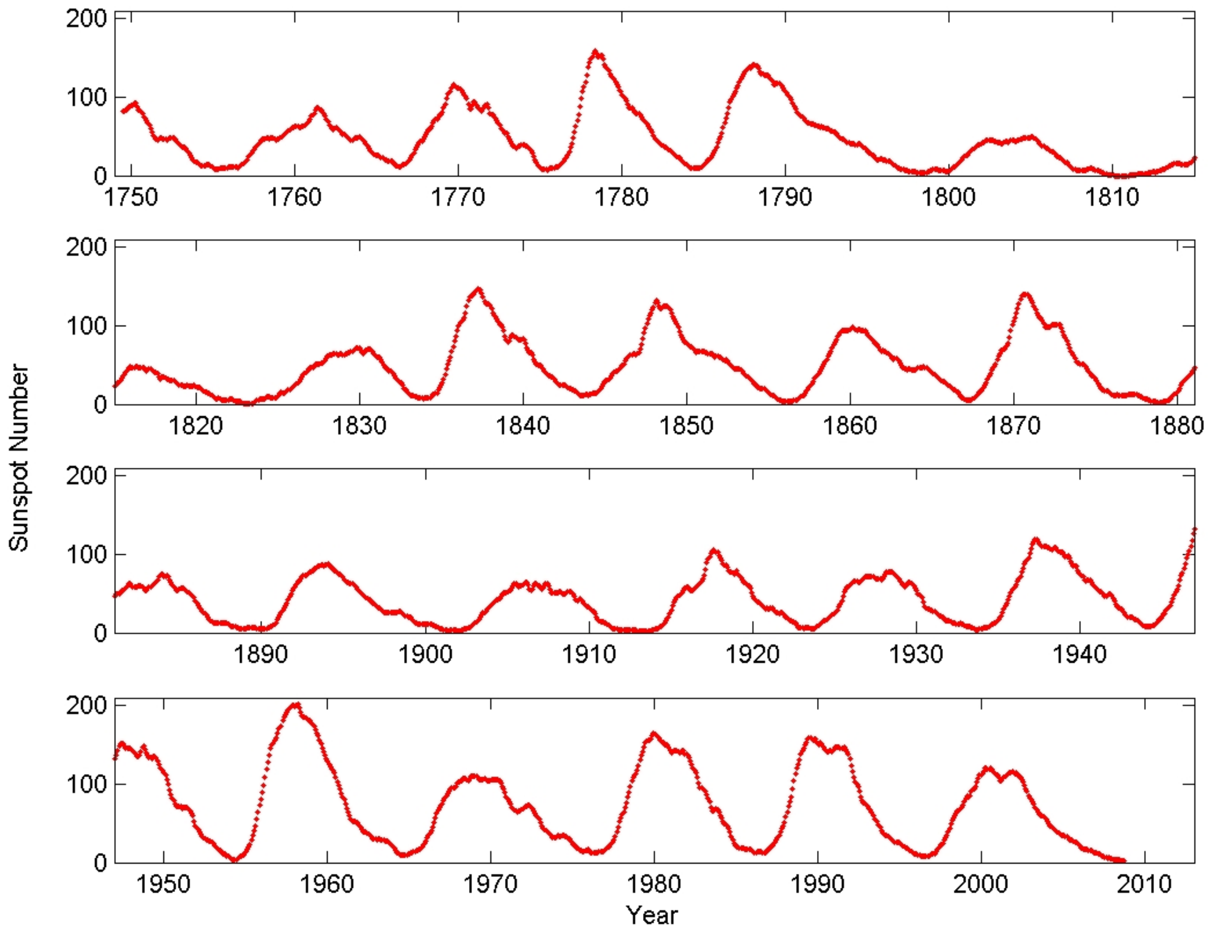
# NRTK tropospheric error



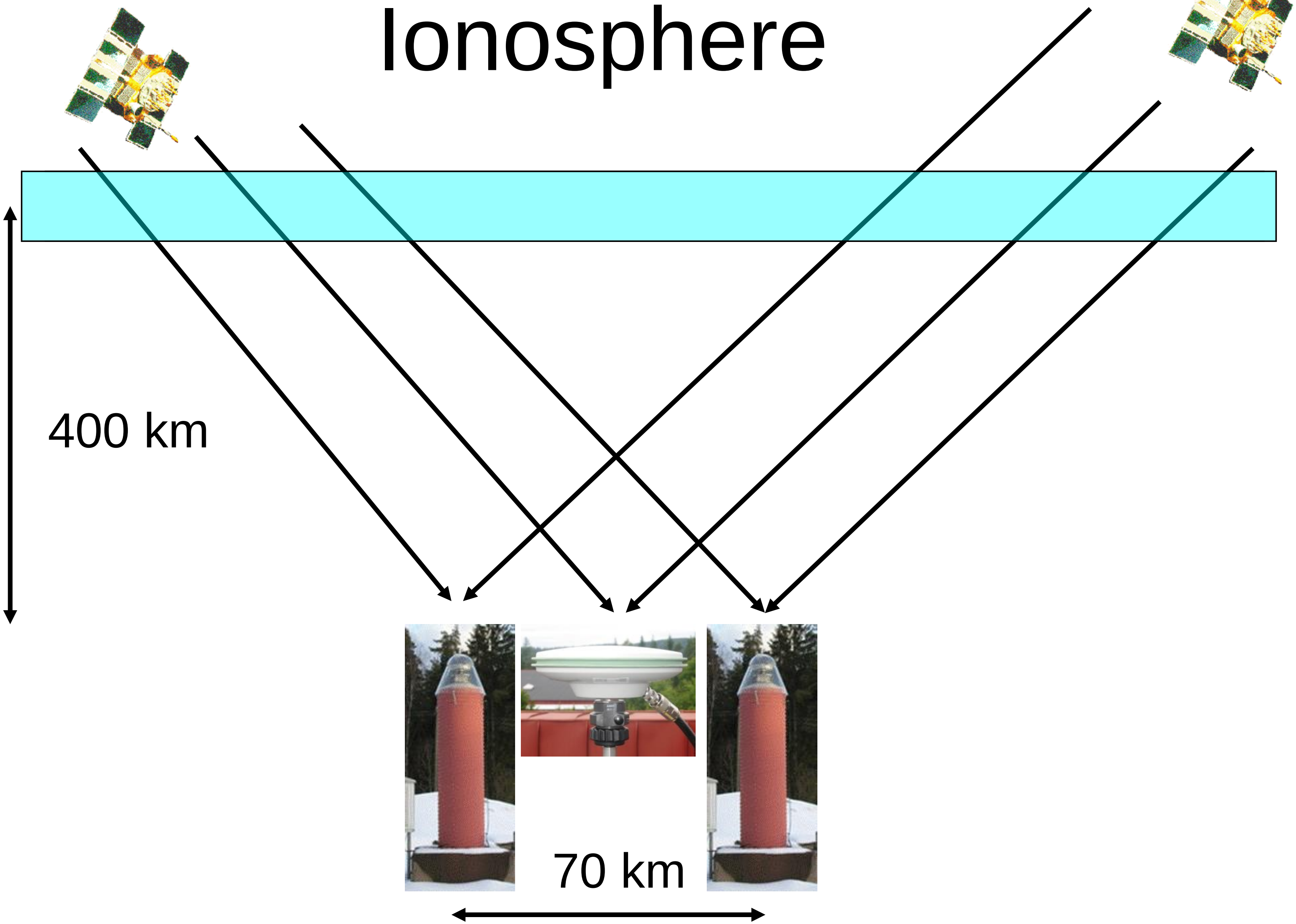
# NRTK tropospheric error



# CLOSE-RTK 2
# Ionosphere and the Solar cycle

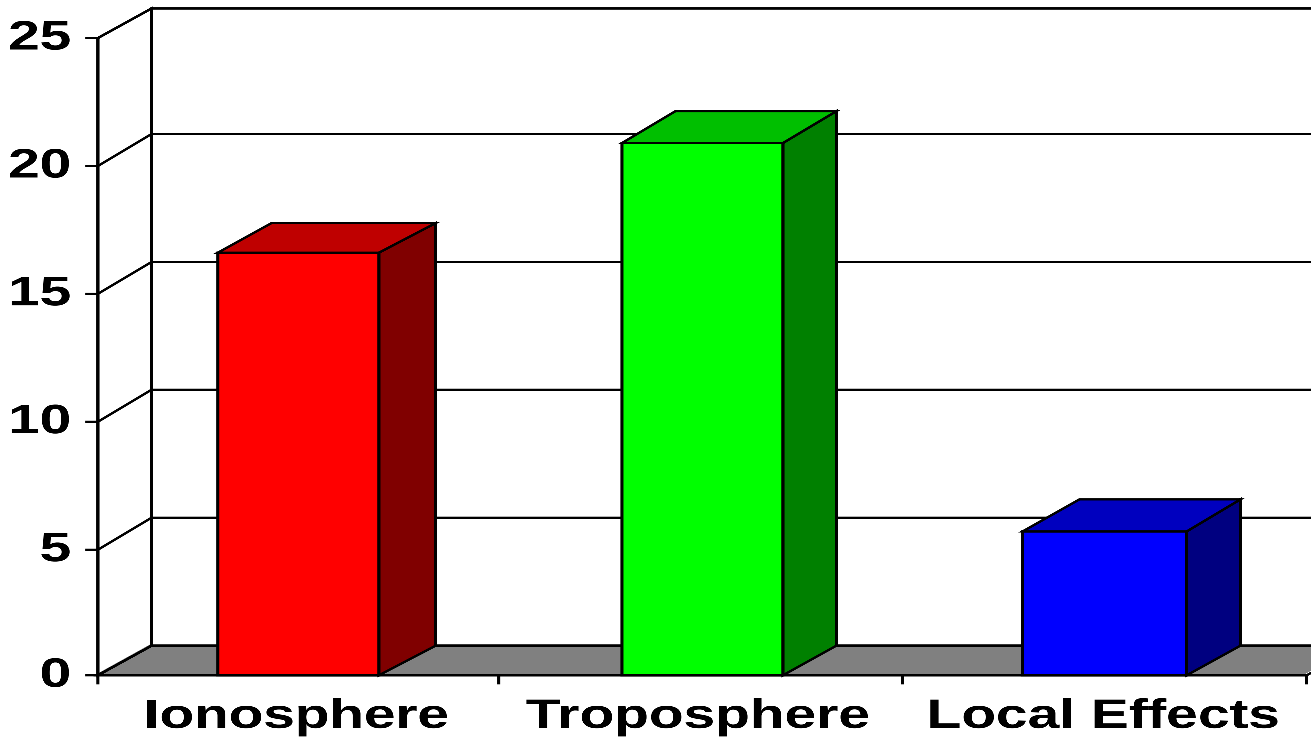


# Ionosphere



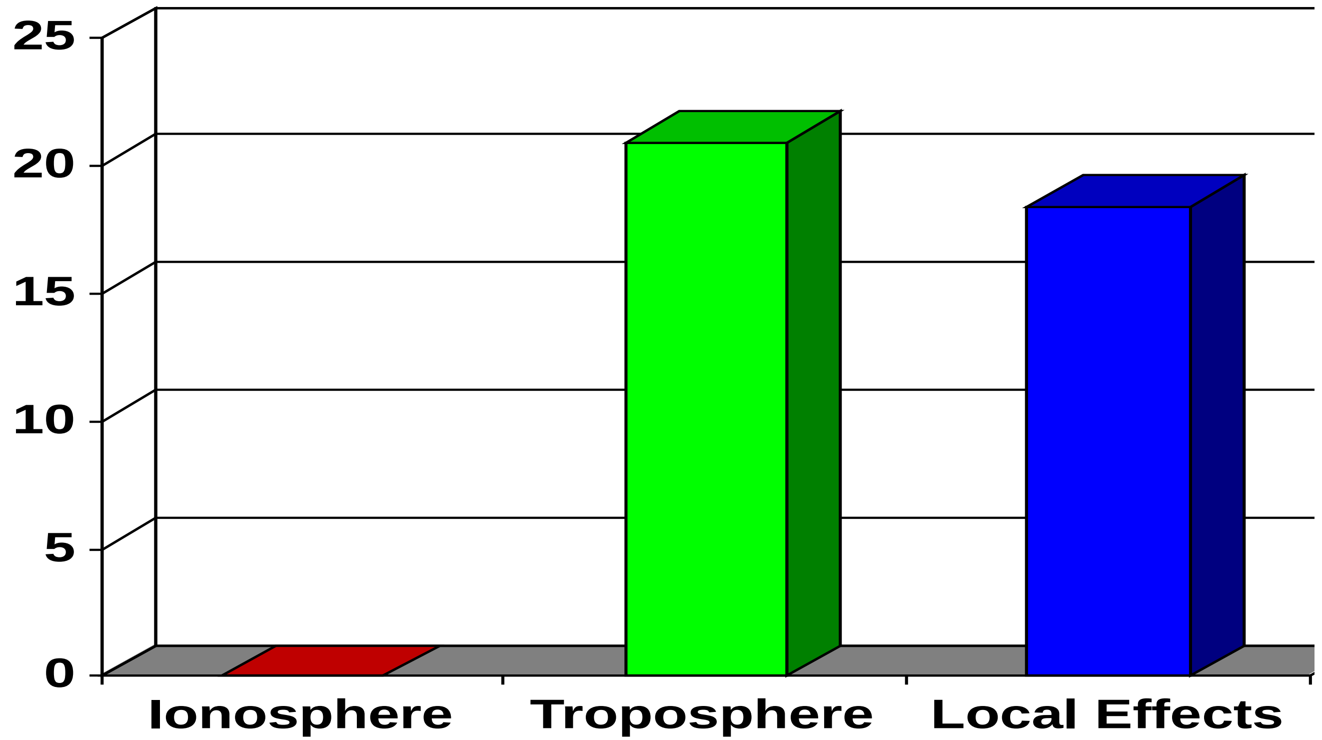
# NRTK L1

Total Vertical
Error
27 mm



# NRTK L3(L1+L2)

Total Vertical Error
28 mm

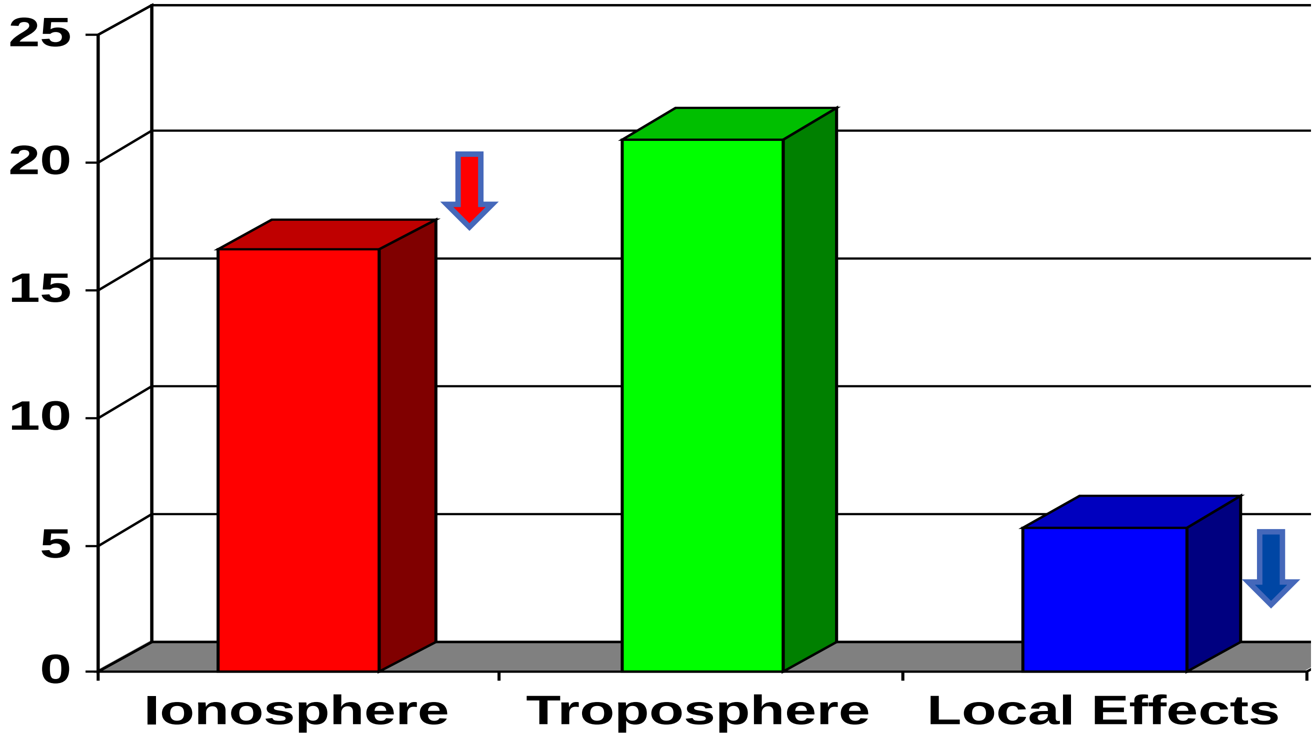



$L_3 = 2.546 * L_1 – 1.546 * L_2$

# NRTK L1+L2+L5

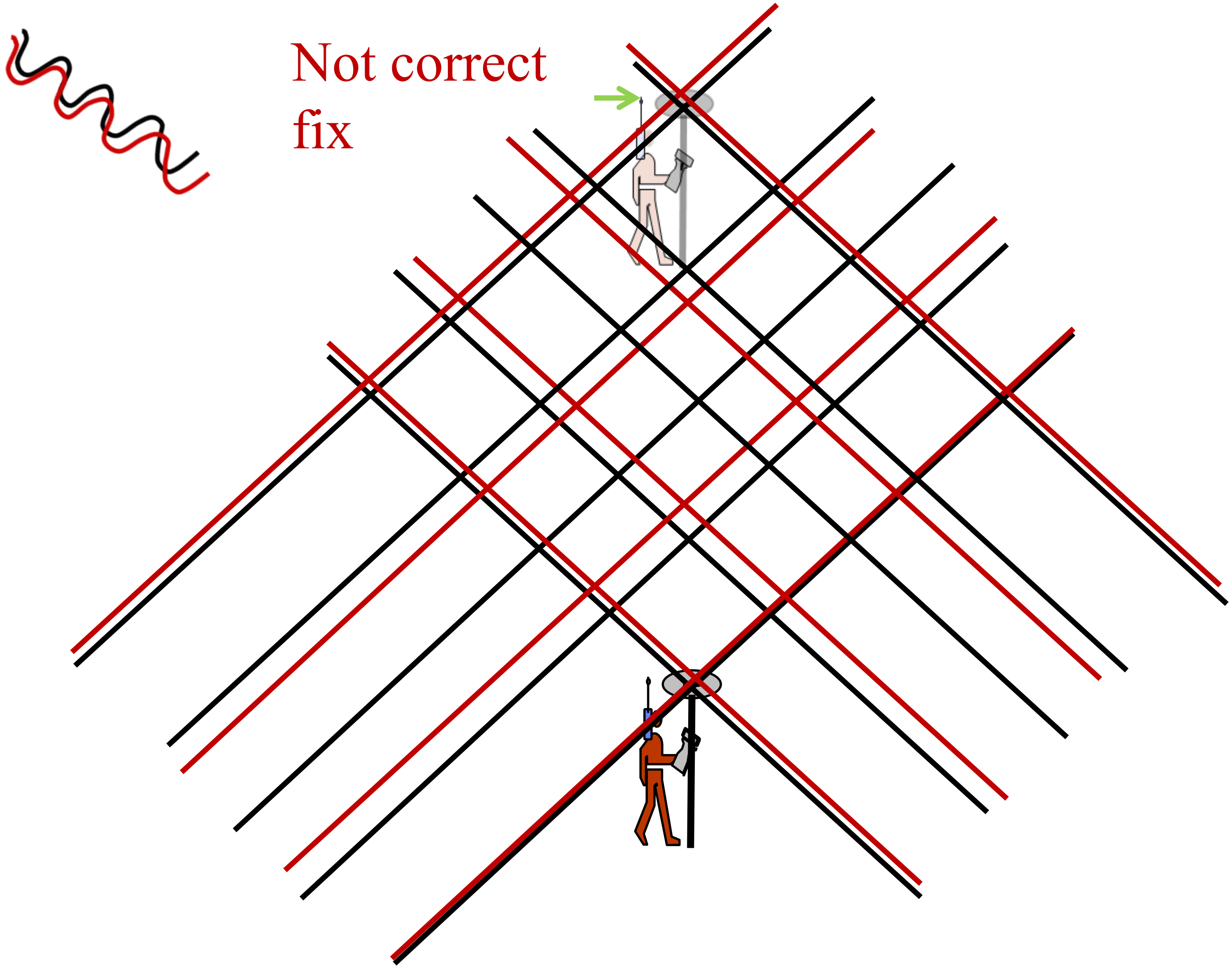
Future 3-frequency systems => new linear combinations

Total Vertical
Error
?? mm



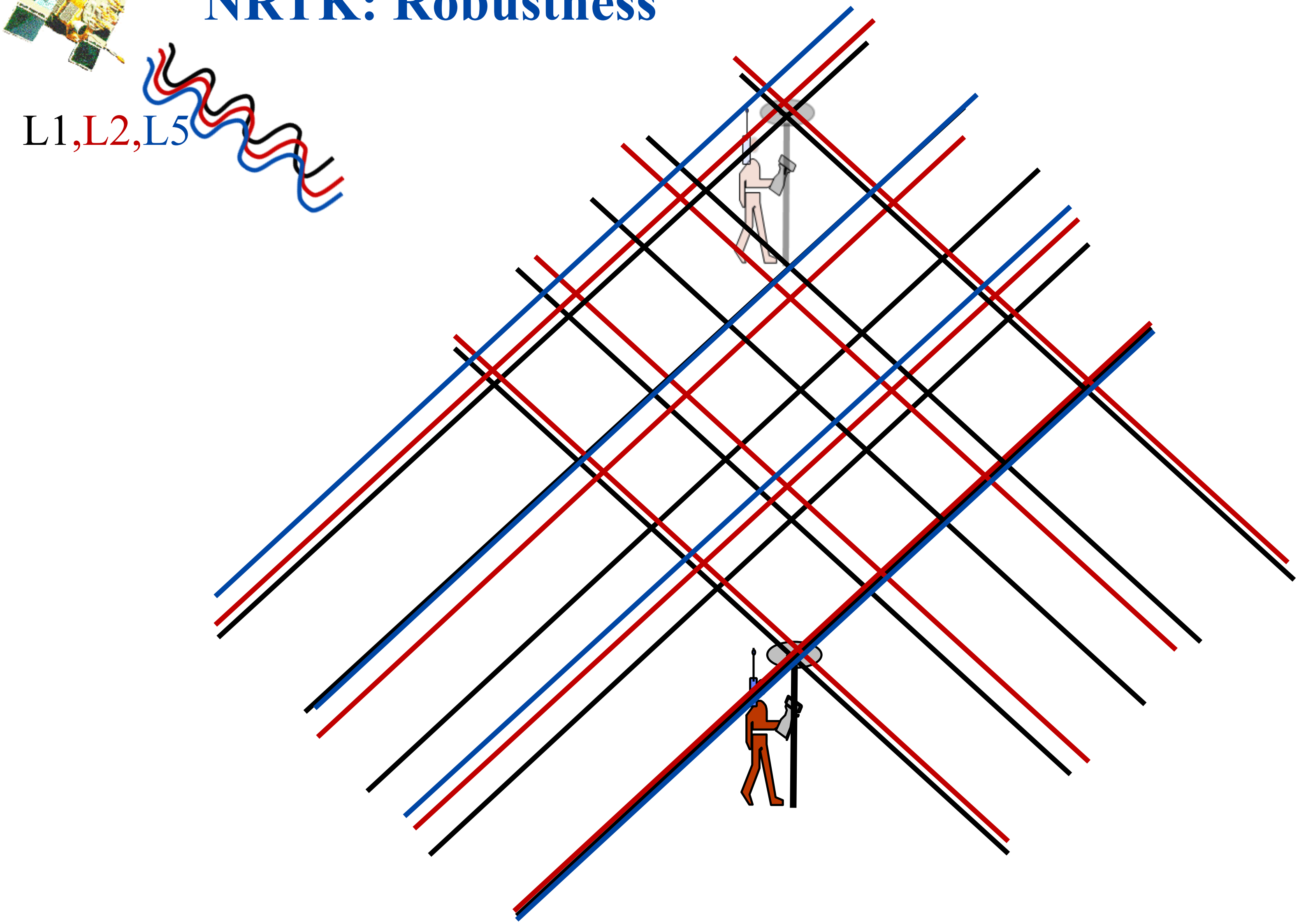
# NRTK: Robustness

L1,L2



Not correct fix

# NRTK: Robustness



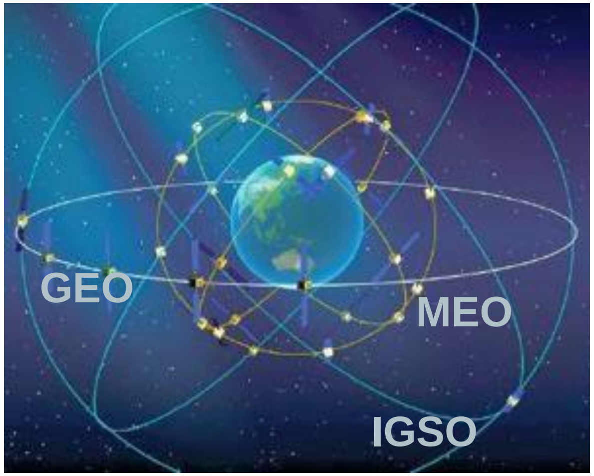
# Interoperability with other GNSS

- Global Navigation Satellite Systems (GNSS)

| | | | | | |
|---|---|---|---|---|---|
| GPS | United States | CDMA | 20 200km, 12.0h | ≥ 27 | operational, 2014: 32 sat |
| GLONASS | Russia | FDMA | 19 100km, 11.3h | 24 | operational, 2014: 29 sat |
| Galileo | Europe | CDMA | 23 222km, 14.1h | ≥ 27 | in preparation, 2014: 6 sat |
| Compass/Beidou | China | CDMA | GEO (5) + IGSO (3) + MEO (27) | 35 | in preparation, 2014: 14 sat |

GEO: Geostationary Earth Orbit
IGSO: Inclined Geo-Synchronous Orbit
MEO. Medium Earth Orbit

Beidou orbits




- Regional Satellite Navigation Systems

| System | Country | Frequency | Orbital height & period | Number of satellites | Status |
|---|---|---|---|---|---|
| QZSS | Japan | L1, L2, and L5 | HEO | 4 | in preparation, 2014: 1 sat |
| IRNSS | India | L5 and S-band | GEO (3) + IGSO (4) | 7 | in preparation, 2014: 1 sat |


IGSO ground track

- Regional Satellite Based Augmentation Systems (SBAS):
  - WAAS(US), EGNOS (EU), MSAS (Japan) and GAGAN (India).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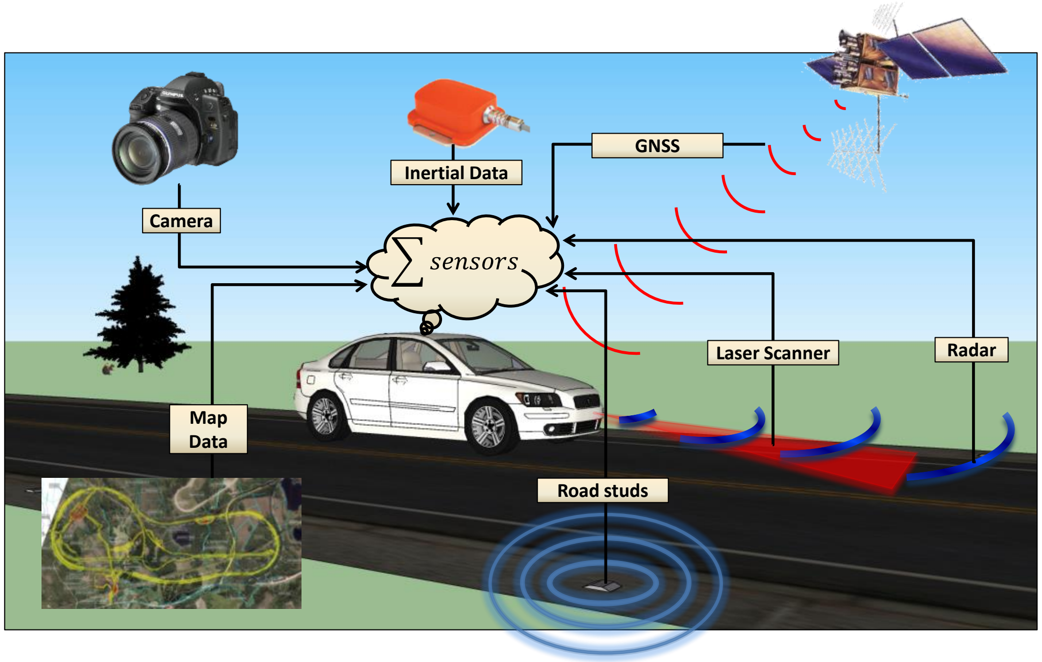
# Sensor fusion - Interoperability with other sensors

Example of multi-sensors in a “standard” car

- GNSS provides position, velocity, acceleration and time
- Accelerometer provides acceleration, Gyro provides angles
- CAN bus provides speed
- Radar, Laser, Cameras, Maps etc
- Measurements are combined through sensor fusion in a Kalman filter

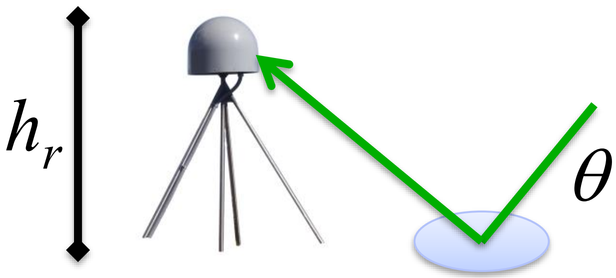



- Increased update frequency
- Navigation in difficult environments such as indoors and tunnels
- Increased robustness

$$SNR^2 \sim 2A_d A_m \cos\psi$$

$$\psi = \frac{2\pi}{\lambda}\delta$$

excess path due to MP

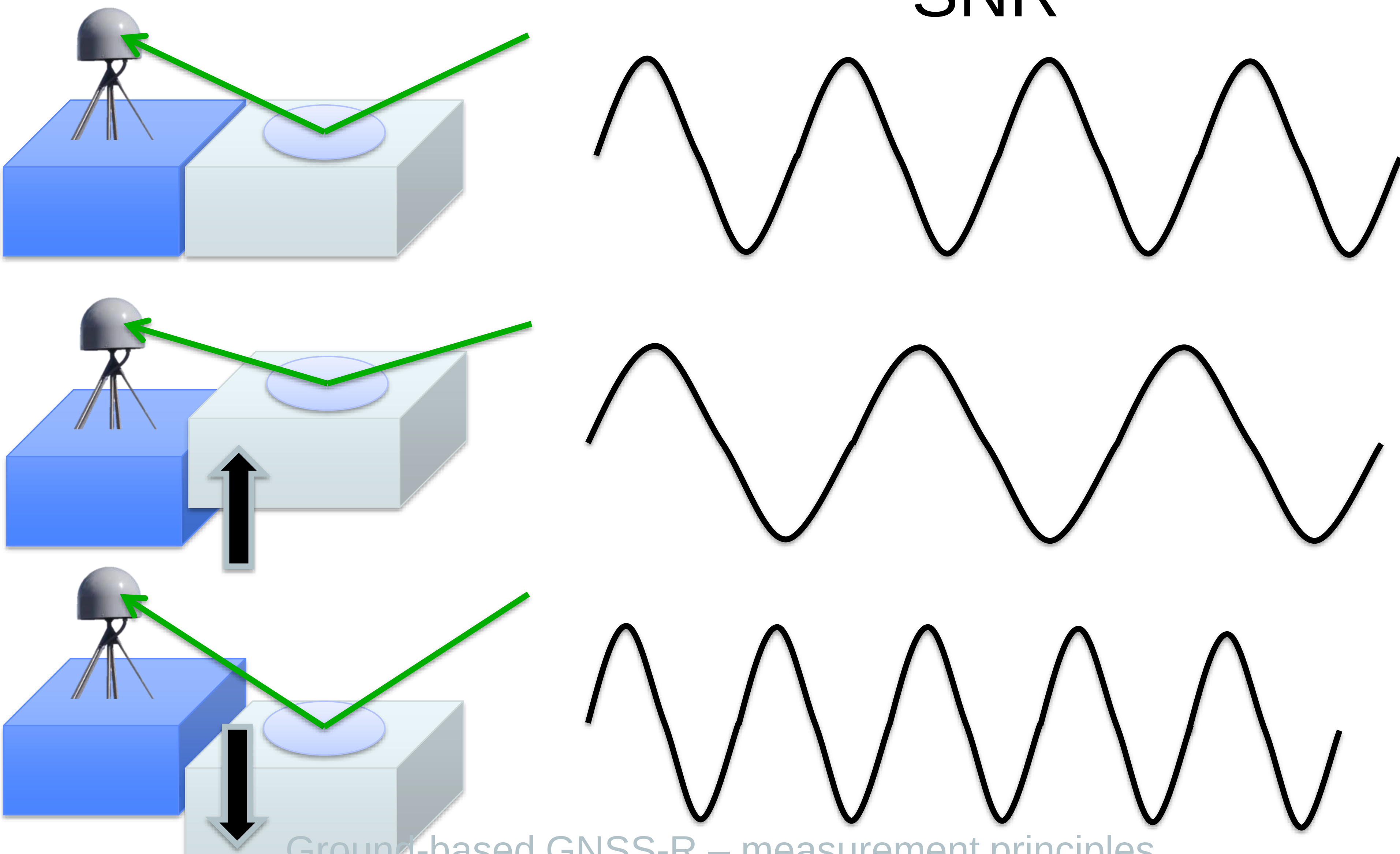



Excess path = height of the antenna above the reflector x sin (elevation)

$$\psi = \frac{4\pi h_r}{\lambda}\sin(\theta)$$

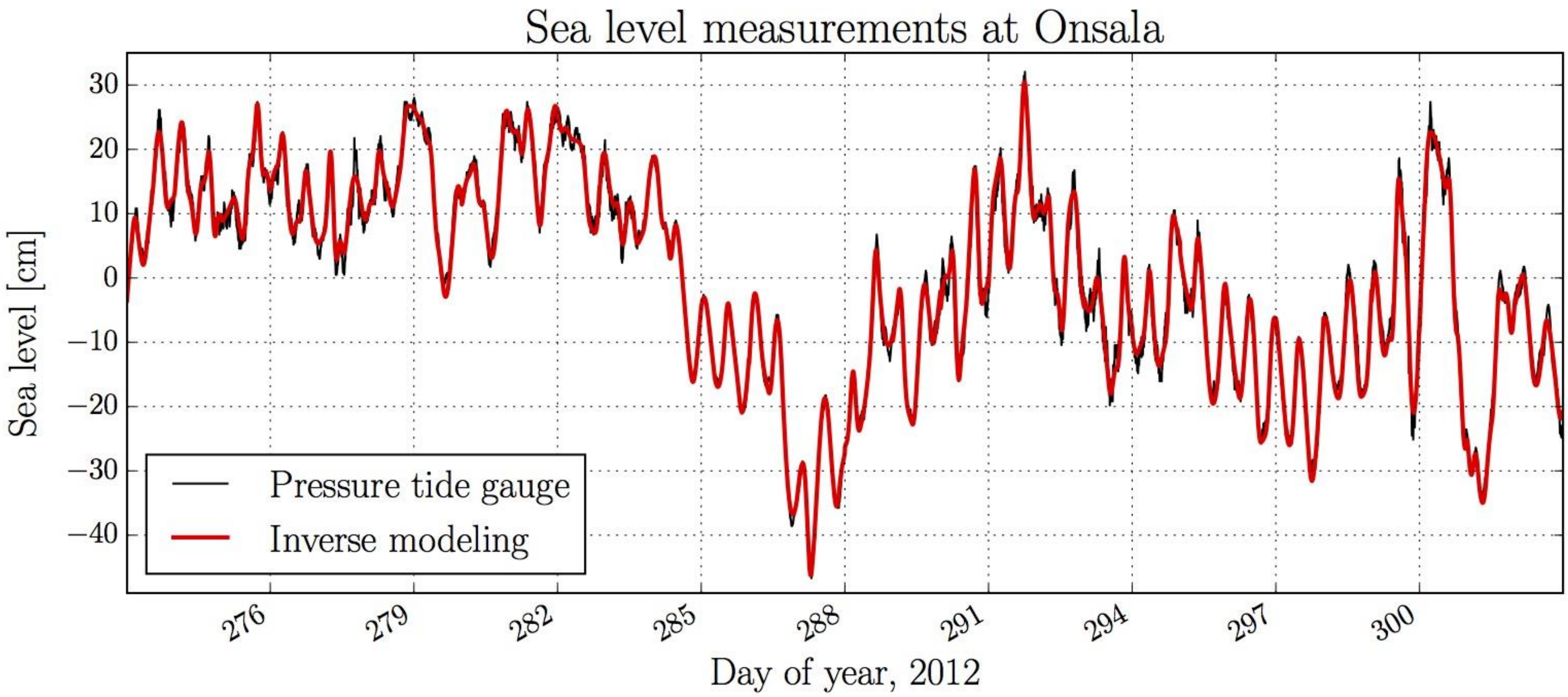
Ground-based GNSS-R – measurement principles

# SNR



Ground-based GNSS-R – measurement principles

# Better precision through inverse modeling (Strandberg et al., 2016)




Ground-based GNSS-R – results

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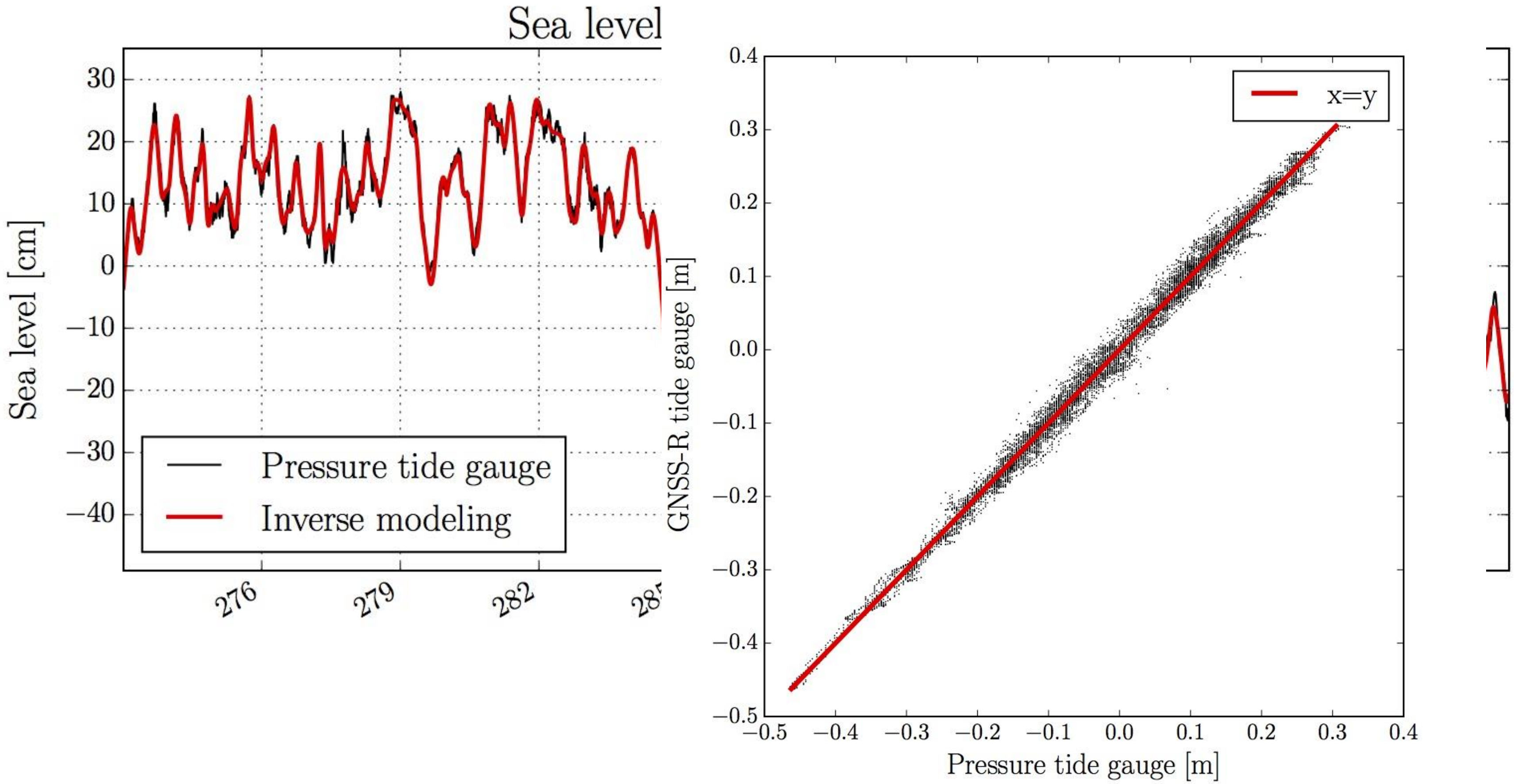
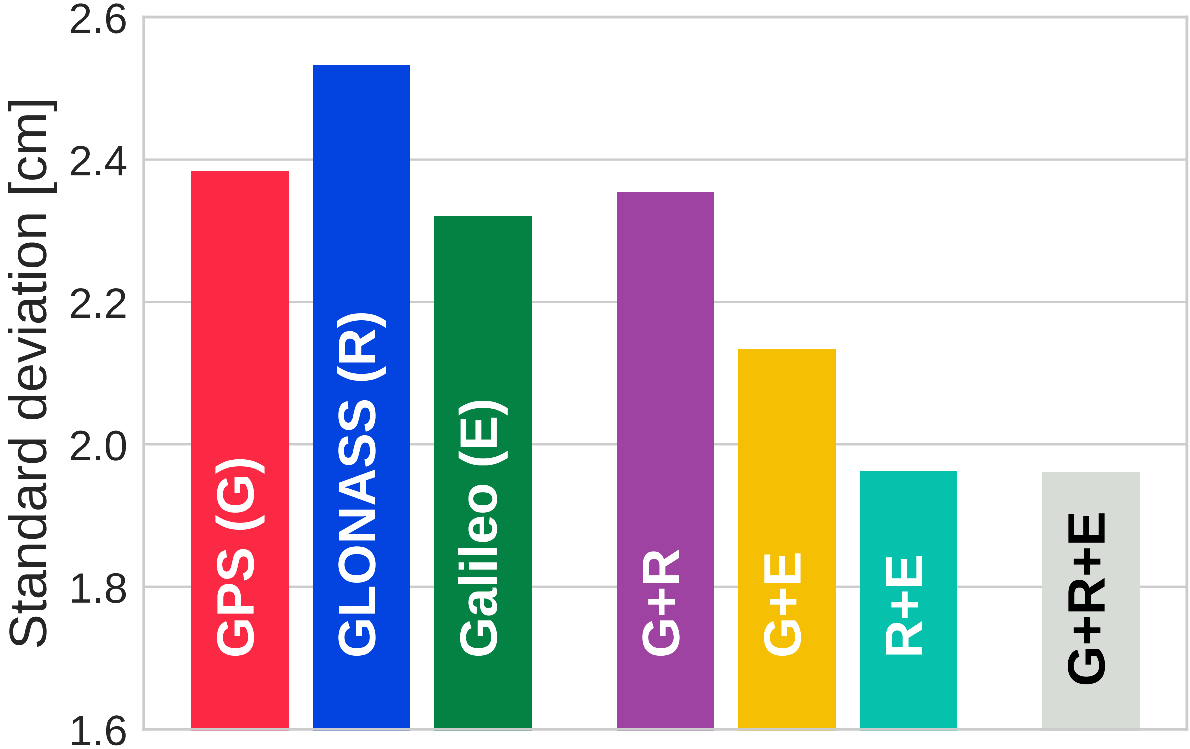



Ground-based GNSS-R – results

# GPS

# GPS and Galileo

# GNSS-R - Results for different GNSS combination



# Increased robustness

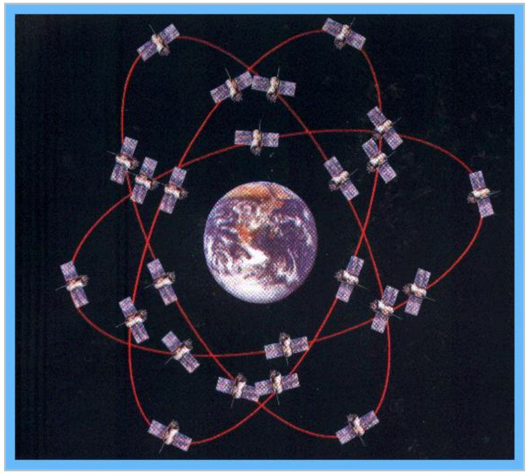
- Improving the signal (backward-compatible?)
  - Increased signal power; Improved frequency standards;
  - New and more signals (carrier frequencies)
  - New coding and increased bandwidth
  - Multi-constellation GNSS
- Augmentation, integrity, monitoring
  - Atmospheric corrections, Resistance/warning against interference
  - High-latitudes solutions
- Receiver systems
  - Multipath and interference resistance
  - GNSS Interoperability, Multi-constellation GNSS
  - Sensor fusion

# Expectations for the future

- GNSS is used in many more applications
  - Scientific, Commercial, Personal
  - Positioning, Navigation and Time (PNT)
- GNSS weaknesses mitigated
  - Augmentation e.g. PNT at high-latitudes
  - Modelling Troposphere and Ionosphere
  - Resistance/warning against interference
- Additional technical achievements
  - GNSS Interoperability and Sensor Fusion
  - Augmentation (Galileo OS/CS) from satellite or ground
  - Additional signals => robustness and redundancy

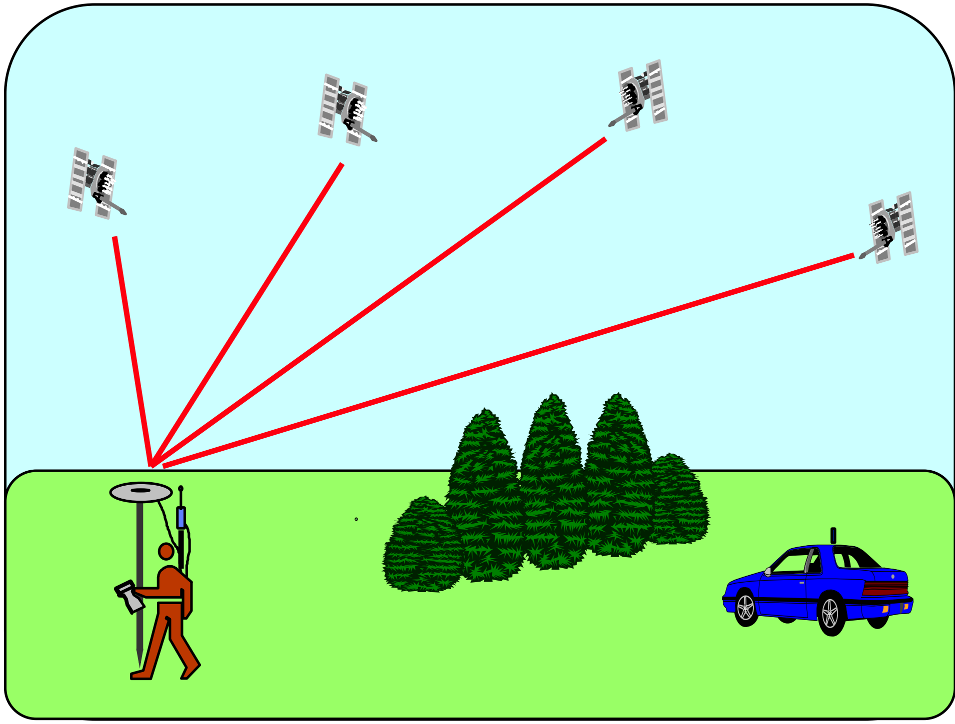
# GNSS Challenges for the future

- ***Long term stability of systems and reference frames***
- Error sources
- Robustness
- Interoperability
- Real time positioning in difficult environments



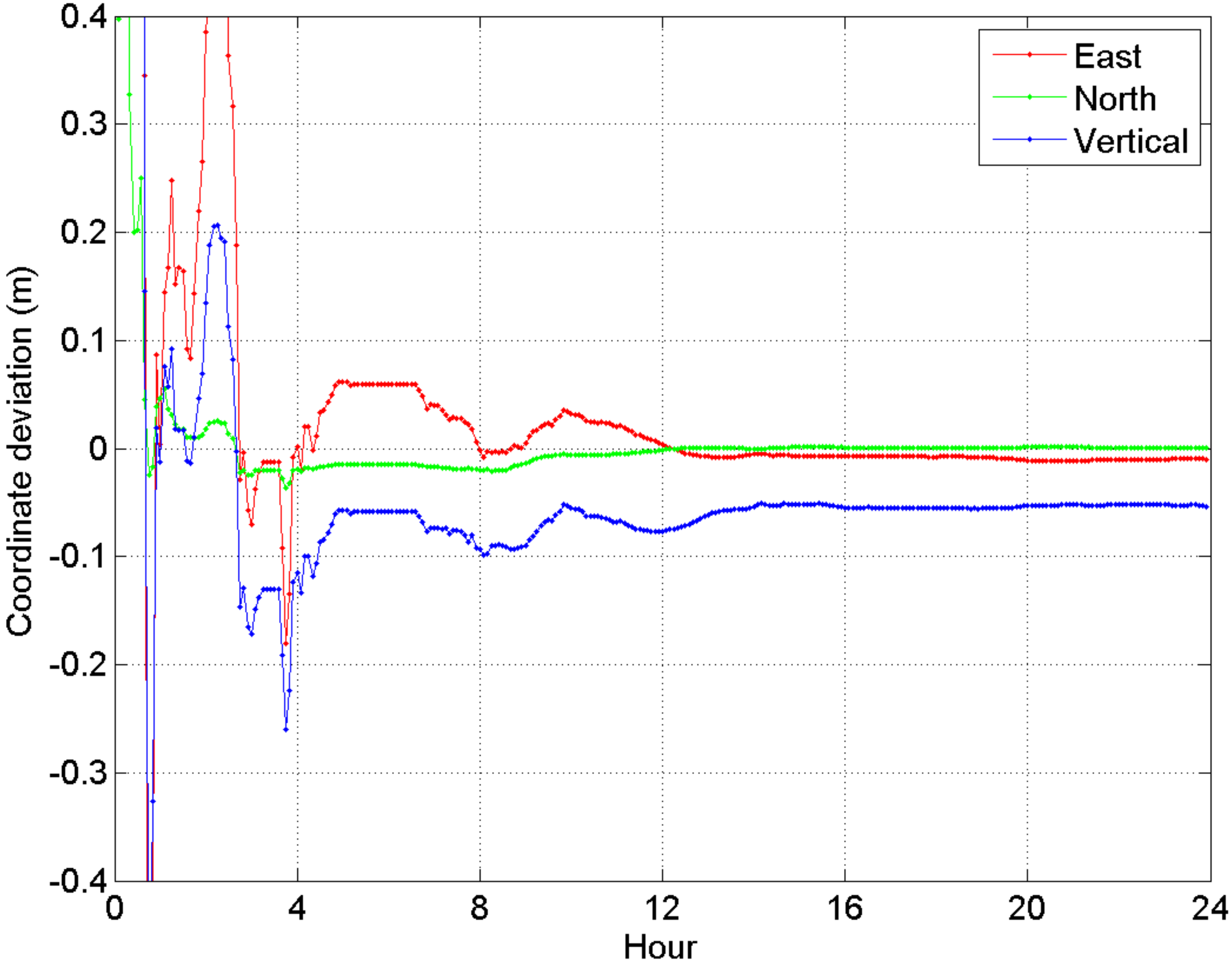
# PPP – Precise Point Positioning

- "Absolute positioning"
- PPP require knowledge of
  - Satellite orbits and clocks
  - Troposphere and Ionosphere
  - Receiver system
  - Local environment



Can all the information be available via the GNSS "signal-in-space" and impossible to jam?

# Galileo PPP Solution



# Comparison of PPP solutions: GPS vs Galileo