Introduction to GNSS

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Content

- GNSS
- Space, control and user segment
- Frequencies and signals
- Error sources
- Basic principle for GNSS positioning
- Code and phase observations
- Reference frame and geoid model
- GNSS applications

Use www.navipedia.com for further information

GNSS

Global Navigation Satellite System – GNSS, includes

Global systems:

- GPS (American)
- Galileo (European)
- GLONASS (Russian)
- Beidou (Chinese)

Regional systems:

- IRNSS (Indian)

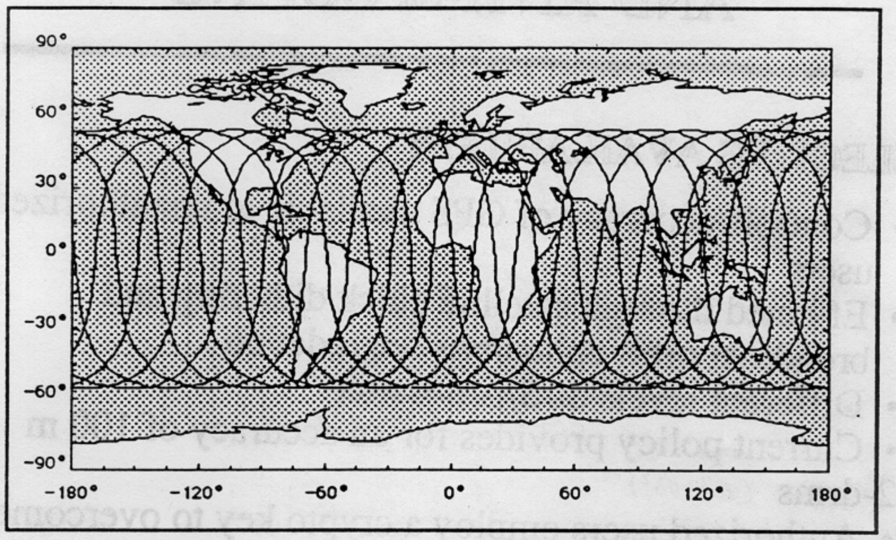
Augmentation systems such as:

- EGNOS (European)
- WAAS (American)
- QZSS (Japanese)

GPS space segment

Original design with
24 satellites

6 orbital planes with
55 degrees
Inclination angle

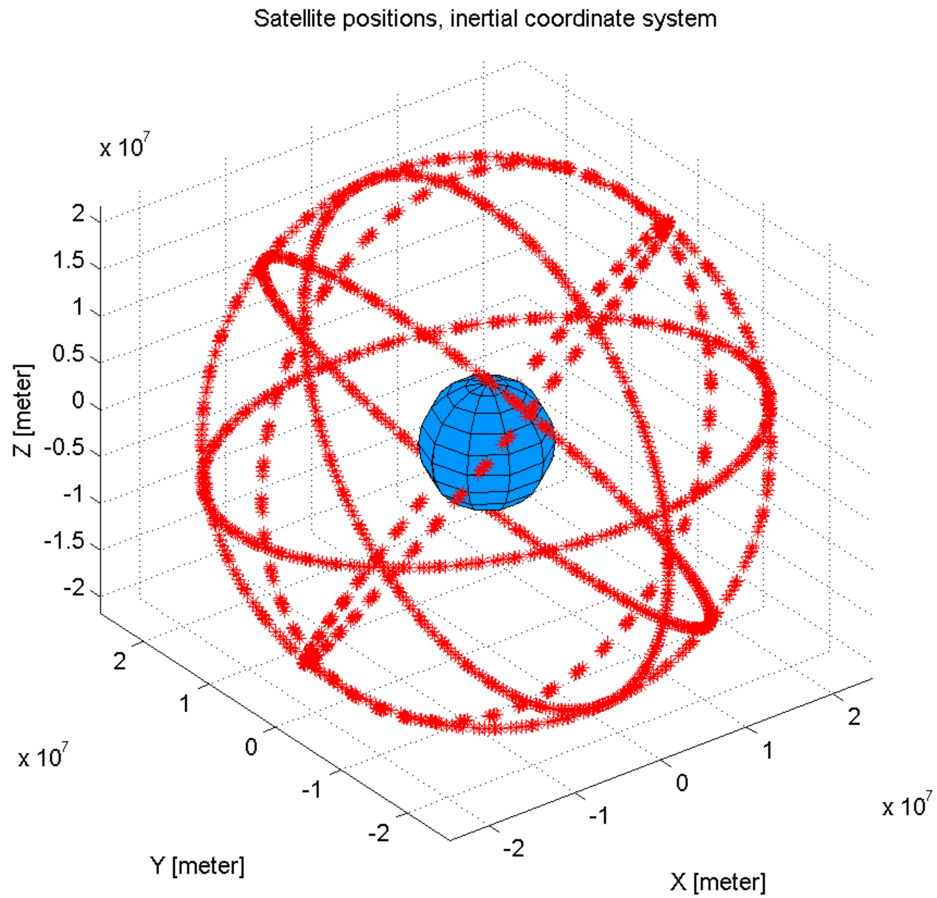


Typical Ground Tracks (After Santerre, 1989)

20 000 km above the surface of the Earth

Speed ~ 4 km/s
=> period: 11 hours and 58 minutes

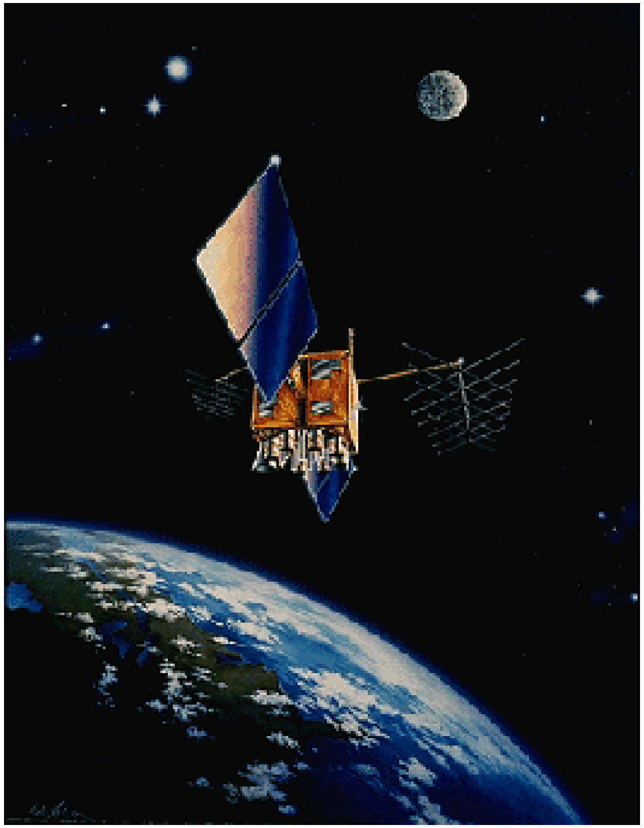
GPS orbits - simulation



GPS satellites

Rubidium and Cesium atomic clocks for precise timing

Transmits binary codes and electromagnetic waves



Solar panels primary source of energy

Block IIF satellites have expected life time of 12 years

Picture from U.S. Naval Observatory

GPS control segment (or ground segment)

The control stations monitor the condition and location of the satellites, collect transmitted data, compute orbit parameters, and clock corrections

Upload data
to the satellites

Operated by the US Department of Defence

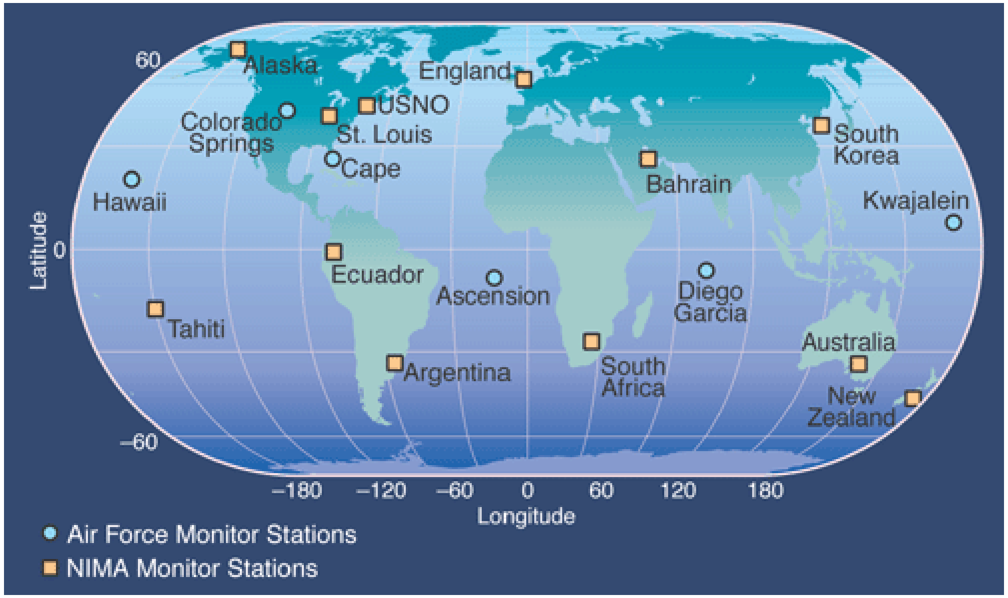


Figure from: The Aerospace Cooperation

GNSS user segment

Military and civil users

Equipment:

- Antenna
- Receiver
- Power

Equipment prices range between 500 and 200.000 SEK

High correlation between price and obtainable accuracy

GPS satellite signals - frequencies

L1: 1575.42 MHz

- Wave length: 19 cm
- Protected frequency

L2: 1227.60 MHz

- Wave length: 24 cm

L5: 1176.45 MHz

- Wave length: 25 cm
- Realized with new block IIF satellites since 2010

GPS PRN codes

- PRN codes:
  - C/A code (Coarse Acquisition)

  - P code (Precision)
    Is encrypted. The encrypted
    code, called the Y-code,
    is transmitted

  - New civil code on L2, called L2C
    Realized with block IIR-M satellites from 2005
  - M-code, new military code on L1 and L2

- Navigation message

GNSS signals – current and planned

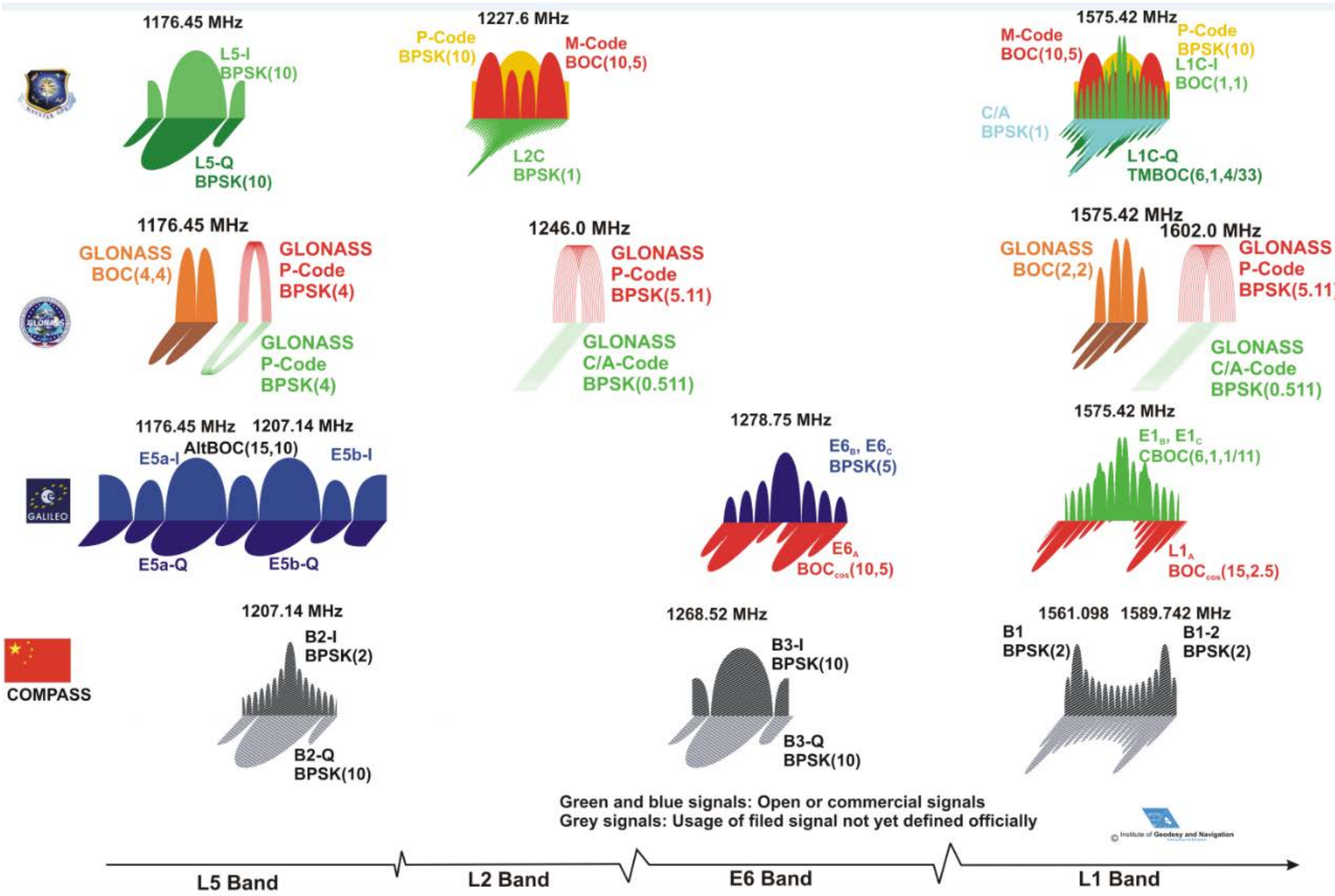


Figure from Navipedia.net

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Error sources

Generated errors - GPS:

- AS (Anti Spoofing): Encryption of P code
- SA (Selective Availability): Errors in navigation message Deactivated since May 2000

Natural error sources - GNSS:

- Effects on the signal in the atmosphere
- Uncertainty in information in navigation message
- Multipath (signal reflection)
- Interference and jamming (intentional or un-intentional)

Equipment related error sources – GNSS:

- Receiver noise, clock errors, antenna phase center variations etc.

Positioning – basic principle

The receiver determines the distance to the satellites based on received satellite signals and the signal travel time. The distance is called a pseudorange

Pseudorange = speed * transmission time

The pseudoranges and the known positions of the satellites are used to determine the position of the receiver (X, Y, Z) and the receiver clock error

At least 4 pseudoranges are required for a 3D position

Positioning – basic principle

Pseudorange = c · (transmission time + clock error)
= geometric range + c · clock error

$$R = \rho + c \cdot \Delta\delta$$

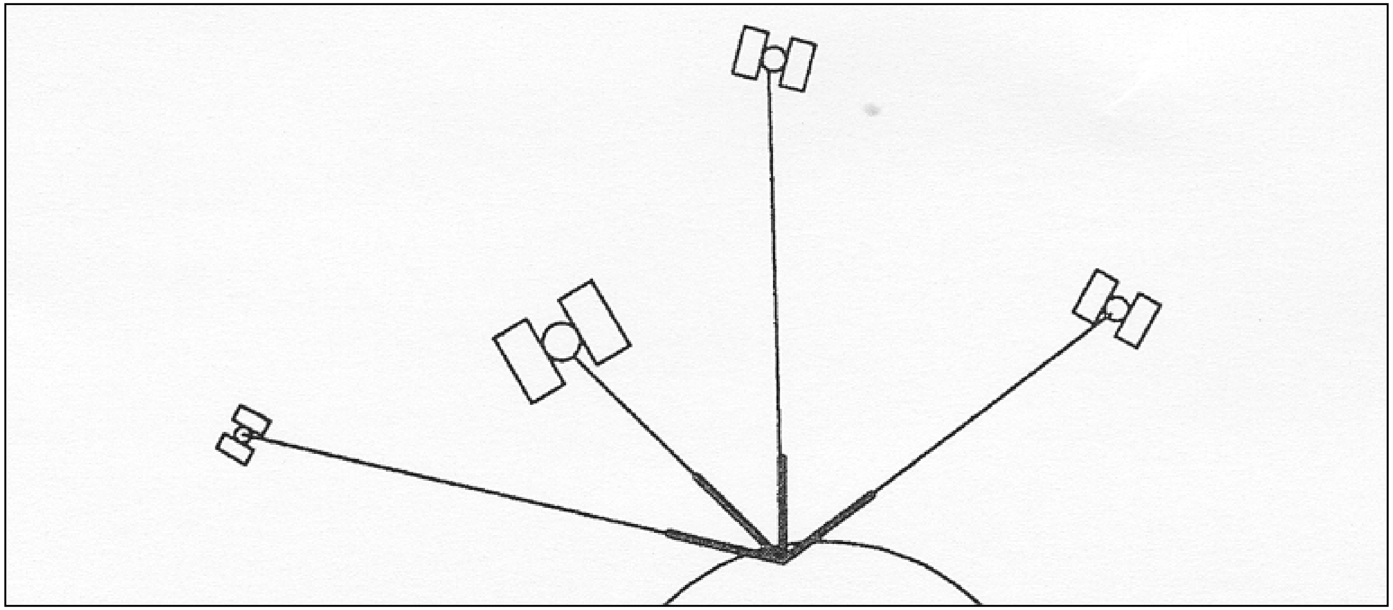

Figure: ”GPS” by Dueholm, Laurentzius, and Jensen, Nyt Teknisk Forlag, 2005

Positioning – basic principle

Observation equation:

$$R_r^s = \rho_r^s + c \cdot \Delta\delta_r = \sqrt{(X_r - X^s)^2 + (Y_r - Y^s)^2 + (Z_r - Z^s)^2} + c \cdot \Delta\delta_r$$

Where:

R_r^s	measured pseudorange between satellite, s and receiver, r
ρ_r^s	geometric distance between satellite and receiver
X_r, Y_r, Z_r	unknown coordinates of the receiver
X^s, Y^s, Z^s	known coordinates of the satellite
c	speed of light
$\Delta\delta_r$	GPS receiver clock error

We have four unknown in the equation, so it can be solved with 4 observations

Positioning – basic principle

Four equations and four unknown

$$R_r^I = \sqrt{(X_r - X^I)^2 + (Y_r - Y^I)^2 + (Z_r - Z^I)^2} + c \cdot \Delta\delta_r$$

$$R_r^{II} = \sqrt{(X_r - X^{II})^2 + (Y_r - Y^{II})^2 + (Z_r - Z^{II})^2} + c \cdot \Delta\delta_r$$

$$R_r^{III} = \sqrt{(X_r - X^{III})^2 + (Y_r - Y^{III})^2 + (Z_r - Z^{III})^2} + c \cdot \Delta\delta_r$$

$$R_r^{IV} = \sqrt{(X_r - X^{IV})^2 + (Y_r - Y^{IV})^2 + (Z_r - Z^{IV})^2} + c \cdot \Delta\delta_r$$

Normally observations to more than 4 satellites are available and mathematical methods for adjustment and error estimation can provide better position accuracies

GPS code based positioning

Transmission time determined with C/A code

Transmission time converted to pseudorange with accuracy at about 0.3 – 3 meter

Pseudorange corrected for atmospheric effects using models, and satellite clock error is corrected using corrections from navigation message

Position determined based on at least 4 pseudo-ranges

Position accuracy: 3 – 10 meter

Carrier phase based positioning

Preliminary position from code observations

Distance from satellite to receiver is determined
as the full number of cycles + the last fraction of a cycle

The last fraction of a cycle (the phase) is measured continuously by the receiver with an accuracy better than 1% of the wavelength ~ 2 mm

Models are used for correction of atmospheric effects and satellite clock error

The number of full cycles (the ambiguity) is determined using more advanced mathematical methods

Obtainable position accuracy: < 1 cm

GNSS based positioning

GNSS positions can be determined with data from:

- Code observations only
  - More simple, faster, smaller and cheaper units
- Code and phase observations
  - More robust, better accuracy, but larger and more expensive units
- One frequency (L1 only)
  - More simple, faster, smaller and cheaper units
- Multiple frequencies
  - More robust, better accuracy, but larger and more expensive units
- GPS only
- GPS + GLONASS
- Other combinations of GNSS

=> Multi constellation multi frequency

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- ✓ GNSS
- ✓ Space, control and user segment – more tomorrow
- ✓ Frequencies and signals – more tomorrow
- ✓ Error sources – more on Wednesday and Thursday
- ✓ Basic principle for GNSS positioning – more tomorrow
- ✓ Code and phase observations – more tomorrow
- Reference frame and geoid model – more tomorrow
- GNSS applications

Reference system

GNSS positioning is carried out in the reference system used for the satellite coordinates and clocks (absolute), or for the reference station coordinates (relative)

Positions given as:

- X, Y, Z
- Latitude, longitude, ellipsoid height

Coordinates can be converted, or transformed, to map projection or another reference system

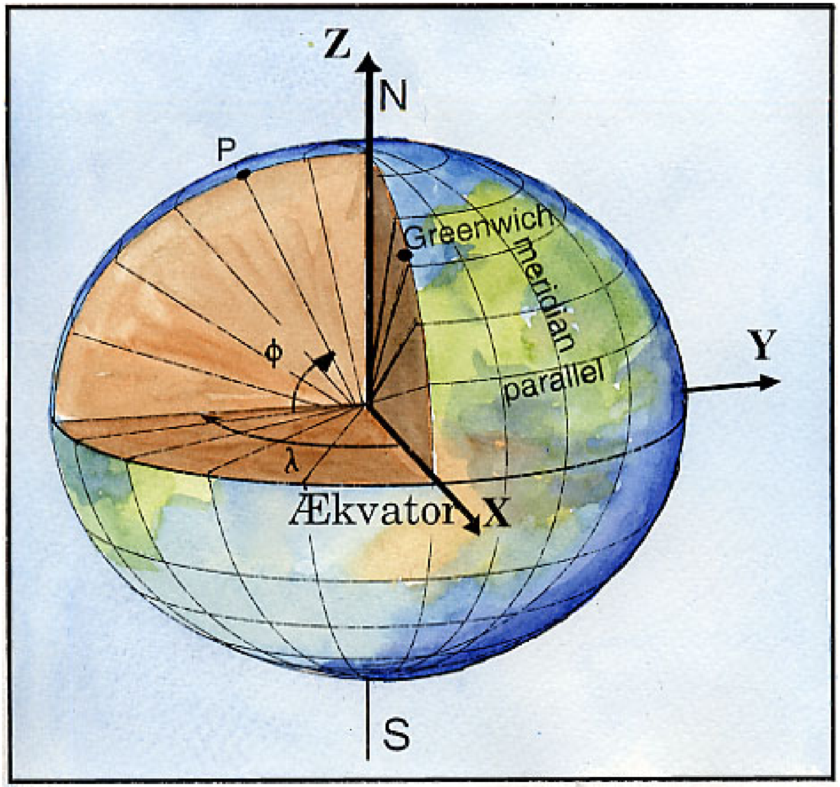

Figure from ”Bogen om GIS og Geodata”, Balstrøm, Jacobi, Bodum. 2006 – with permission

Reference frame

- Realization of a reference system
- Realisation of the ITRS (International Terrestrial Reference System):
  - ITRF, latest realization ITRF2014
- Realisation of the ETRS (European Terrestrial Reference System):
  - ETRF, latest realization ETRF2000
- National realizations – e.g. SWEREF, REFDK etc.

Geoid model

Given:

Heights determined with GNSS are relative to a reference ellipsoid

Wanted:

Heights relative to national or local height system e.g. mean sea level

Needed:

Adapted geoid model for the conversion, often simplified

as $h = H + N$

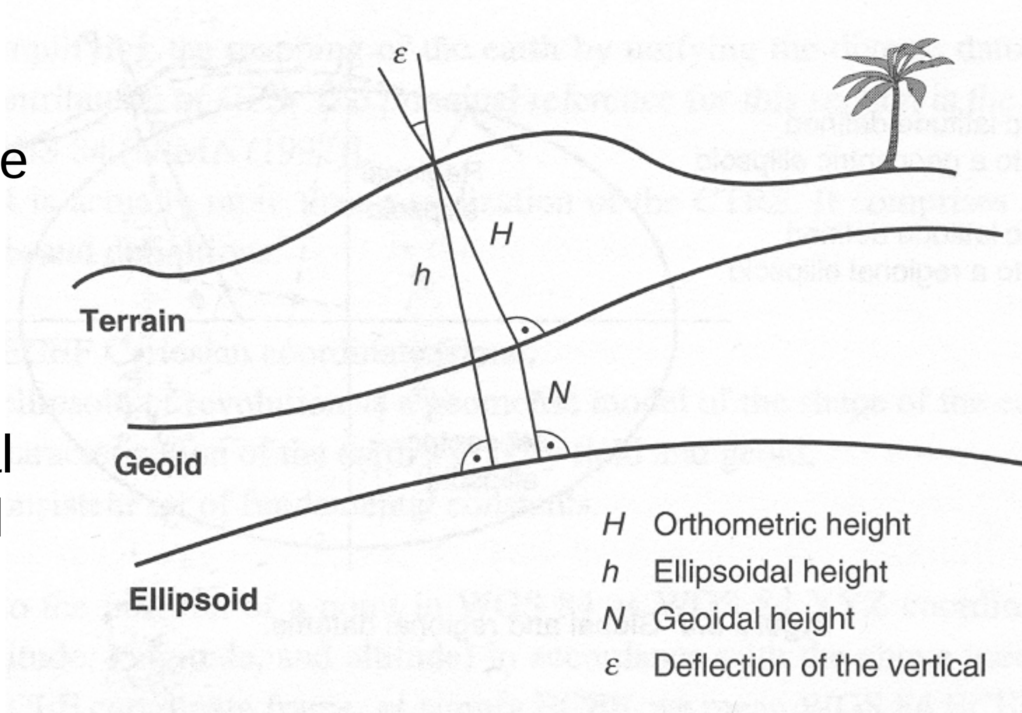

Fig. 3.5 from “Global Positioning System” by Misra and Enge, 2001

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Conventional GNSS positioning

GNSS in mobile phones

Might be assisted with other information; this is called A-GNSS

Personal services

Where is the closest bar, how do I get there, and when is happy hour?

Photos from www.apple.com and www.samsung.dk

Vehicle navigation and fleet management

Car navigation

- Units composed of GPS, digital map and real time traffic information from external source
- Used by private and professionals

Fleet management and logistics

- Car navigation system connected via data link to the order, storage and/or management systems of the company
- Used by for instance:
  - Taxi companies, ambulance service providers etc.
  - Shipping and transportation companies like UPS, DSV etc.

Illustration from firmabilen.dk

Air navigation

GPS is being used for more and more phases of flight. Augmentation is needed to enhance safety.

Accuracy required: from meter en route, to cm at landing

Supplemented by integrity information

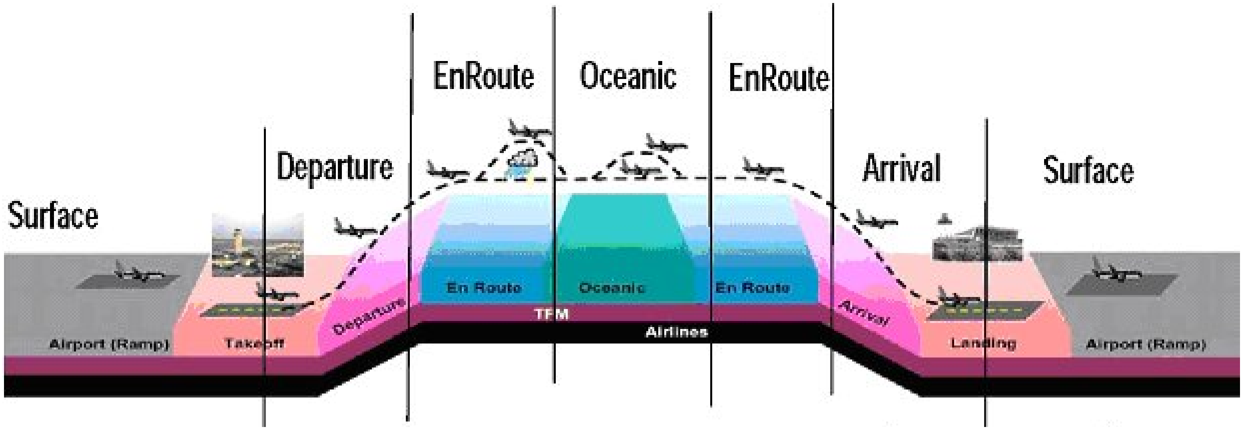


Figure from: atc-network.com

Land surveying

Requirement: Position accuracy at the 1–10 cm level

Use of so-called RTK technique (Real Time Kinematic)

Same technique used for precision farming, machine guidance in construction work, open mining etc.

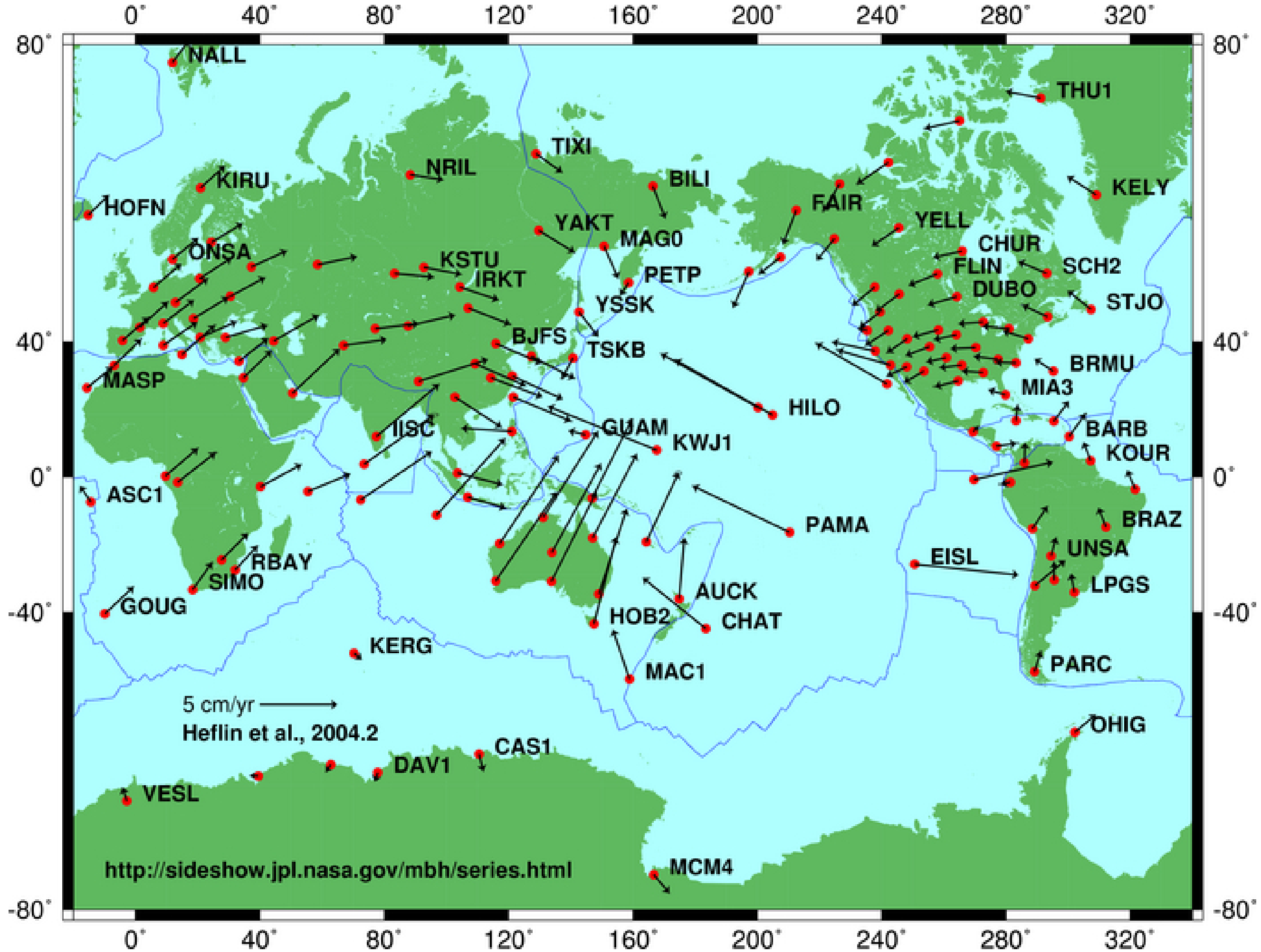
Figure: http://ciscokidz.com/index.htm

Sports and training

The RTK-technique is also used for performance optimization of high level athletes

Figure: www.gpsworld.com

Geodynamics – crustal movements



GNSS positioning techniques, by accuracy

Real time

- Absolute code positioning, 5 - 10 meter
- DGNSS, code, relative positioning, 1 – 5 meter
- RTK, phase, relative positioning, 1 - 5 cm
- PPP, phase, non-relative positioning, 1 - 10 cm

Post processing

- Kinematic, phase, 1 – 10 cm
- Static, phase, < 1 cm

Military use of GNSS

GNSS is a very important tool in the modern high tech. warfare

GNSS is for instance used for military navigation, missile guidance, and communication

www.softwar.net

Non-positioning applications of GNSS

Surveillance of activity in the ionosphere

Modeling of water vapor content in the atmosphere

=> improved weather predictions

Timing and time tagging