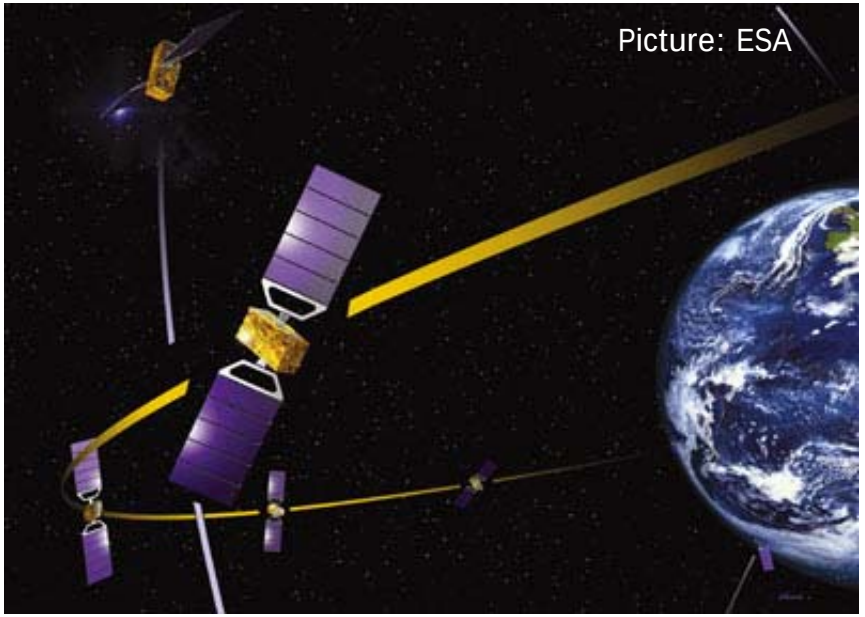
# Satellite Navigation (and positioning)




**AE4E08**

**Instructors:**
**Sandra Verhagen, Hans van der Marel, Christian Tiberius**

**Course 2010 – 2011, lecture 1**

TU Delft
Delft University of Technology

# Today's topics

- Course organisation
- Course contents
- Introduction navigation and positioning
  - History and principles
  - Radionavigation methods and systems
  - Applications

# Course organisation

Instructors:

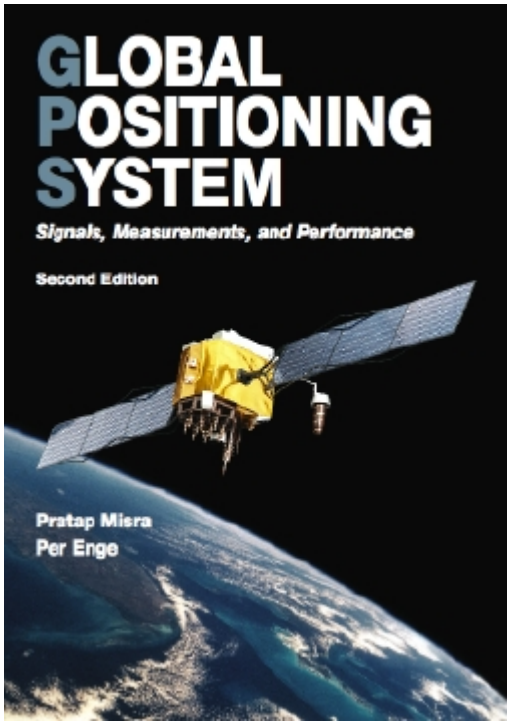
- Sandra Verhagen (a.a.verhagen@tudelft.nl)
- Hans van der Marel (h.vandermarel@…)
- Christian Tiberius (c.c.j.m.tiberius@…)

# Course organisation

- Period 2 + 3
- 1 lecture per week (2h)
- Computer exercises
- Final part: Space and Geomatics track!
- Assessment:
  - graded assignments (report / presentation)
  - Assignments (pass / fail)
  - written exam

# Course organisation

- Book:
  *Global Positioning System, Signals, Measurements, and Performance*, 2nd edition, Pratap Misra and Per Enge
  http://www.gpstextbook.com




- Blackboard:
  - slides
  - assignments
  - schedule and course info
  - links, glossary
  - graduation topics

# Course contents

1. Technical principles
   - space, control and user segments
   - satellite ephemeris and reference systems
   - signals, clocks and receivers
   - propagation errors

# Course contents

2. Positioning and integrity
   - observation equations
   - parameter estimation in dynamic environments
   - integrity

3. High-precision GNSS
   - relative positioning and Precise Point Positioning
   - permanent networks

# Course contents

4a. **Geomatics track**: RTK services, Location Based Services, surveying and mapping, civil engineering applications

**or**

4b. **Space track**: space based GNSS for navigation, control and guidance of space missions, formation flying, attitude determination

# Navigation and positioning

# History

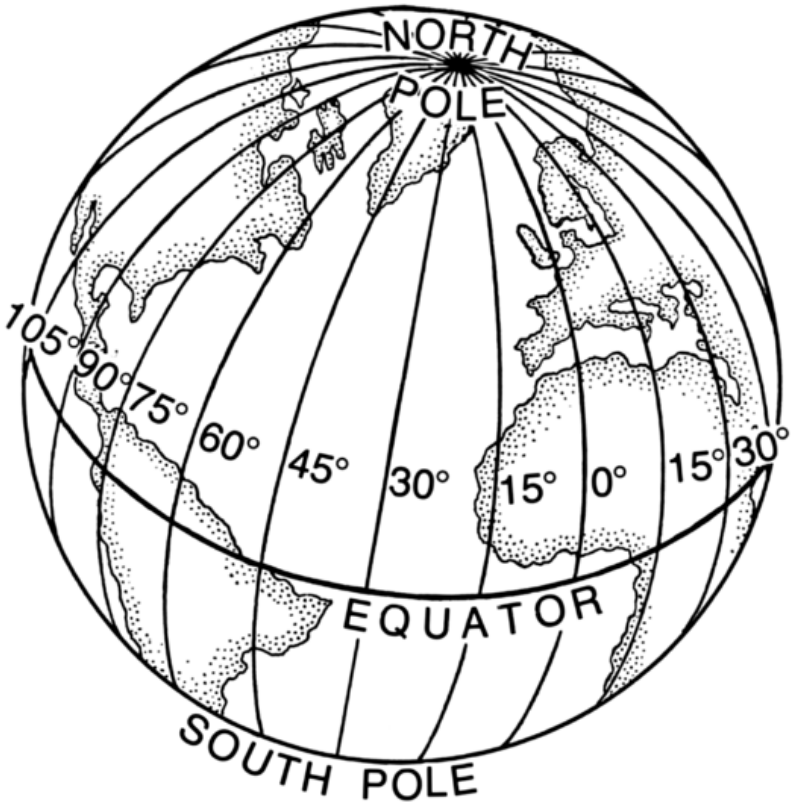
- **Magellan (1519)**:
  sea charts, terrestrial globe,
  wooden and metal theodolites,
  quadrants, compasses,
  magnetic needles, hour glasses, ...

→ speed, direction, latitude

# History

- **Harrison (~1730)**:
  invented marine chronometer

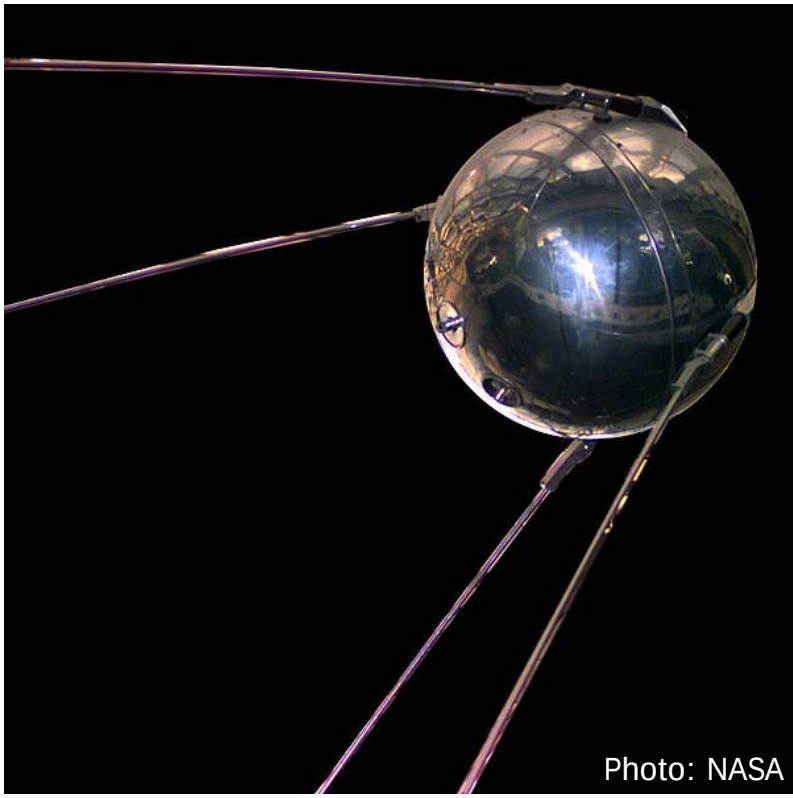
→ longitude!



# History

## Sputnik

- apogee 1450 km, perigee 223 km
- 29,000 km/h
- orbital period ~100 minutes
- radio signals: 20.005 and 40.002 MHz
- monitored by amateur radio operators throughout world



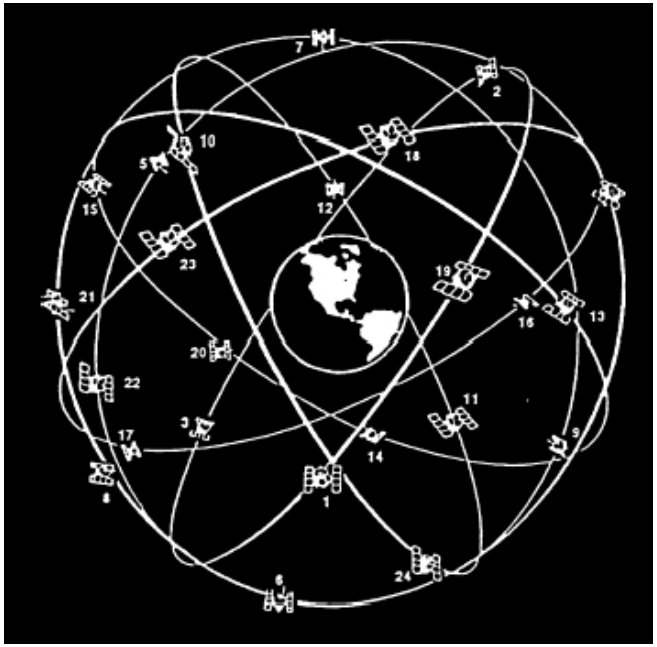

Discovery: observed Doppler shift can be used for positioning!!!

# History

## Global Positioning System (1995)

→ 3D position, velocity and time

- accurate
- instantaneous
- continuous
- everywhere (Earth, air, space)
- inexpensive
- effortless
- in all weather circumstances



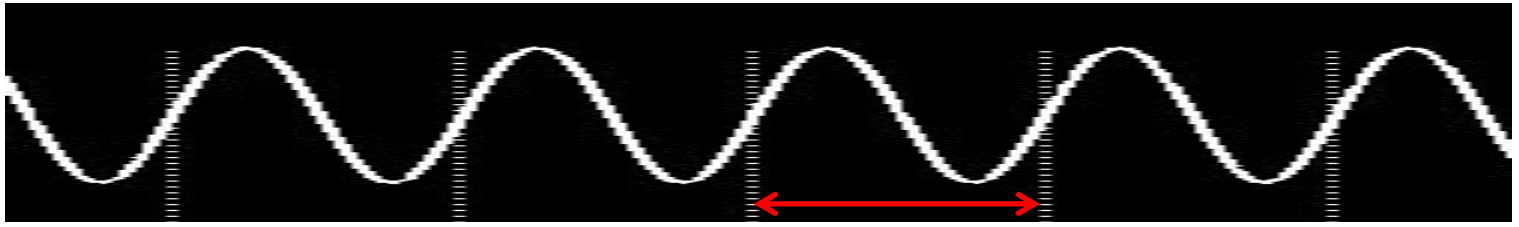
# Navigation principles

- **Dead reckoning**:
  - keep track of direction and distance
  - inertial navigation systems (INS), microelectromechanical systems (MEMS)
- **Guidance systems**:
  - provide course to steer
  - lighthouses, radio beacons, Instrument Landing System and Microwave Landing System, heat sensors
- **Position finding systems**:
  - Loran, Omega, Transit, GNSS

# Radionavigation – radio waves

- Radio waves: electromagnetic waves with frequencies from 10 kHz – 300 GHz

- Frequency : $f$ [1 Hz = 1 cyc/s]
- Wavelength : $\lambda = c / f$
- Propagation speed : $c = 299,792,458 \approx 3 \times 10^8$ m/s



# Radio navigation – frequency spectrum

| Band | Frequency | Wavelength | Examples |
|---|---|---|---|
| Very Low (VLF) | < 30 kHz | >10 km | Submarine comm. |
| Low (LF) | 30-300 kHz | 1 – 10 km | RFID, time signals |
| Medium (MF) | 300 kHz – 3 MHz | 100 m – 1 km | AM radio |
| High (HF) | 3-30 MHz | 10 – 100 m | Radio, RFID |
| Very High (VHF) | 30-300 MHz | 1 – 10 m | FM radio, TV, aviation, land + maritime mobile |
| Ultra High (UHF) | 300 MHz – 3 GHz | 10 cm – 1 m | TV, microwave ovens, mobile phones, WLAN, Bluetooth, **GNSS** |
| Super High (SHF) | 3-30 GHz | 1 – 10 cm | Radar, WLAN, satellite comm. |
| Extremely High (EHF) | 30-300 GHz | 0.1 – 1 cm | Radio astronomy, radar remote sensing |

# Radionavigation - methods

## Trilateration

Time of Arrival (TOA) measurements

$$r_k = c \cdot t_k$$

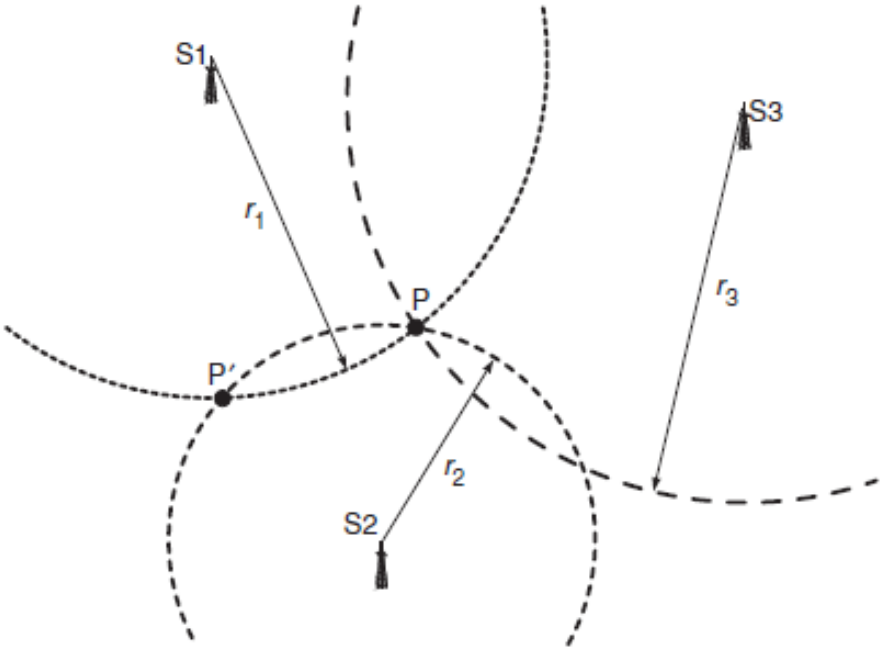



Figure 1.5 Trilateration.

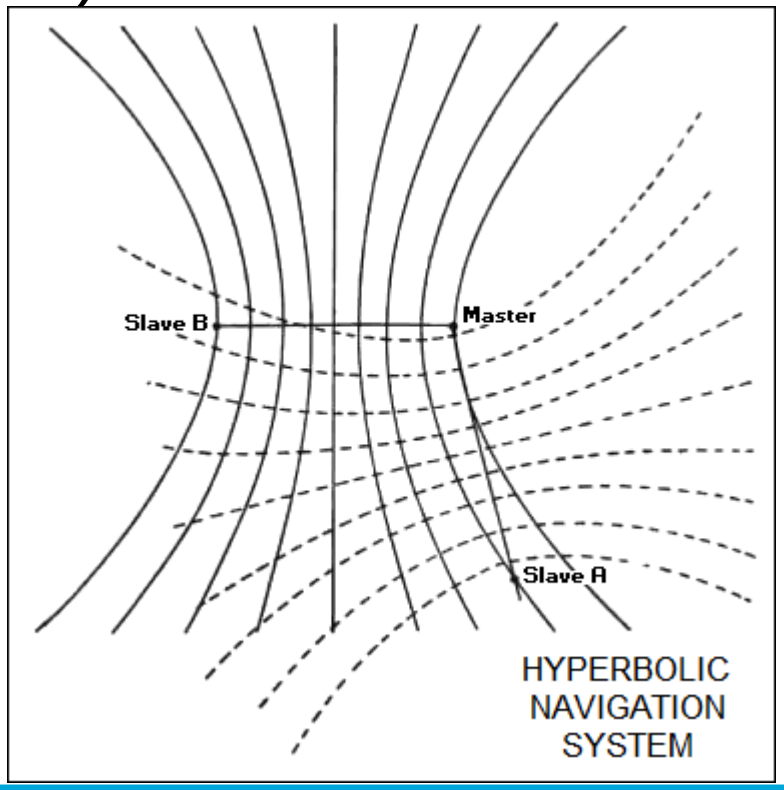
From: Misra and Enge

$$\sqrt{(x_k - x)^2 + (y_k - y)^2} = r_k$$

# Radionavigation - methods

## Hyperbolic positioning

Time Difference of Arrival (TDOA) measurements



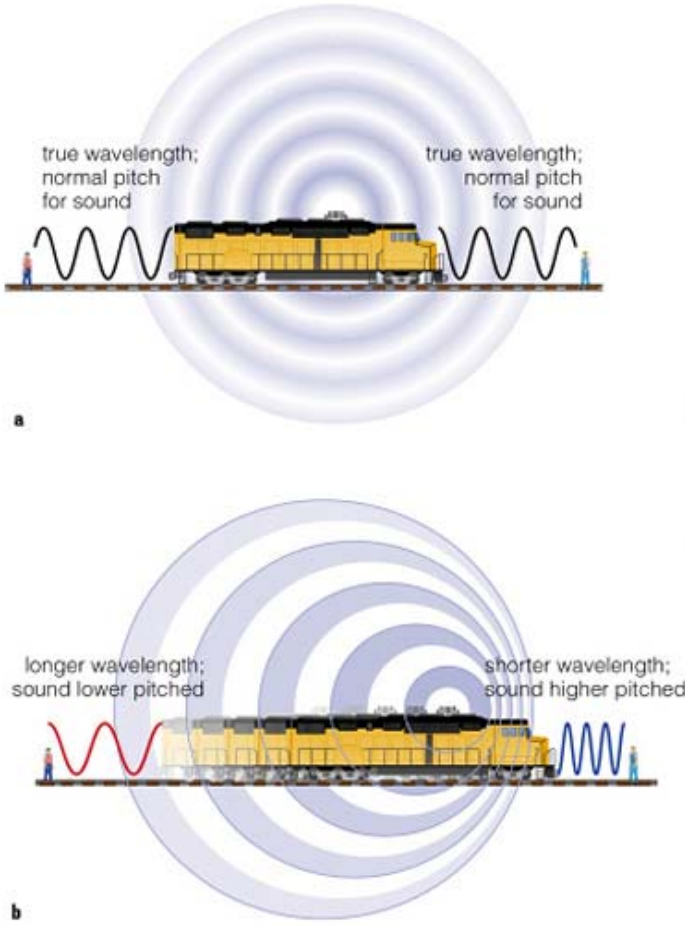
# Radionavigation - methods

## Doppler positioning

Doppler shift measurements:

distance determined based on frequency difference between source and receiver

$$f_R - f_T = -\frac{\dot{r}}{\lambda}$$



# Radionavigation - systems

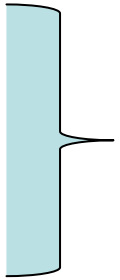
- **Loran** (**Lo**ng-**ra**nge **n**avigation system):
  hyperbolic system developed in World War II, marine navigation

- **Omega**
  early 1960's, worldwide+continuous, 8 ground-based transmitters (VLF band), hyperbolic system (phase differences), marine and civil aviation apps

# Radionavigation - systems

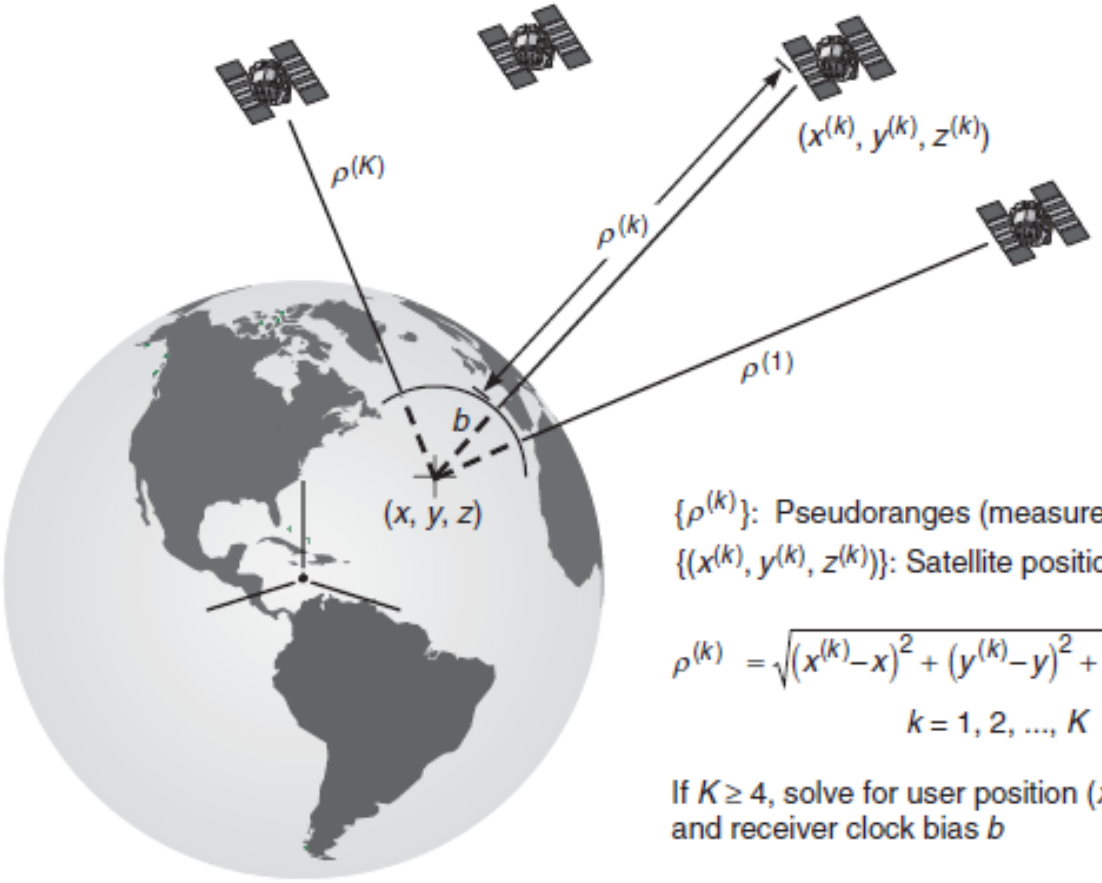
- **Transit** (1964)
  - 4-7 satellites at 1100 km, polar orbits
  - 150 and 400 MHz
  - 1 satellite in view; wait 100 minutes for next satellite pass
  - record Doppler shift + navigation message (satellite position)

- **GPS** (**G**lobal **P**ositioning **S**ystem)
- GLONASS, Galileo, Beidou, ...



**G**lobal
**N**avigation
**S**atellite
**S**ystems
(**GNSS**)

# GNSS – principle




$\{\rho^{(k)}\}$: Pseudoranges (measurements)

$\{(x^{(k)}, y^{(k)}, z^{(k)})\}$: Satellite positions (known)

$$\rho^{(k)} = \sqrt{\left(x^{(k)}-x\right)^2 + \left(y^{(k)}-y\right)^2 + \left(z^{(k)}-z\right)^2} - b$$

$$k = 1, 2, \ldots, K$$

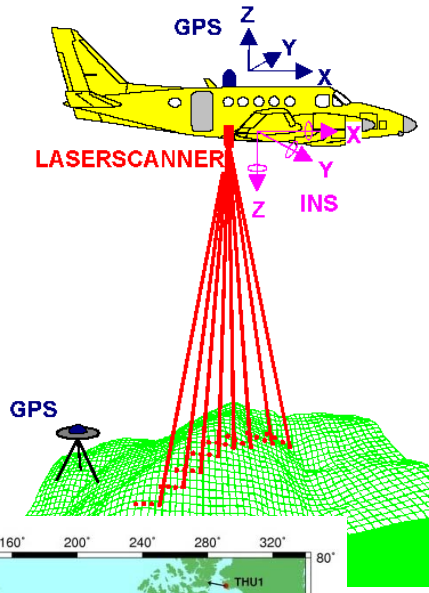
If $K \geq 4$, solve for user position $(x, y, z)$, and receiver clock bias $b$

From: Misra and Enge

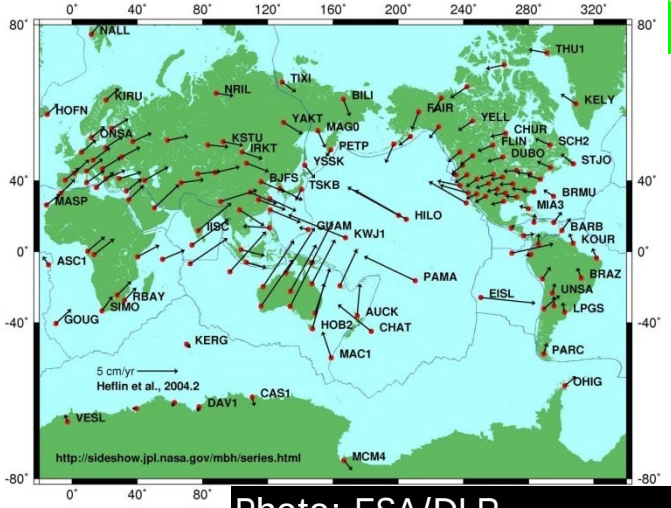
# GNSS – essential technologies

- stable space platforms in predictable orbits
  - → ranges measured to >3 satellites with “known” positions
  - → satellite positions predicted within few meters 1-2 days ahead
- ultra-stable clocks
  - → transmission time imprinted on signal
  - → satellite clocks synchronized
- spread spectrum signaling
  - → each satellite transmits unique signal on same frequency
- integrated circuits
  - → receivers are light, compact, relatively cheap

# Applications






# Applications - land

- geodynamics: plate tectonic, sea level rise (0.01 – 0.1 ppm)
- continental 3D reference frame (0.1 – 1 ppm)
- deformation monitoring (surface / constructions) (1 ppm)
- national control networks (1 – 10 ppm)
- large scale topography (10 – 100 ppm)
- land navigation (10 – 50 m)

# Applications - sea

- hydrographic surveying (0.1 – 10 m)
- marine 3D seismic surveys (1 – 5 m)
- marine gravity surveys (<10 cm/s)
- harbour approach (50 – 100 m)
- navigation in open waters (1 – 5 km)

# Applications - air

- airborne laser profiling (Hor. 1 – 10 m, Vert. 5 – 50 cm)
- aero-triangulation (0.5 – 2 m)
- airborne gravimetry (Hor. 50 m, Vert. 2 m, Vel. 10 cm/s)
- airborne laser bathymetry (Hor. 15 m)
- air transport terminal approach (Hor. 100 – 500 m)
- air transport en route (1 – 5 km)
- aircraft approach and landing (10 – 50 m)

# Applications - space

- precise orbit determination (cm – m)
- orbit determination (10 – 100 m)
- formation flying (cm – m)
- attitude determination (0.1 – 1$^{o)}$

# Homework and outlook

- Assignment 1 on Blackboard:
  - Four GNSSs: characteristics, differences, interoperability
  - Report including REFERENCES (to websites / publications / books)

- Next: GPS overview (chapter 2)