Positioning systems: GNSS

Area **2** – **Technologies**

Lesson **3** – **Positioning Systems**

Sequence ID – **11**

UPM

Co-funded by the Erasmus+ Programme of the European Union

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A2.L3.T1 Positioning systems: GNSS:

Constantino Valero Ubierna, Universidad Politécnica de Madrid, Spain, 0000-0003-4473-3209

Constantino Valero Ubierna, *Positioning systems: GNSS*, © 2020 Author(s), CC BY-SA 4.0 International, DOI 10.36253/978-88-5518-044-3.11, in Marco Vieri (edited by), *SPARKLE - Entrepreneurship for Sustainable Precision Agriculture*, © 2020 Author(s), content CC BY-SA 4.0 International, metadata CC0 1.0 Universal, published by Firenze University Press, ISSN 2704-6095 (online), eISBN 978-88-5518-042-9, DOI 10.36253/978-88-5518-044-3

Positioning systems in Precision Agriculture

SPARKLE

GNSS

Who am I?

Constantino Valero

Assistant Professor

Universidad Politécnica de Madrid

"LPF_Tagralia" research group

@lpf_tagralia

constantino.valero@upm.es

I work and teach on sensorics applied to farm machinery, mechatronics, data analysis, robotics and precision agriculture in general

Table of Contents

Where are we on Earth?

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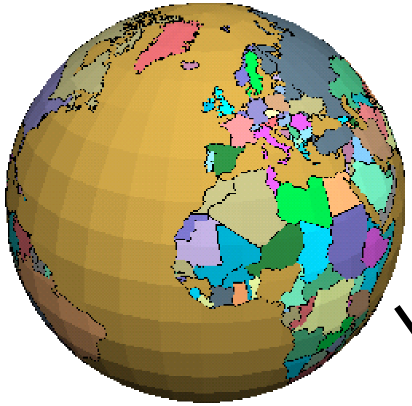
- GNSS (global navigation satellite systems) devices give you Latitude, Longitude and Elevation (3D)

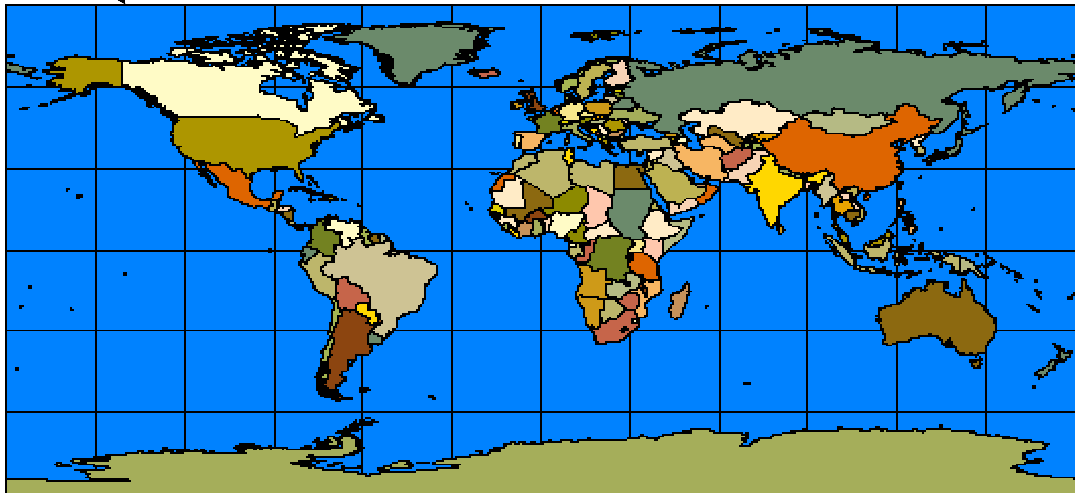
- But technicians work with maps (2D)

➢ We need to work with coordinate systems and conversions

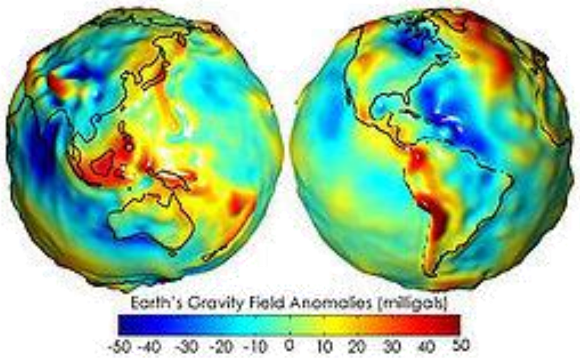
Geographical coordinates

Angular deviations from the Equator and Greenwich Meridian

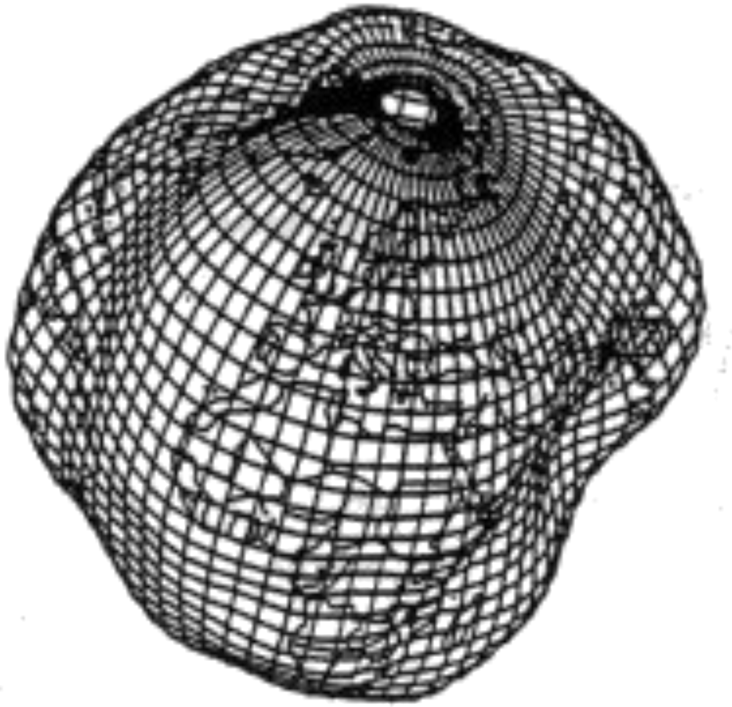




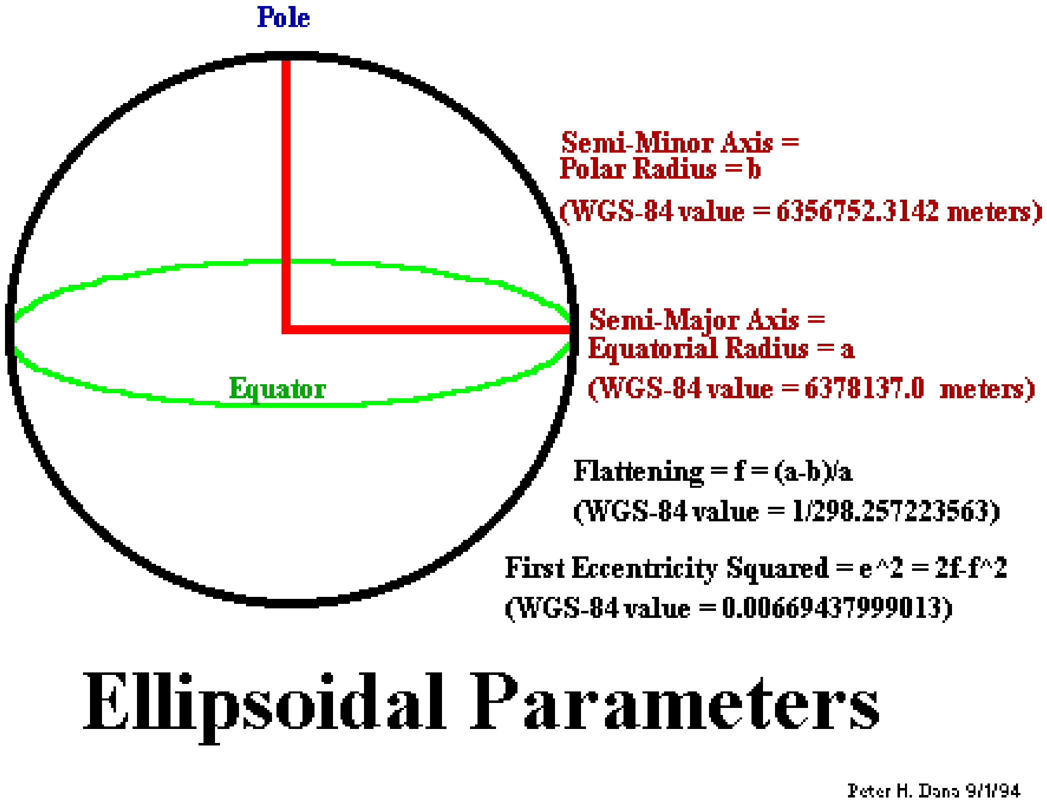
Earth's shape



- The real shape: Geoid

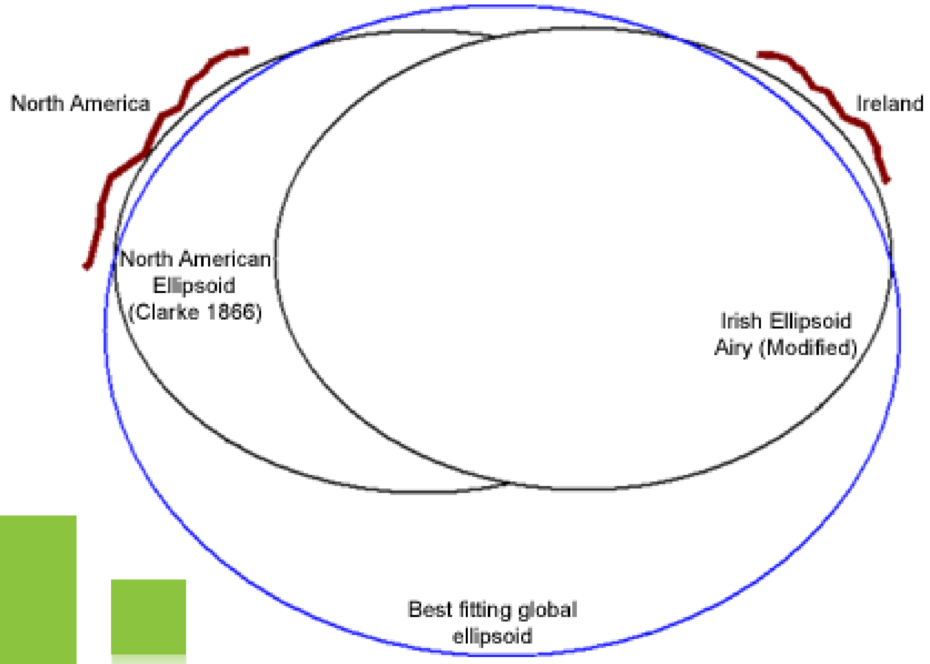


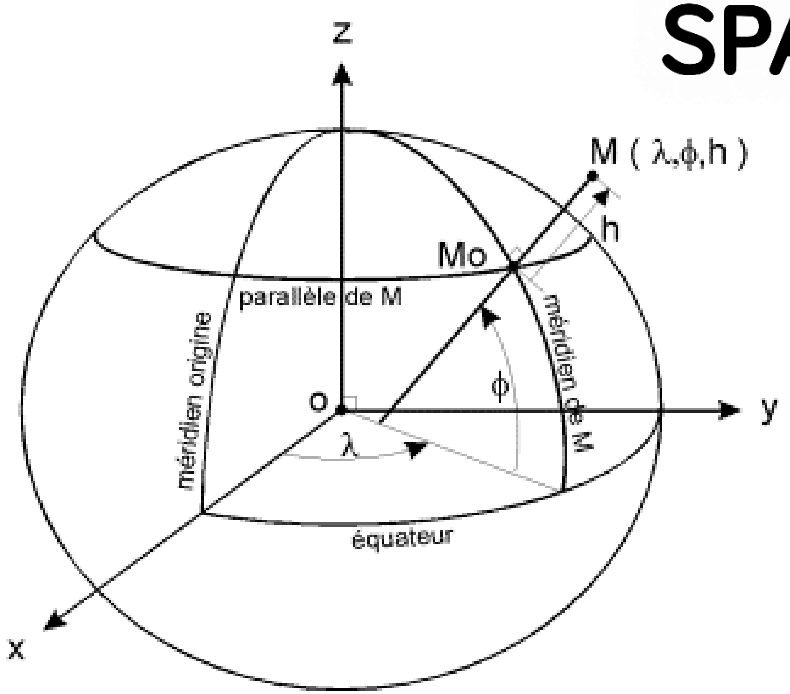
- The approximation: ellipsoid



What is a Datum?

- AKA “Terrestrial Reference System” (TRS)
- It is a combination of an ellipsoid with a 3D Coordinate System (Cartesian) to fit the Earth’s surface

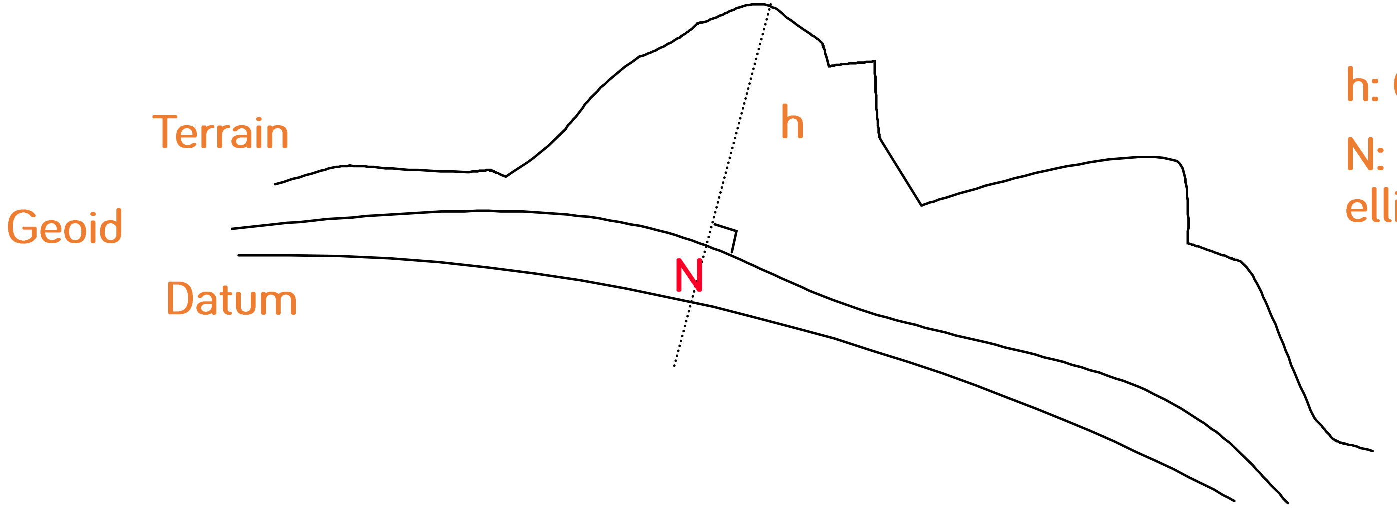




- Datums may be global (i.e. **WGS84** for the World) or local (i.e. ED50 & ETRS89 for Europe)
- Check your GPS device to see the datum at the Setup

Geoid, Separation from the Ellipsoid & Geoidal Models

- The geoid is **not** an even surface



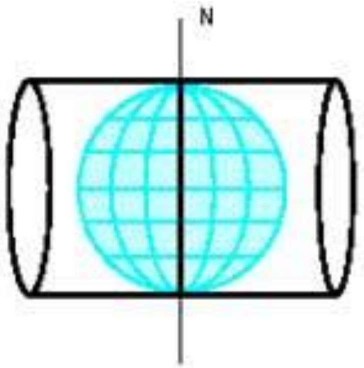
h: Orthometric height

N: Separation Geoid-ellipsoid

- The N (height) accuracy of a geoidal model is enough within a certain area
- GNSS altitude has the highest error

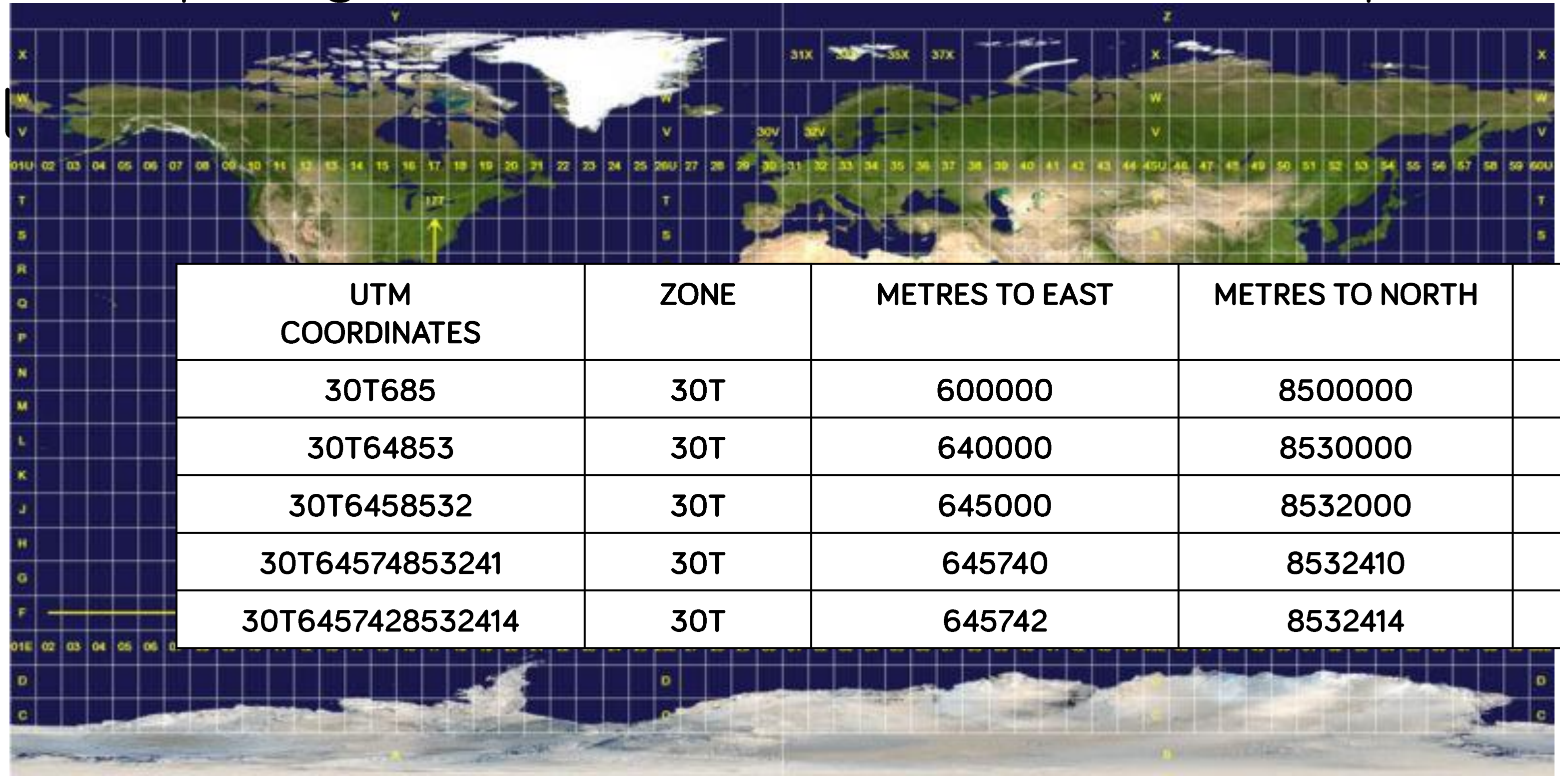
What is a projection?

- Definition: a representation of part of the Earth's surface on a flat surface,
- Or: a method to represent a 3D surface on a 2D surface
- UTM (Universal Transverse Mercator):
  - projection of Earth's surface on a cylinder
  - widely used in Agriculture



UTM Coordinates

- Earth is divided in:
  - E – W: 60 latitude zones (6º) (named 1 to 60)
  - N – S: 20 bands (8º) (named C to W)
  - The meridian passing over the center of each band crosses the Equator at x=500.000m y=0m
- Exampl



UTM COORDINATES	ZONE	METRES TO EAST	METRES TO NORTH	PRECISION m^2
30T685	30T	600000	8500000	100000
30T64853	30T	640000	8530000	10000
30T6458532	30T	645000	8532000	1000
30T64574853241	30T	645740	8532410	10
30T6457428532414	30T	645742	8532414	1

UTM Coordinates

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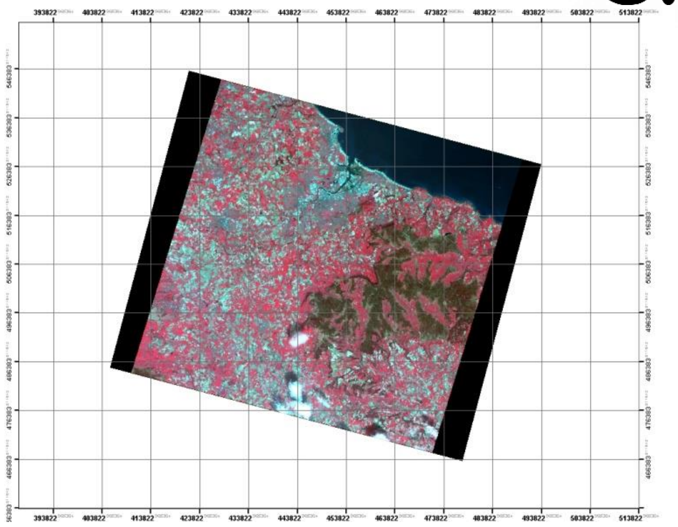
  - N – S: 20 bands (8º) (named C to W)
  - The meridian passing over the center of each band crosses the Equator at x=500.000m y=0m
- Example: all UTM coordinates in the next table indicate the same place, with increasing level of accuracy:

UTM COORDINATES	ZONE	METRES TO EAST	METRES TO NORTH	PRECISION m^2
30T685	30T	600000	8500000	100000
30T64853	30T	640000	8530000	10000
30T6458532	30T	645000	8532000	1000
30T64574853241	30T	645740	8532410	10
30T6457428532414	30T	645742	8532414	1

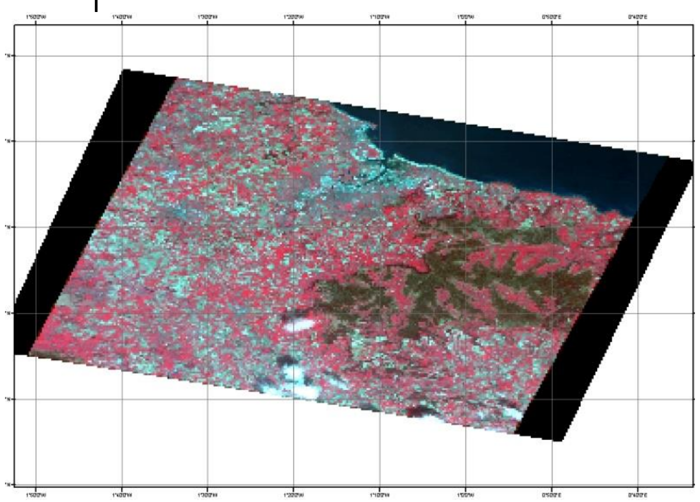
Use the Datum and Projection correctly!

- If datum is not correct in the setup of your device, your maps will contain errors
- Not all deformations can be corrected afterwards!

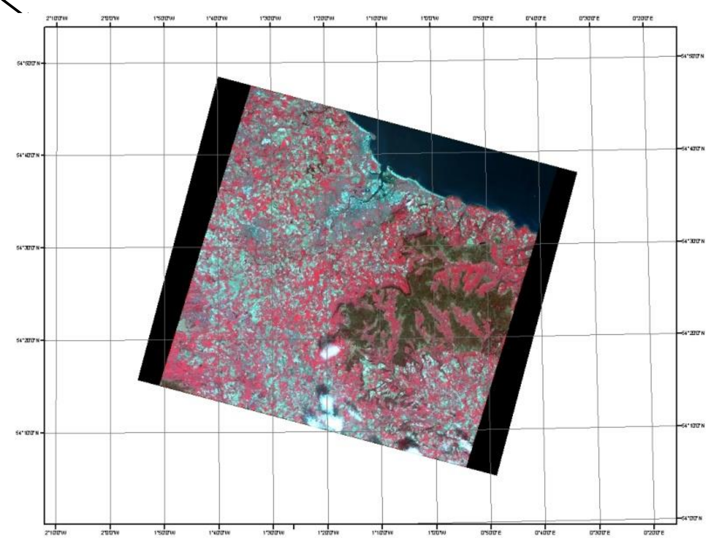
OSGB System
1:500000 scale
10 km grid



Geographic System
1:500000 scale
10 minute graticule



OSGB System
1:500000 scale
10 minute graticule



Global navigation satellite systems (GNSS)

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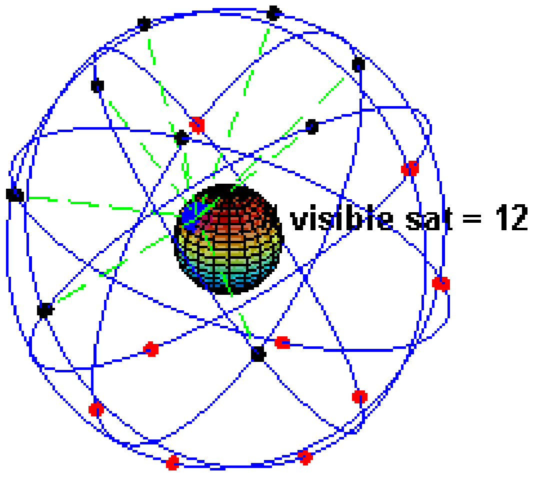
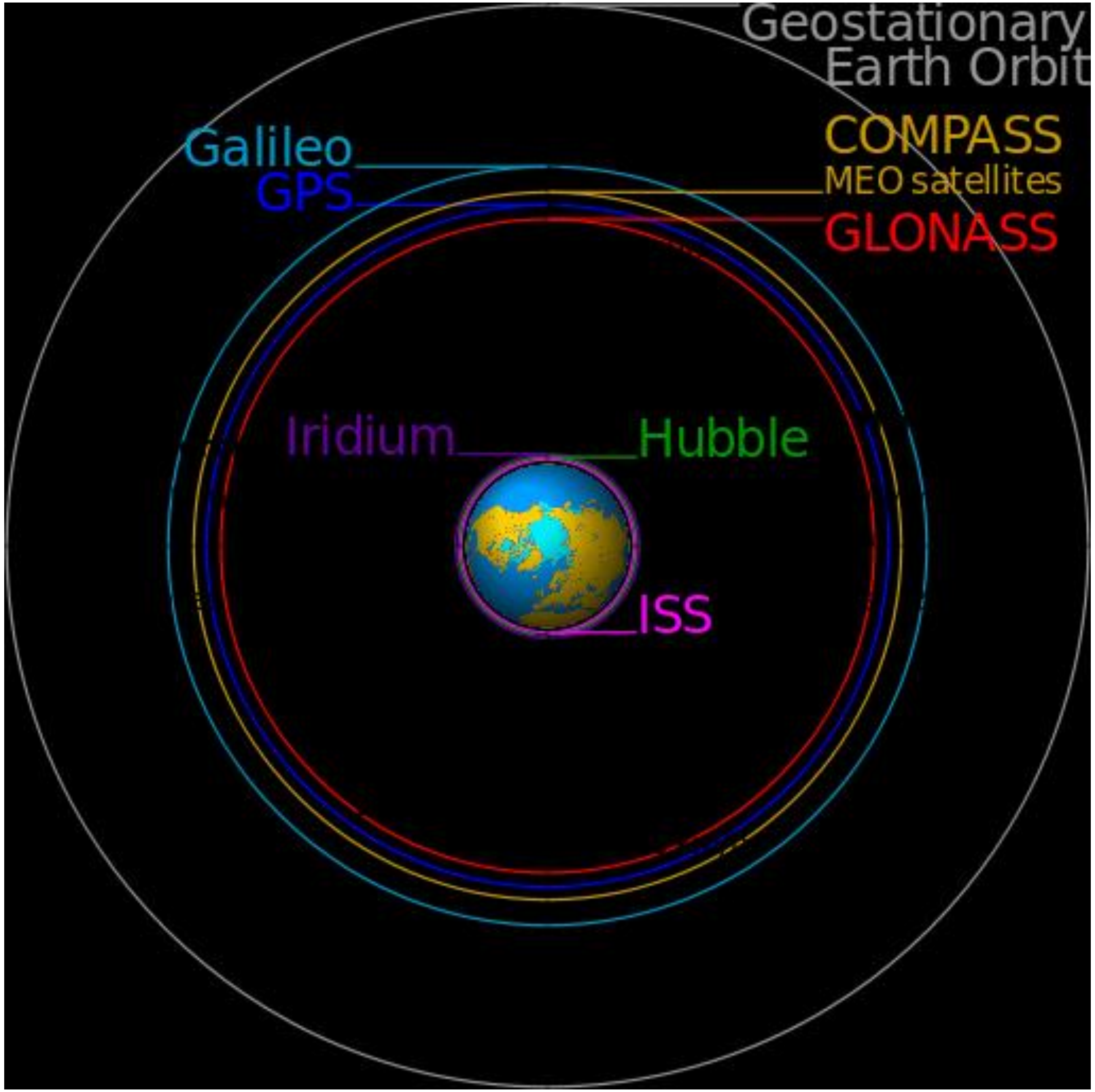
- Constellations of satellites around orbits
- Normally called “GPS systems”
- Provide your position on Earth, using triangulation
- Organized in “Segments”:
  - Aerial: the satellites themselves
  - Control: terrestrial control stations
  - User: you with your device
- Many applications: military & civil

Active Constellations

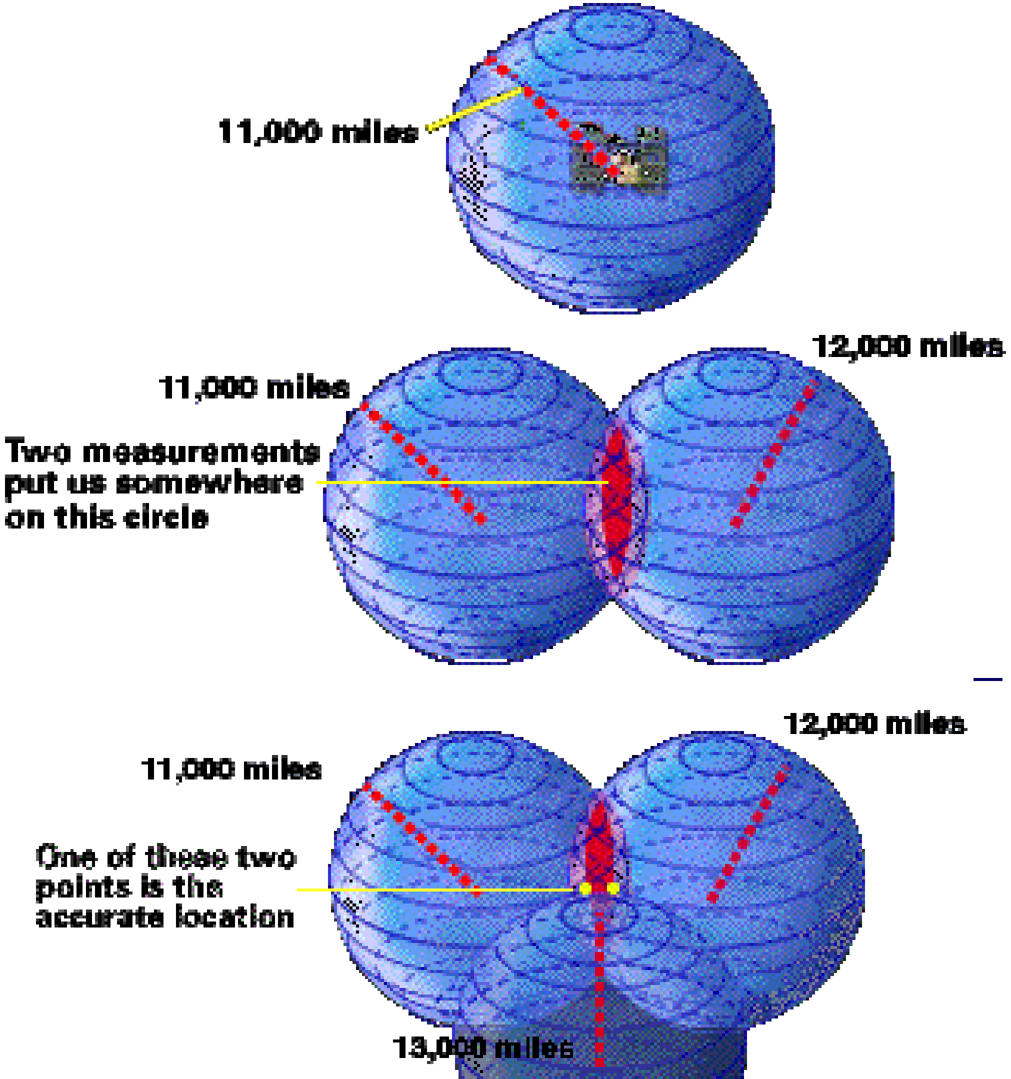
- Constellation “GPS”:
  - USA Defense Dept.
  - 1978-1992: real name “NAVSTAR” (NAVigation System and Ranging)
  - 26 satellites, 6 orbits
  - In process of renewal (GPS2→2012; GPS3→2017)
- Constellation “GLONASS” (*GLObal'naya NAvigatsionnaya Sputnikovaya Sistema*):
  - Russia
  - 1985-2004-2011
  - 24 satellites (renewed: GLONASS-K)
- Constellation “GALILEO”:
  - European Union
  - End: 2020?
  - 30 satellites (Giove 1 y 2; in orbit validation phase =14 sats
- Constellation “Beidou - COMPASS” (China, in development, 2020?)




Geostationary
Earth Orbit
COMPASS
MEO satellites
GLONASS
Galileo
GPS
Iridium
Hubble
ISS

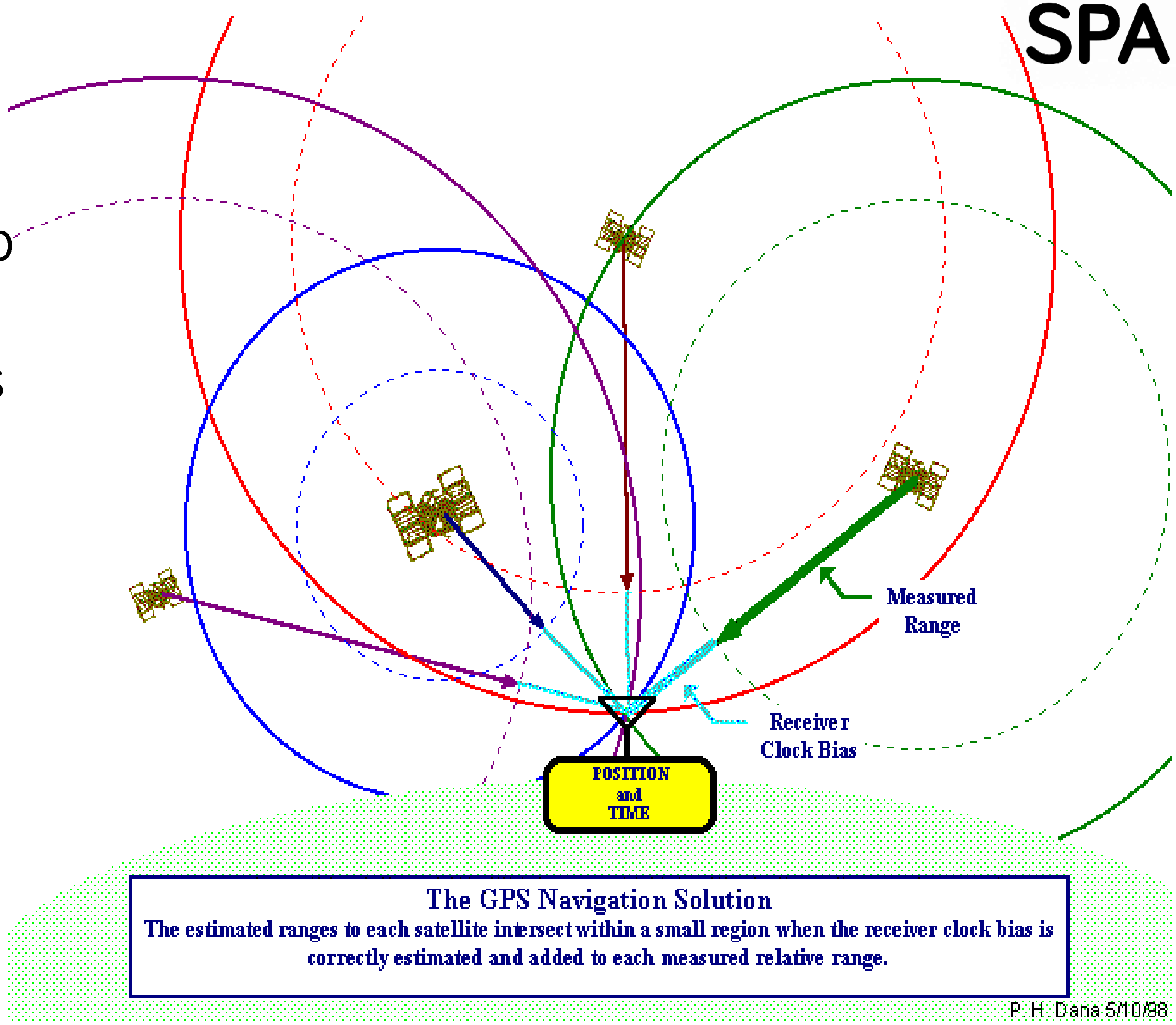
How many satellites are needed to define a point on Earth's surface?

- One satellite defines a sphere
- Two: a circumference
- Three: two points (it is enough, as one point is impossible)



But we need 4 !

Because the clock inside the GPS receptor is not so accurate as the atomic clocks inside the satellites



The GPS signal: physical characteristics

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- Each satellite transmits a signal composed by ‘two’ frequencies & ‘two’ coded messages
  - **L1** (1575.42 MHz)
  - **L2** (1227.6 MHz)
  - L5 (GPS2 y GPS3) = E5a and E5b in Galileo

- *CA* Code *(in L1)*
  - *Coarse acquisition code*
  - Short sequence repeated each millisecond; it is different for each satellite
  - Anyone can receive it and use it
- *P* Code *(in L2)*
  - *Precision code*
  - It is repeated each 267 days and is transmitted by each satellite every 7 days
  - To be able to use it a cryptographic key is needed, only available to the *US Department of Defense (DoD)*
  - “*Selective Availability*” S/A († 2 May 2000)
- New *civil* codes will be used in new satellites *(in L2c & L5…)*

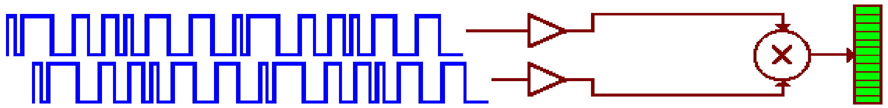
http://www.oreillynet.com/pub/a/wireless/2000/12/08/gps_intro.html

The GPS signal: the information contained

- Satellite global signal is called “pseudo random code” and it is a digital pulse sequence

- The measure of a GPS receiver: the “delay” (Δt) when listening to the signal

Signal sent by satellite
Signal received by receiver



Delay calculated by receiver

- The result of a GPS receiver: Distance to a satellite = “range” = “pseudorange” + “error”

$$D = Dt_{\text{measured}} \cdot c + et \,. \, c$$

(c is the speed of light)

- The “message” emitted by each satellite contains, also:
  - Absolute time
  - Orbital characteristics (ephemerides)
  - Information about the constellation
  - Operational state
  - Atmospheric state estimations

Types of GPS receivers

- In general, three types of GNSS receivers are normally used in Agriculture:
  - GPS antennas: old ones, or when having errors in receiver
  - Differential GPS (DGPS) antennas: most common ones, cheaper
  - RTK antennas: most accurate ones

Types of GPS receivers

But technically there are many types of systems:

According to how many frequencies they can listen to:

- Single frequency (L1), or
- Double frequency (L1 + L2) (or L5…)

According to how many channels (to listen to satellites) they have:

- One channel, multiple channels, multiplexed…

According to how they calculate distance to satellites:

- Based on the message information ("code processing") → "normal receivers" = GPS and DGPS, or
- Based on the signal frequency ("carrier phase processing") → RTK receivers

According to when they apply corrections to calculations:

- Real time, or post processing

The “civil standalone signal” GPS can generate errors up to +/- 10 m. Then…

How to enhance GPS accuracy?

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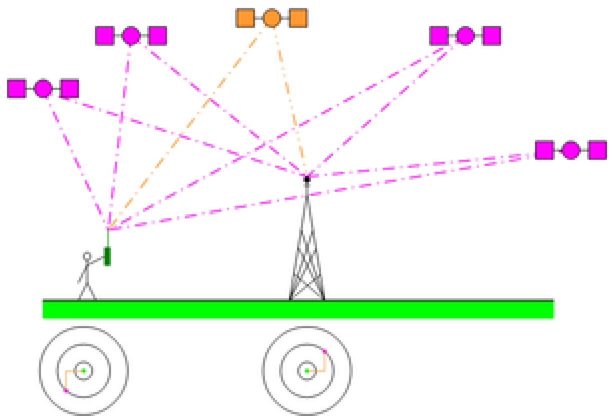
- Using Differential Correction (DGPS): is an additional signal from a **satellite-based augmentation system** (SBAS):
  - additional geostationary satellite private (payment service: Omnistar, JD Starfire, Trimble RTX…)
  - additional geostationary satellite public
  - Some SBAS public systems
    - EGNOS: (European Geostationary Navigation Overlay Service)
    - WAAS (USA)
    - MSAS (Japan)
    - GAGAN (India, project)
    - SNAS (proposed by China)



The “civil standalone signal” GPS can generate errors up to +/- 10 m. Then…

How to enhance GPS accuracy? (2)

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- Using a **Ground-based augmentation system** (GBAS) → Radio signal:
  - Coast wave (*beacons* along the coast for ships)
  - Radio FM-AM (RDS info system) → i.e. National radio stations in Europe
- Using an **RTK** (*real time kinematics*) receiver. Options:
  - Single RTK + base station: using your own terrestrial base station located at your farm, fixed or floating (expensive, maintenance problems, increasing error with distance…)
  - Linked to an “RTK network”
- Post processing: downloading corrections via internet

Types and performance of GNSS receivers

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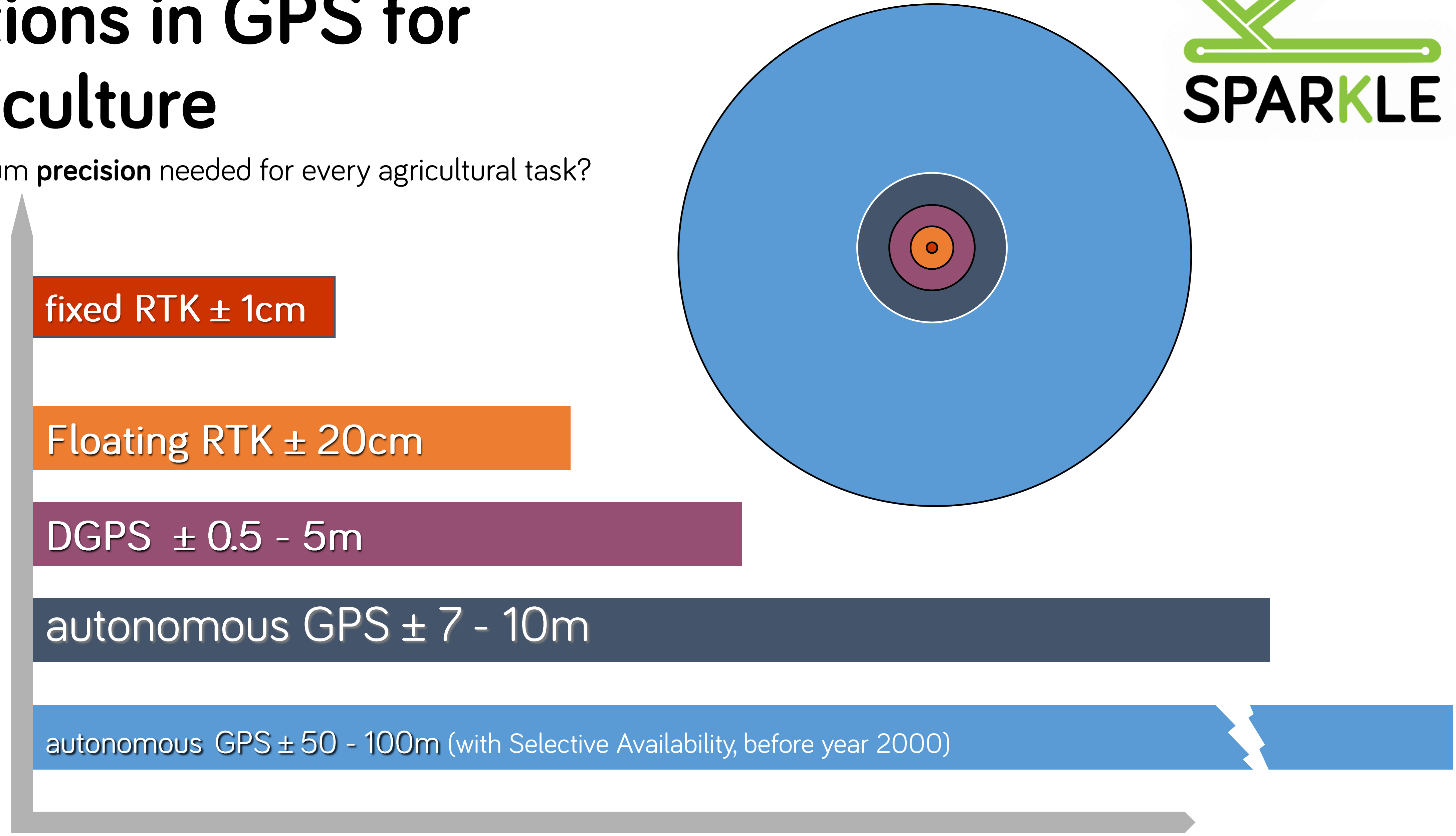
Measurement Type	Real-time or Post-processing	System Type	Accuracy	Coverage Area
Code phase	Post-processing	Post-processed DGPS, post-processed LADGPS or post-processed WADGPS	from < 1 m to ~10 m	From several x 10 km to several x 1000 km
Code phase	Real time	DGPS, LADGPS or WADGPS	from < 1 m to ~10 m	From several x 10 km to several x 1000 km
Carrier phase	Post-processing	Kinematic, rapid static or static	from < 1 cm to several cm	From several km to several x 1000 km
Carrier phase	Real time	Real-time kinematic (RTK)	from < 1 cm to several cm	From several km to several x 10 km

Options in GPS for agriculture

Is maximum **precision** needed for every agricultural task?



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RTK vs. DGPS : differences

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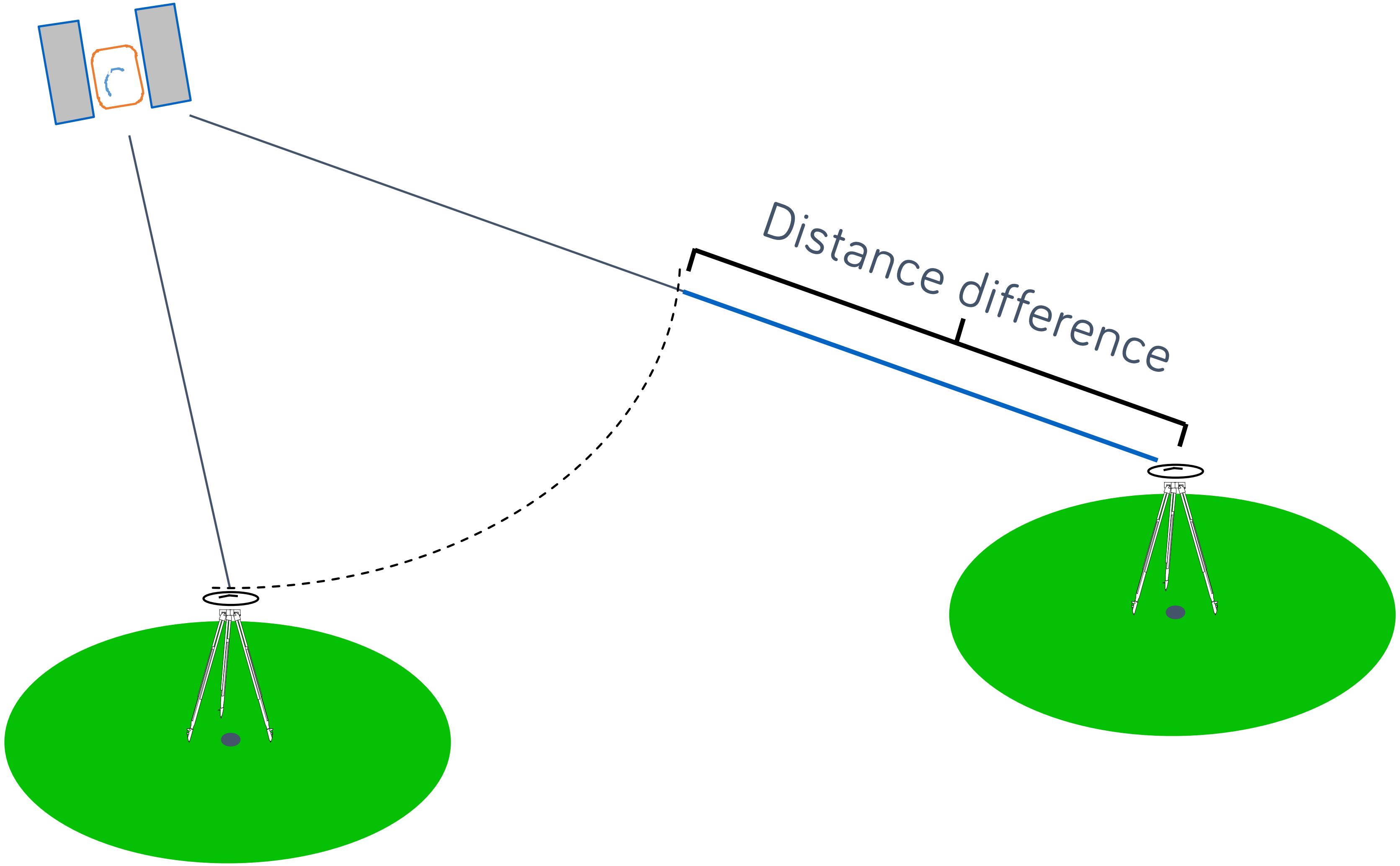
- Precision of solution: higher with RTK receiver
- Number of required receivers:
  - DGPS: only 1 mobile receiver, equipped with correction (from satellite, radio or internet)
  - RTK: at least two devices
    - Base station for reference (at a fixed position in the farm/field)
    - Mobile receiver, “carrier phase” antenna type (in tractor)
    - One base station is enough for several receivers
- Radio – RTK: requires radio link between base & mobile
- Internet – RTK: requires GSM link (mobile data) with internet (NTRIP protocol)

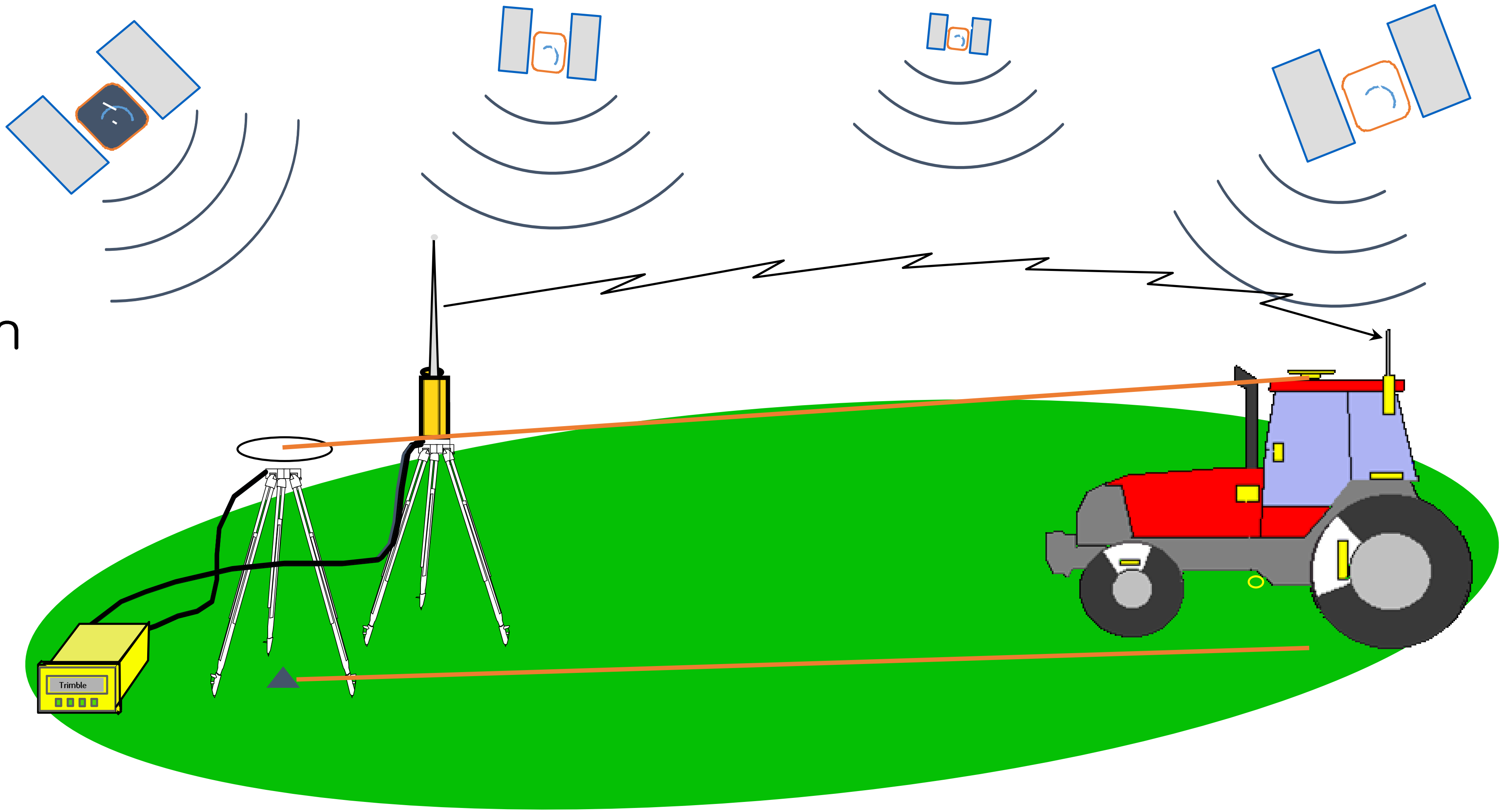
Delay measurement in "Carrier Phase" mode (RTK)

RTK calculations: having two devices listening to the same satellite(s) enhances accuracy calculating distance differences



In movement (“relative delay”)

When working, the tractor receives the “distance difference” calculation from the RTK base station



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Example of RTK devices: tractors equipped with RTK antennas & mobile base station

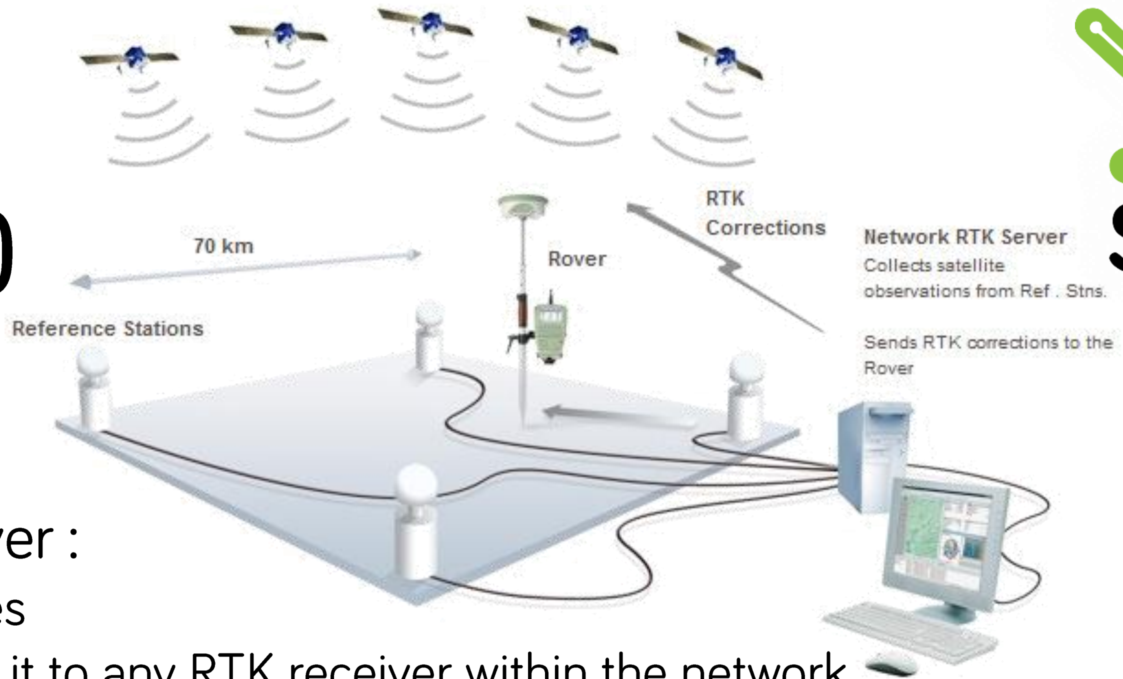
Using RTK to place irrigation pipes

Disadvantages of RTK

- Expensive (more than DGPS)
- A base station must be purchased and installed
- The error is greater with higher distance to base station: the further the tractor is from the base, the higher the error. Error = ± 2ppm (2 cm, if 20km = 2000000cm away)
- Solutions:
  - Cluster of base stations: purchase / share several stations
  - RTK networks: public or private

RTK networks

(GNSS networks)



- Many base stations
  (>5 st at ~70 km distance)
- Connected with a central server :
  - Eliminates ambiguities of satellites
  - Consolidates information to send it to any RTK receiver within the network
- 'Eliminates' the error proportional to the distance to the base, merging information from all of them
- Deferent calculation methods:
  - MAX: master-auxiliary (standard RTCM 3.1)
  - FKP: "Flächenkorrektur" (English: "Area Corrections")
  - VRS: virtual reference station
  - i-MAX: individualized master-auxiliary

Simulates autonomous RTK

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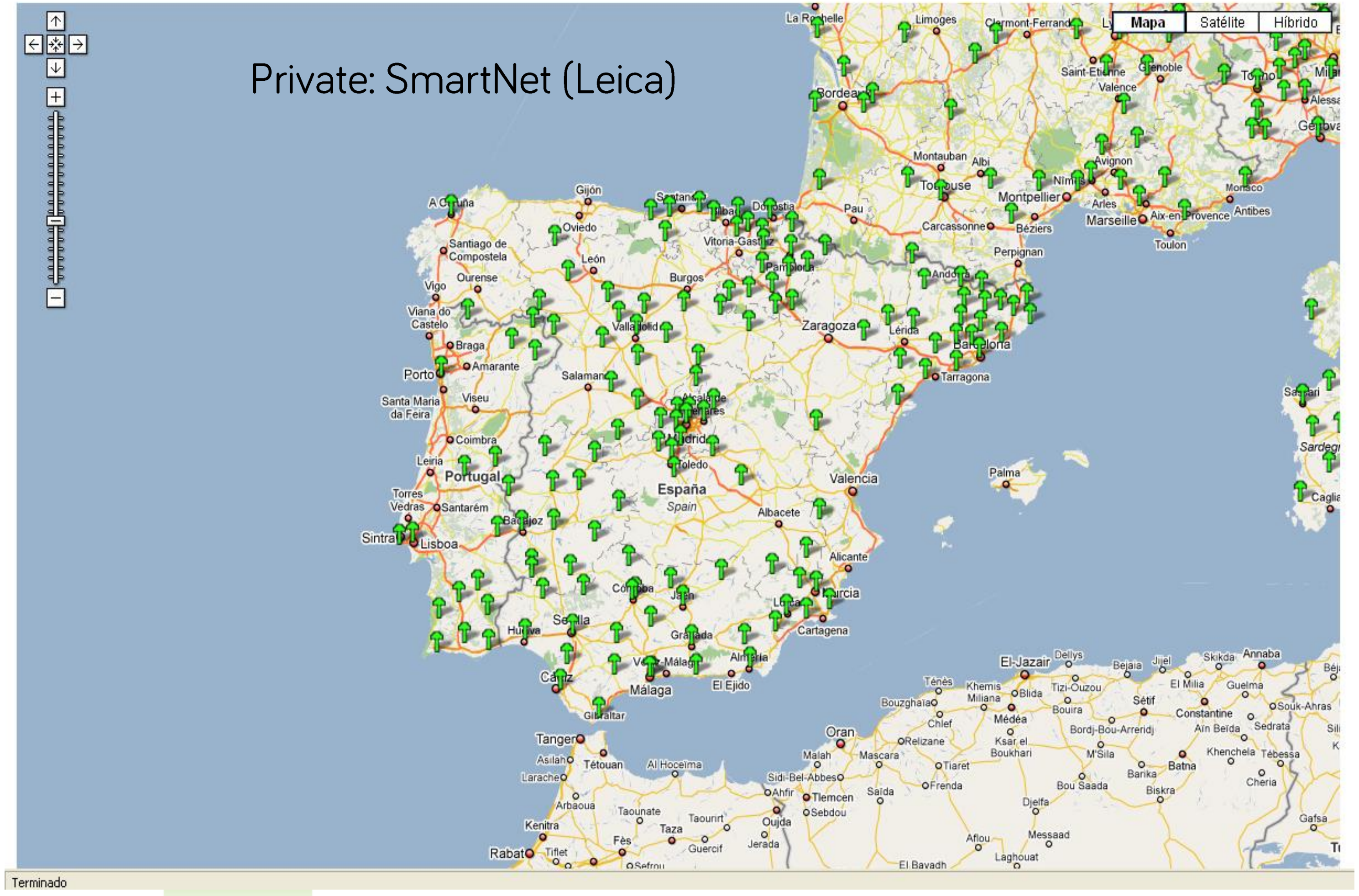
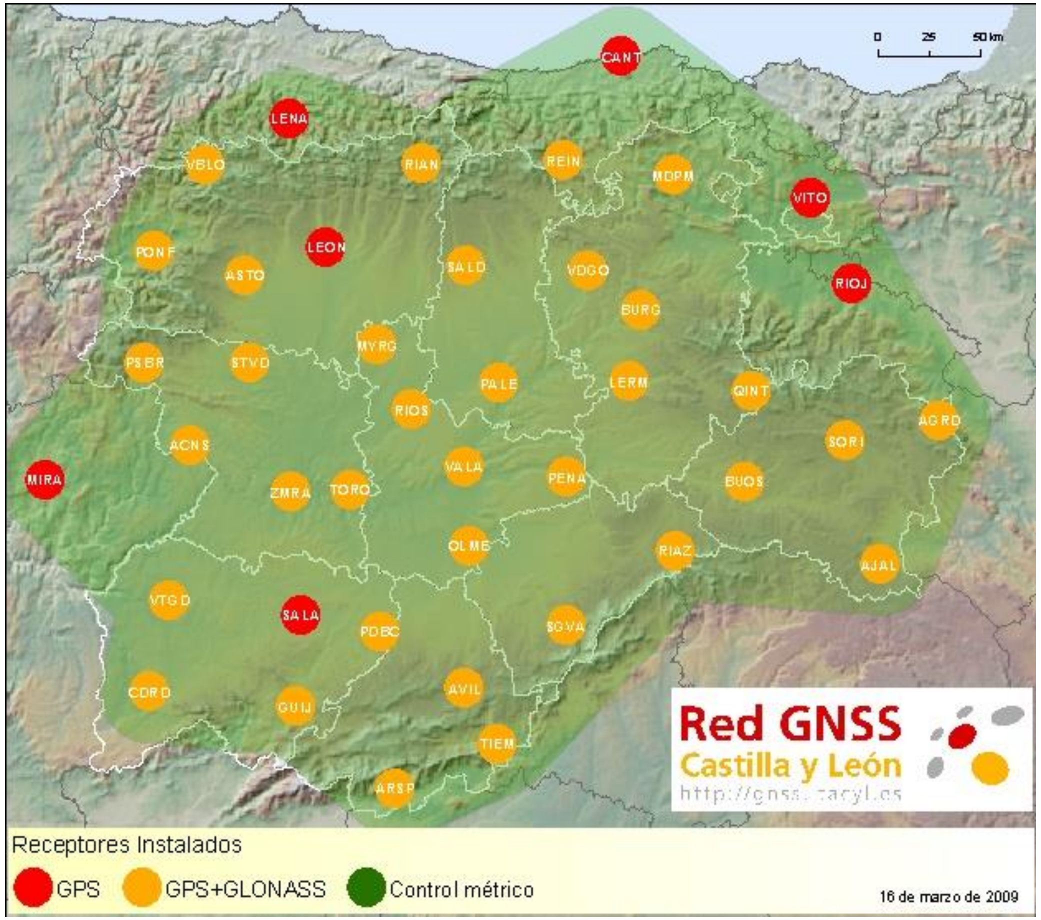
Examples of GNSS networks

- Private RTK networks: i.e. SmartNet (Leica) www.leica.com
- Public RTK networks
  - Europe (EUREF) http://epncb.oma.be/
  - EGNOS Data Access Service (EDAS) https://egnos-user-support.essp-sas.eu/new_egnos_ops/services/about-edas
- In Spain: most regions have a public (free) network
  - Murcia (REGAM y Meristemum)
  - Euskadi
  - Navarra (RGAN)
  - Comunidad Valenciana (ERVA)
  - Madrid (IBEREF)
  - Cataluña (CATNET)
  - Andalucía (RAP)
  - La Rioja
  - Castilla y León (ITACYL)

Examples of RTK networks





“Castilla y León” (ITACYL) public network

Positioning errors using GPS

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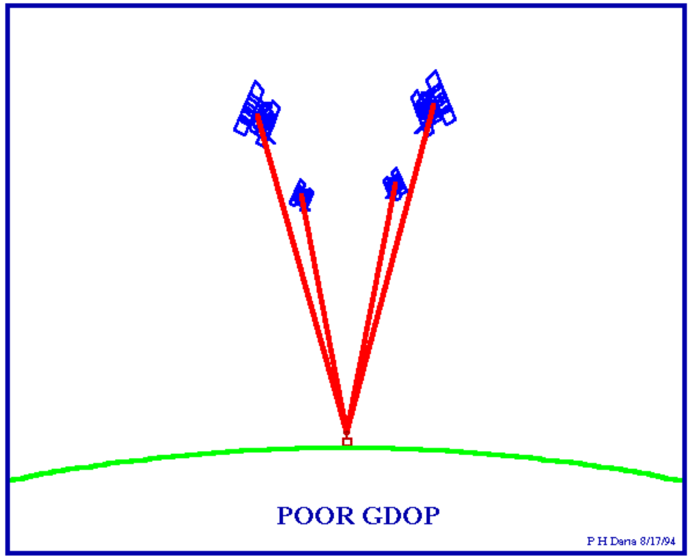
1. Errors in the receiver
2. Errors due to satellites: due to atomic clock, or the orbit
3. Atmospheric errors: status of the ionosphere, troposphere
4. Signal / noise ratio (SNR): i.e. when a satellite is close to the horizon, or the signals cross trees, the noise is higher
5. Multiple path signal: when signal is reflected by a surface (wall, building); latest devices can correct this automatically
6. The GDOP: *"geometric dilution of precision"*

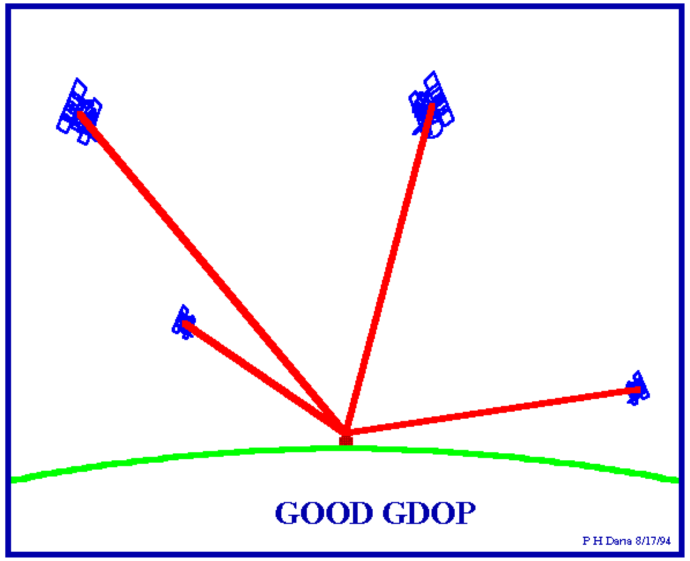
Dilution of Precision (DOP)

- Error due to inadequate geometry of satellites
- Indicates the quality of signal
- Can be expressed with deferent dimensions
  the most known
    PDOP (position DOP: xyz), and HDOP (horizontal DOP: xy)
  the least known
    VDOP (vertical DOP: z), and TDOP (time DOP: t)

What is the DOP?

- When the receiver is only listening to satellites very close in the sky, the positioning error is higher, as the “point of view” of all of them is the same and triangulation is poor
- Do not use GPS coordinates with DOP > 3

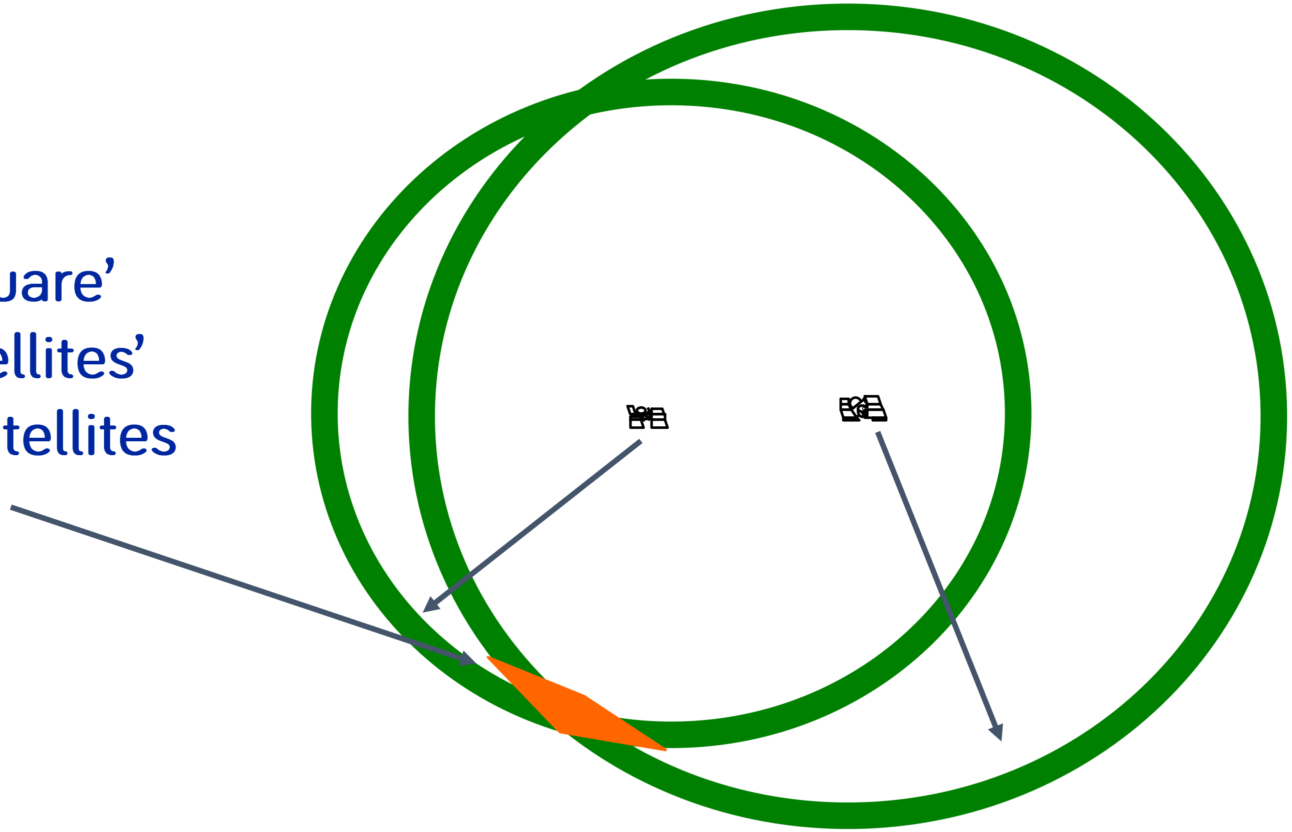




Dilution of Precision (DOP)

Worsens with certain angles

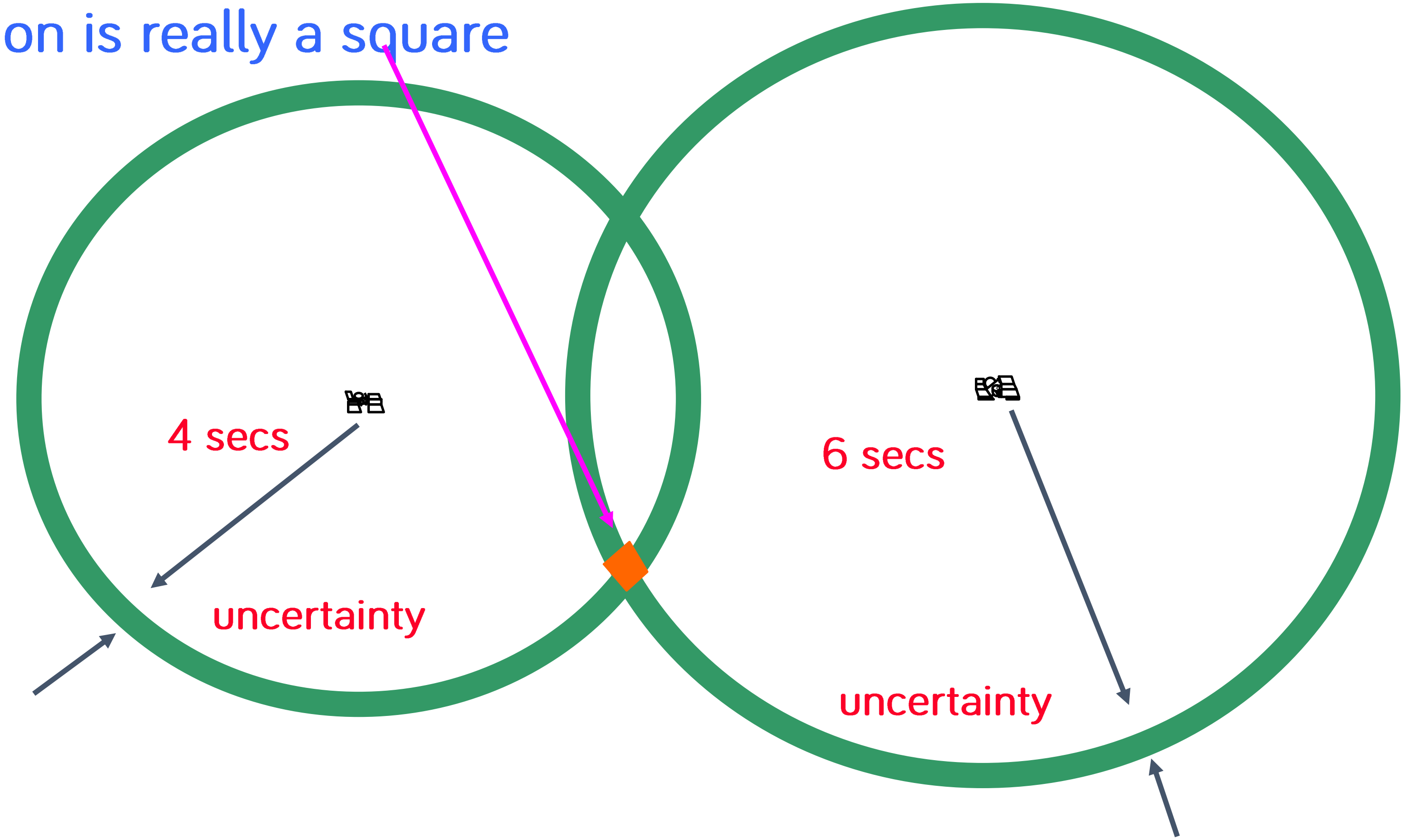
The 'uncertainty square' (intersection of satellites' error) is bigger if satellites are closer



Dilution of Precision (DOP)

Real situation – inexact circles

The point representing the position is really a square



Error sources in GPS vs DGPS

Error sources	Standard GPS	Diferential GPS
Satellite clock	1.5	0
Orbital Errors	2.5	0
Ionosphere	5.0	0.4
Troposphere	0.5	0.2
Noise at receiver	0.3	0.3
Phantom signal (multipath)	0.6	0.6
Selective availability	30	0
Average Position Accuracy		
Horizontal	50	1.3
Vertical	78	2.0
3-D	93	2.8

GPS Precision

- Is different:
  - Precision: repeatability
  - *Accuracy*: degree of closeness of an estimate to the true value
- Different measurements of precision for Agriculture:
  - static
  - dynamic
- Errors behave as a bivariate normal distribution (not equally normal in Lat & Long)

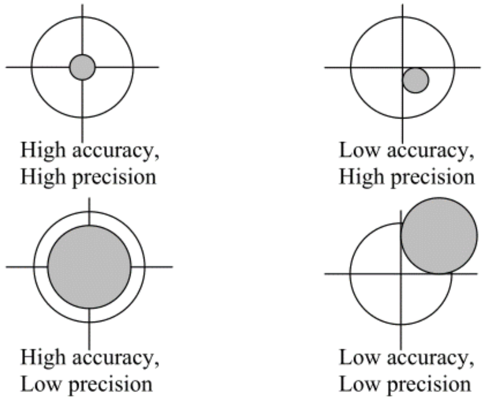
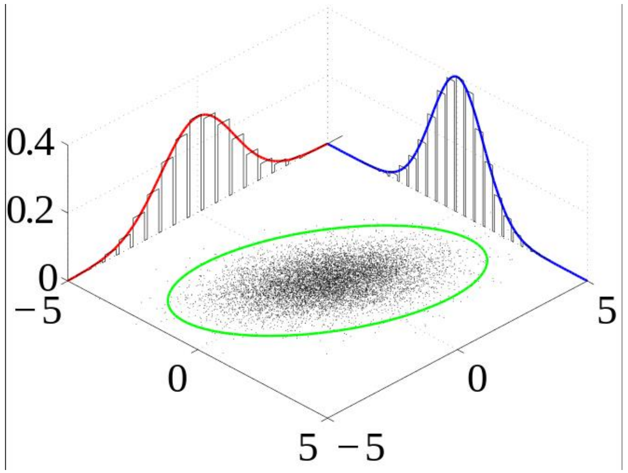
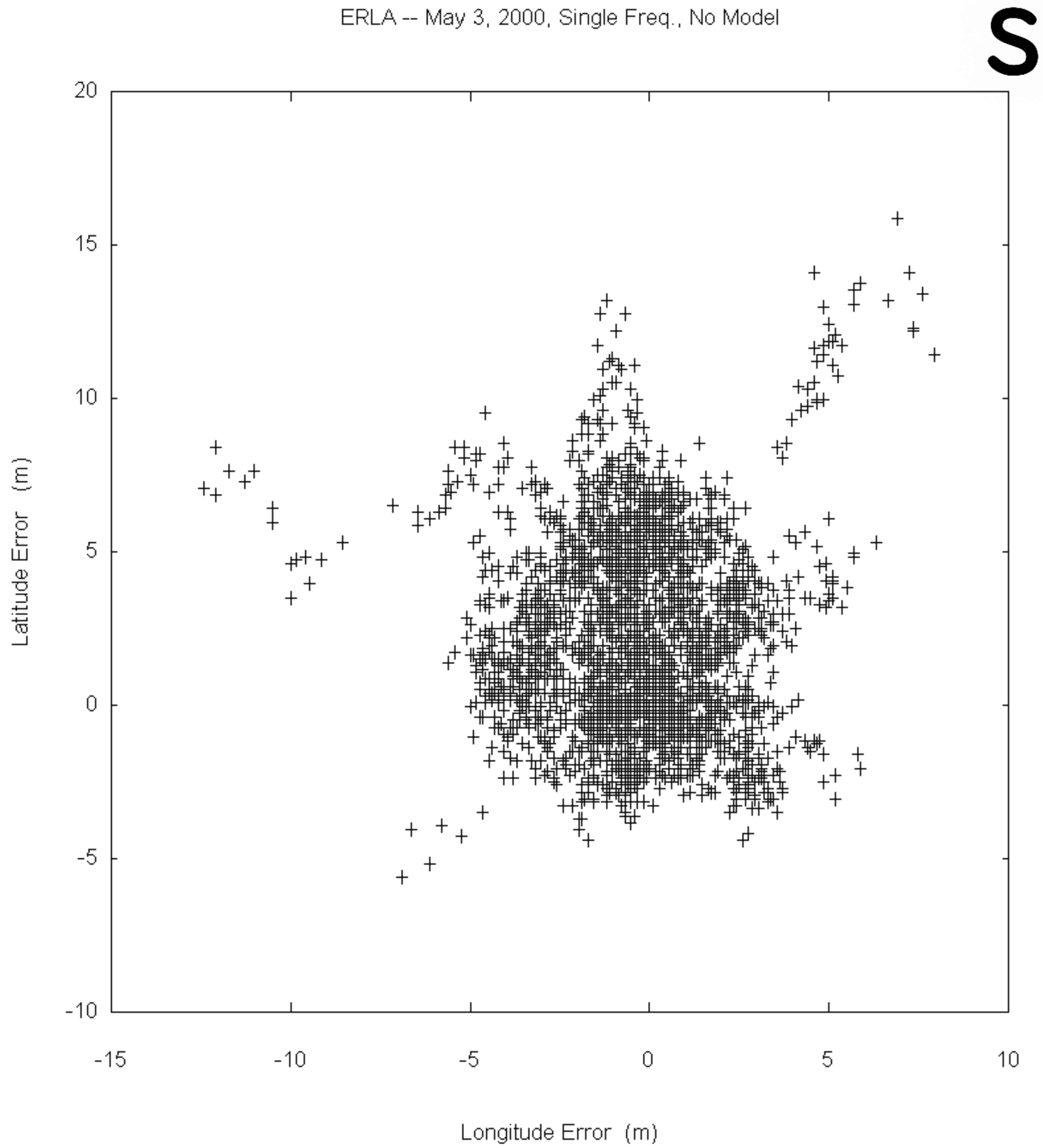


Figure 1: Accuracy versus Precision



Measurements of Static Precision:

GPS device fixed 24h



Measurements of Static Precision:

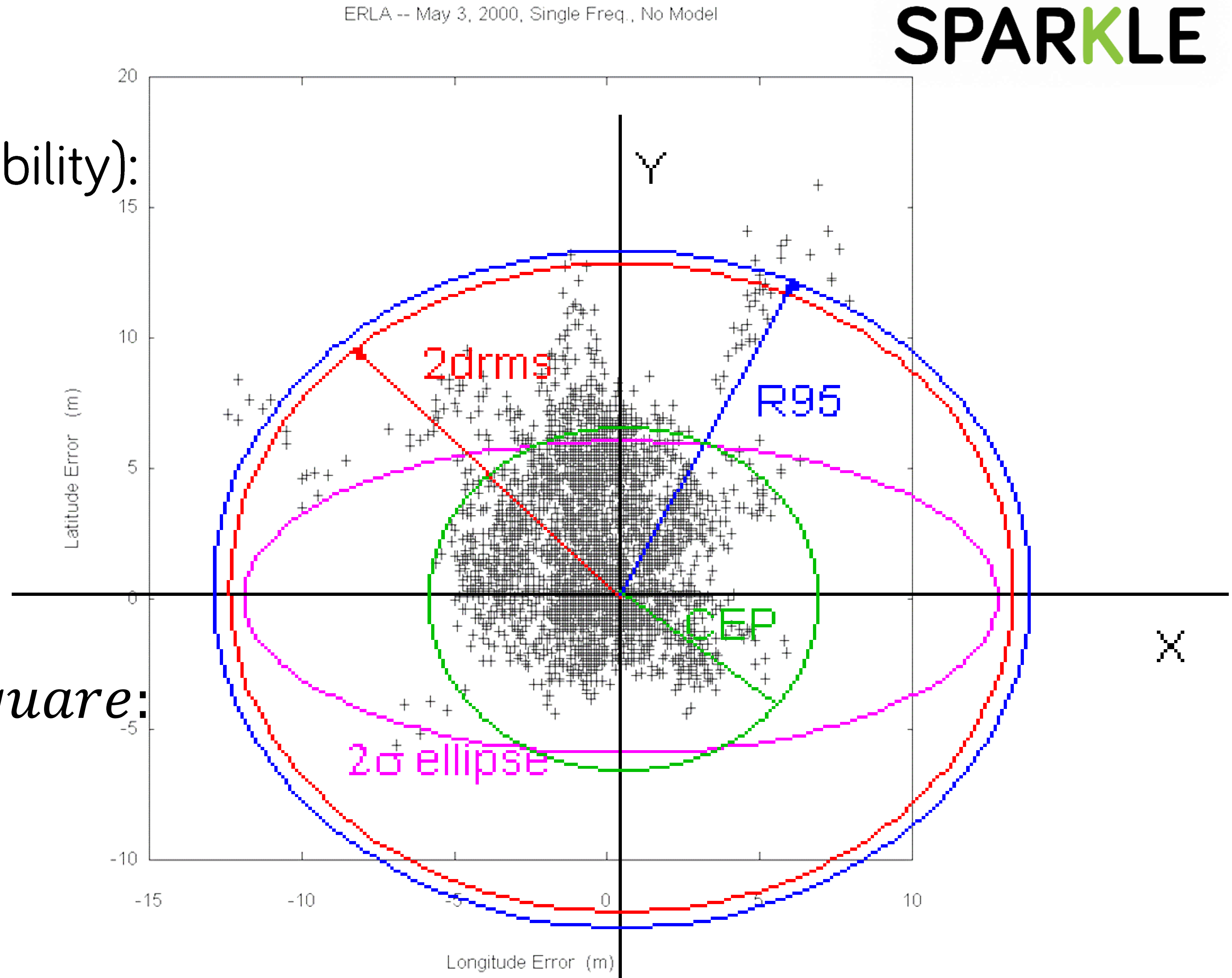
GPS device fixed 24h

- CEP (Circular Error Probability):
  radius of circle containing 50% of observations (error of median)
- R95: idem for 95%
- *Root mean square*:

$$RMS = \sqrt{\sigma^2{}_{Lat} + \sigma^2{}_{Long}}$$

- *Distance root mean square*:

$$DRMS = \sqrt{\sigma^2{}_X + \sigma^2{}_Y}$$



Measurements of Static Precision:
GPS device fixed 24h

Table 1: 2D Position Accuracy Measures

Accuracy Measures	Formula	Probability	Definition
DRMS	$\sqrt{\sigma_x^2+\sigma_y^2}$	**65%**	The square root of the average of the squared horizontal position errors.
2DRMS	$2\sqrt{\sigma_x^2+\sigma_y^2}$	**95%**	Twice the DRMS of the horizontal position errors.
CEP	$0.62\sigma_y+0.56\sigma_x$ (Accurate when $\sigma_y/\sigma_x>0.3$)	**50%**	The radius of circle centered at the true position, containing the position estimate with probability of 50%.
R95	$R(0.62\sigma_y+0.56\sigma_x)$ (R=2.08, when $\sigma_y/\sigma_x=1$)	**95%**	The radius of circle centered at the true position, containing the position estimate with probability of 95%.

similar

https://www.novatel.com/assets/Documents/Books/Intro-to-GNSS.pdf

Approximate conversion

SPARKLE

Assuming normal distribution and DOPs

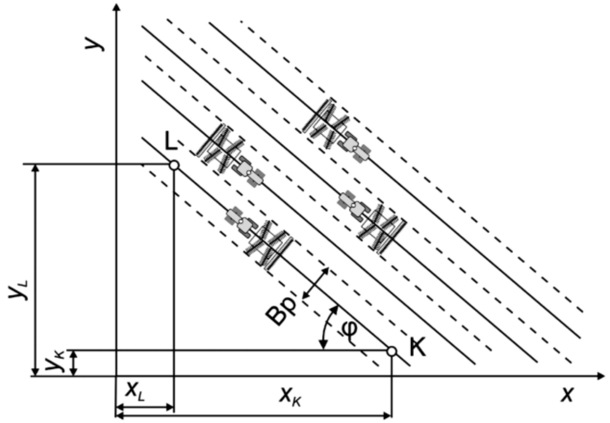
Table 2 gives the multipliers required to go from one accuracy measure to another assuming that $\sigma_x / \sigma_y = 1$ and that VDOP / HDOP = 1.9 and PDOP / HDOP = 2.1.

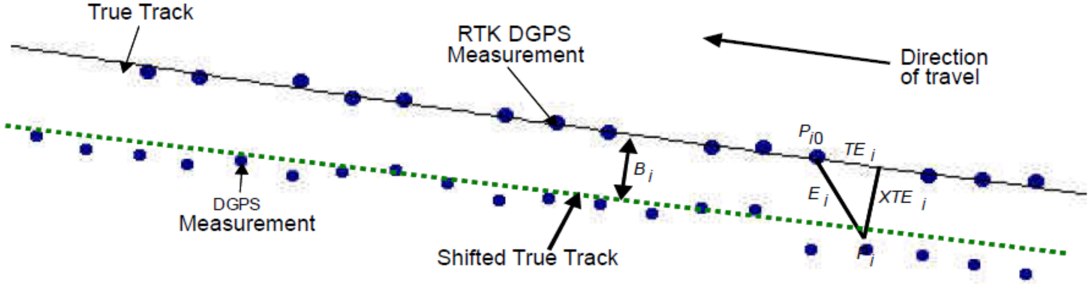
Table 2: Equivalent Accuracy Multipliers

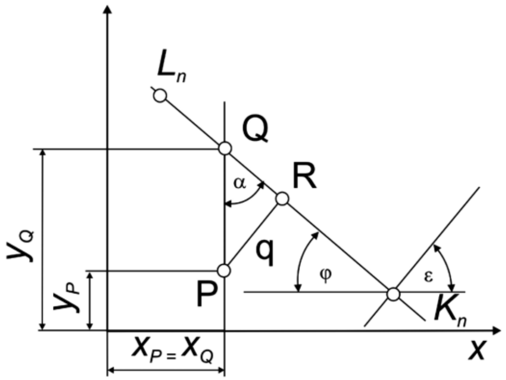
RMS (Vertical)	CEP	RMS (Horizontal)	R95 (Horizontal)	2DRMS	RMS (3D)	SEP	
1	0.44	0.53	0.91	1.1	1.1	0.88	**RMS (Vertical)**
	1	1.2	2.1	2.4	2.5	2.0	**CEP**
		1	1.7	2	2.1	1.7	**RMS (Horizontal)**
			1	1.2	1.2	0.96	**R95**
				1	1.1	0.85	**2DRMS**
					1	0.79	**RMS (3D)**
						1	**SEP**

Measurements of Dynamic Precision

- Tractors trace parallels in space & time
- Relative precision : with the same device, in the same place, in different moment
- Measurements:
  - Cross track error (XTE)
  - Pass-to-pass accuracy







Definitions of the measurement error (E_i), cross-track error (XTE_i), track error (TE_i), and bias error (B_i).

Measurements of Dynamic Precision

- Official standard: ISO 12181-1: Dynamic testing of satellite based positioning devices used in agriculture
- Pass-to-pass accuracy: combination of
  - Biases among tracks (phase shift between tracks):

$$Ep_i = (B_i\text{-}B_{i-1}) = \overline{XTE_i} - \overline{XTE_{i-1}}$$

  - Standard deviation at each track (s)

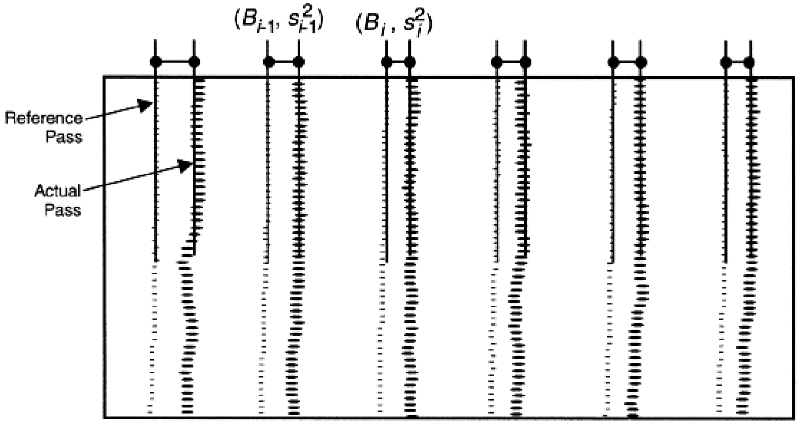


Figure 4. Definitions of the pass-to-pass accuracy: B_i is the bias error, and is the standard error.

$$sp_i^{\,2} = s_i^{\,2} + Ep_i^{\,2}$$

$$RMS_{\,i} = \sqrt{s_i^{\,2} + B_i^{\,2}}$$

References and Additional Material

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