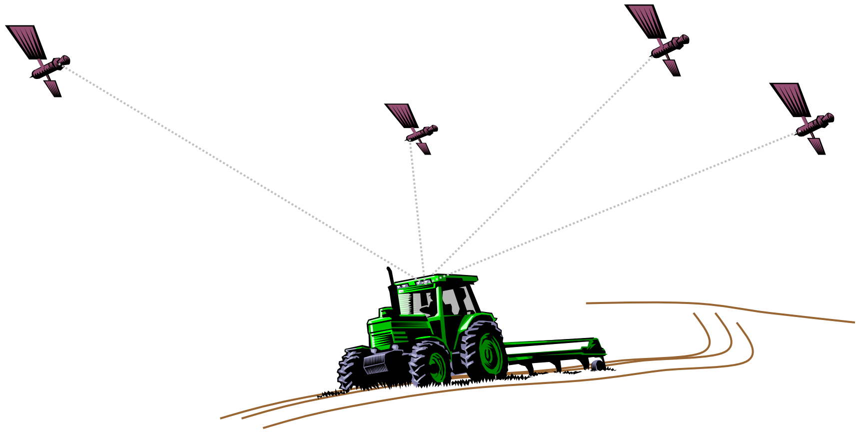
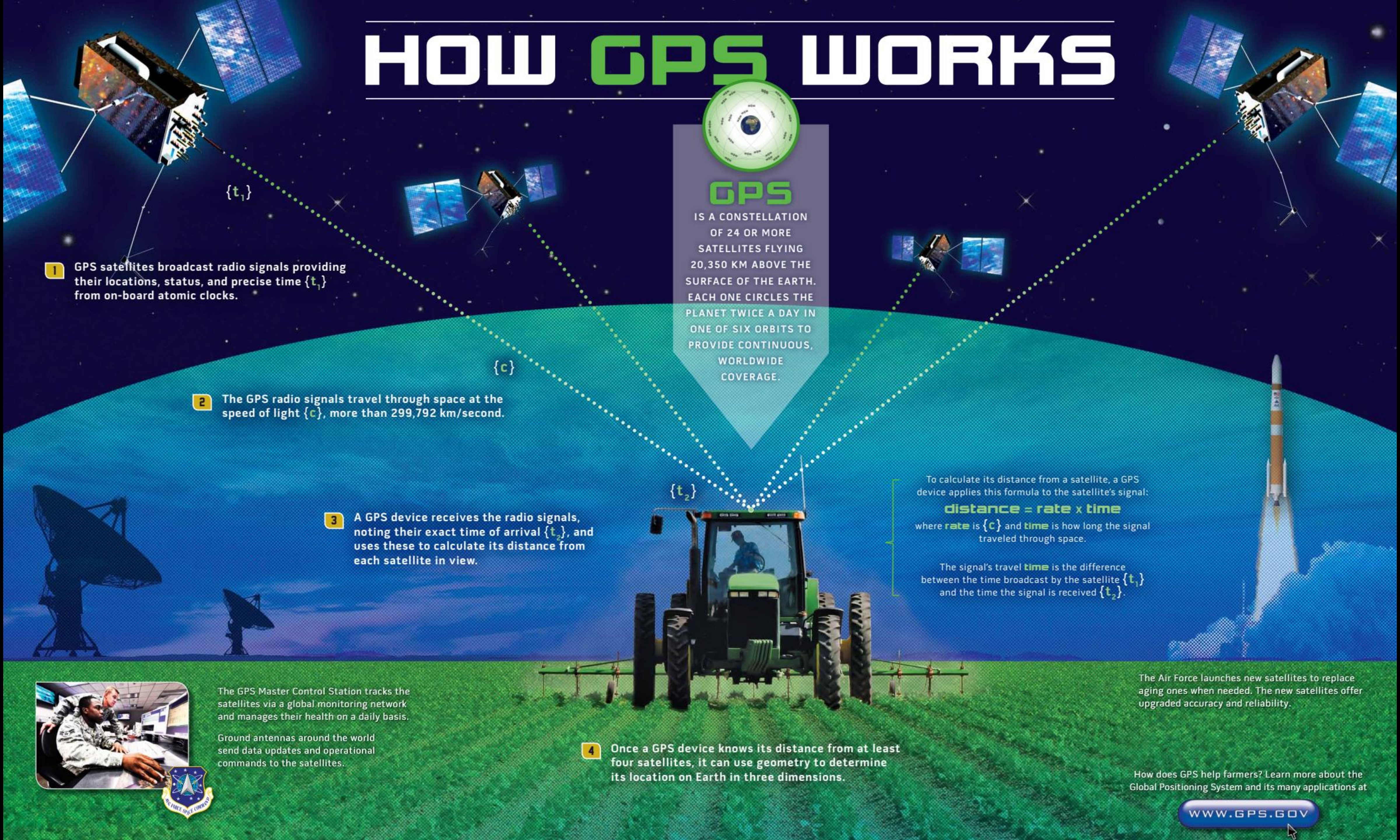


Global Navigation Satellite Systems (GNSS)

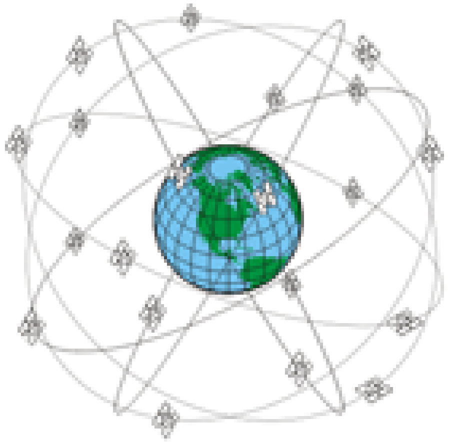
Precision Agriculture

Topic 2

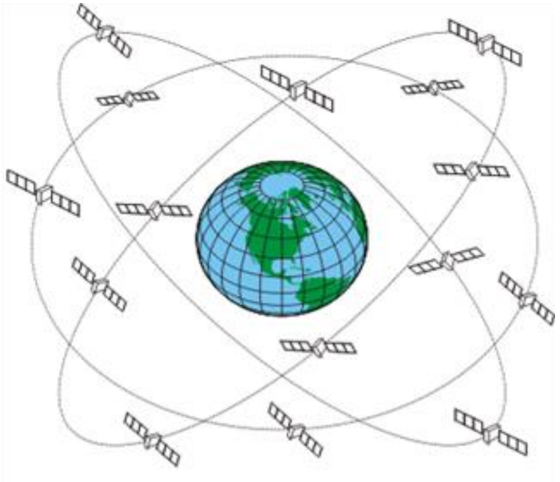


HOW GPS WORKS
{t1}
GPS IS A CONSTELLATION OF 24 OR MORE SATELLITES FLYING 20,350 KM ABOVE THE SURFACE OF THE EARTH. EACH ONE CIRCLES THE PLANET TWICE A DAY IN ONE OF SIX ORBITS TO PROVIDE CONTINUOUS, WORLDWIDE COVERAGE.
1 GPS satellites broadcast radio signals providing their locations, status, and precise time {t1} from on-board atomic clocks.
{c}
2 The GPS radio signals travel through space at the speed of light {c}, more than 299,792 km/second.
{t2}
3 A GPS device receives the radio signals, noting their exact time of arrival {t2}, and uses these to calculate its distance from each satellite in view.
To calculate its distance from a satellite, a GPS device applies this formula to the satellite's signal:
distance = rate x time
where rate is {c} and time is how long the signal traveled through space.
The signal's travel time is the difference between the time broadcast by the satellite {t1} and the time the signal is received {t2}.
The GPS Master Control Station tracks the satellites via a global monitoring network and manages their health on a daily basis.
Ground antennas around the world send data updates and operational commands to the satellites.
4 Once a GPS device knows its distance from at least four satellites, it can use geometry to determine its location on Earth in three dimensions.
The Air Force launches new satellites to replace aging ones when needed. The new satellites offer upgraded accuracy and reliability.
How does GPS help farmers? Learn more about the Global Positioning System and its many applications at
WWW.GPS.GOV

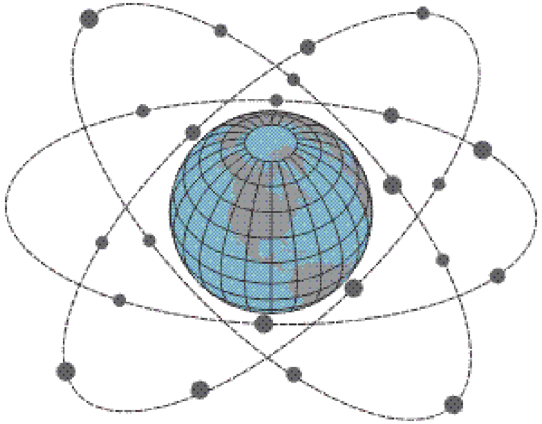
GNSS



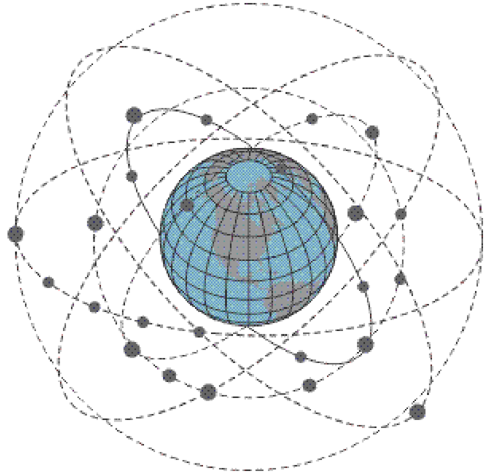
GPS
6 Orbital planes
24 Satellites + Spares
55° Inclination Angle
Altitude 20,200 km



GLONASS
3 Orbital planes
21 Satellites + 3 Spares
64.8° Inclination Angle
Altitude 19,100 km



Galileo
3 Orbital planes
27 Satellites + 3 Spares
56° Inclination Angle
Altitude 23,222km



BeiDou
6 Orbital planes
5 Satellites + 5 GEO + 27 MEO + 3 IGSO
55° Inclination Angle
Altitude 38,300 km, 21,500 km

https://www.e-education.psu.edu/geog862/

GNSS

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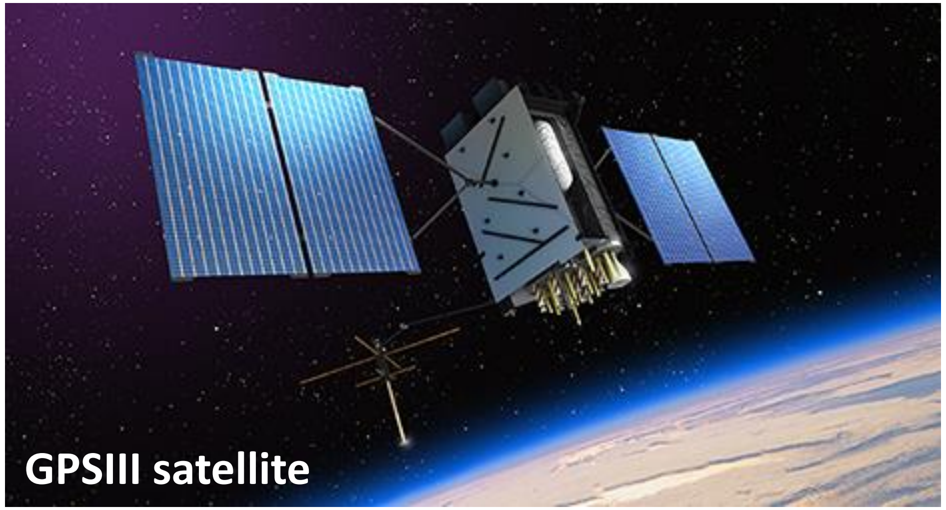
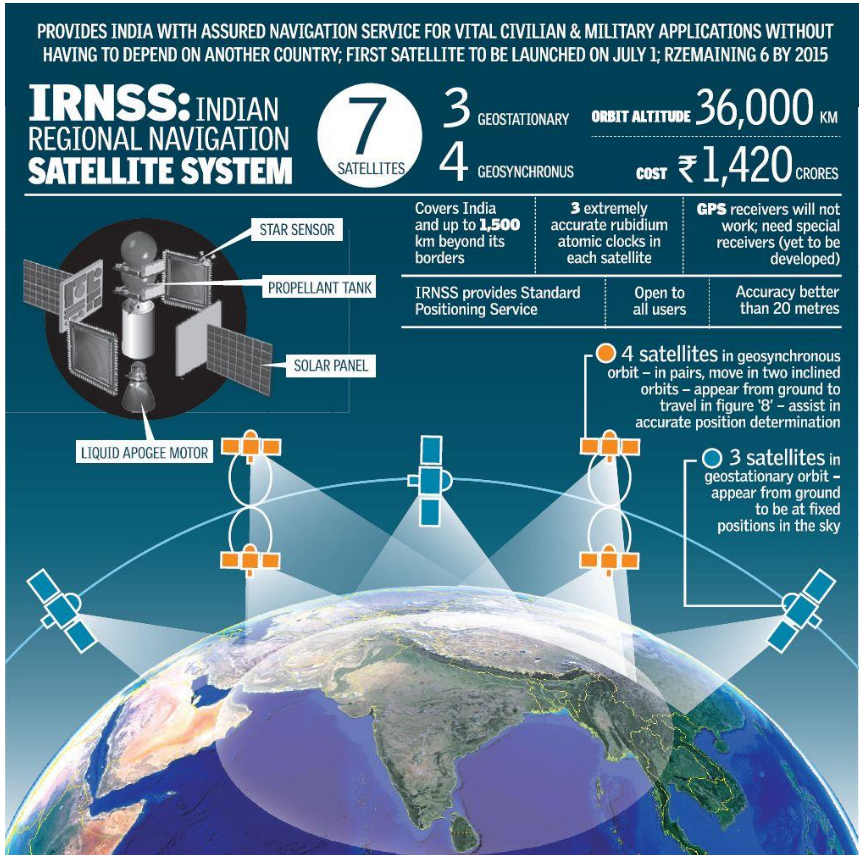
- All providers offer free use of their respective systems to the international community
- All providers have developed International Civil Aviation Organization (ICAO) Standards and Recommended Practices to support use of these constellations for aviation



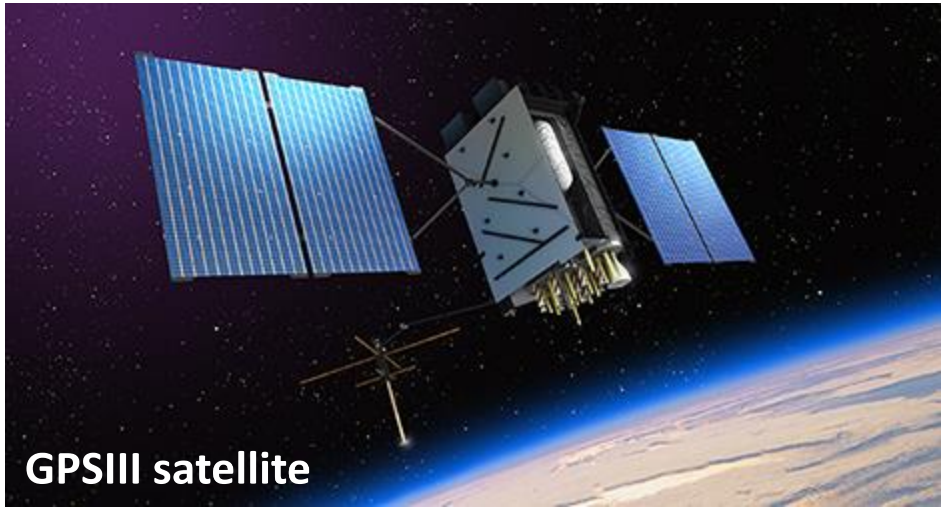
Regional NSS

- Indian Regional Navigation Satellite System (IRNSS)
  - Covers India and a region extending 1,500 km around it
- Japanese Quasi-Zenith Satellite System (QZSS), also known as Michibiki (みちびき)
  - Four-satellite system to enhance GPS in the Asia-Oceania regions, with a focus on Japan.



Wikipedia

Global Positioning System (GPS)


GPSIII satellite

- Currently 31 GPS satellites
- Altitude of approximately 11,000 miles
- GPS is operated and maintained by the Department of Defense (DoD)
- The National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee (EXCOM) provides guidance to the DoD
- The DoD and the Department of Transportation co-chair EXCOM.
- The U.S. Coast Guard acts as the civil interface to the public for GPS matters and receives problem reports from civil users.
- The Federal Aviation Administration oversees the use of GPS in civil aviation and receives problem reports from aviation users

English | español | français | 中文 | عربي

For Legislative Staff | For Students & Teachers

GPS.GOV

Official U.S. government information about the Global Positioning System (GPS) and related topics

Search

Home | What's New | Systems | Applications | Governance | Multimedia | Support

GPS: The Global Positioning System

A global public service brought to you by the U.S. government

INFORMATION FOR THE GENERAL PUBLIC

How to Correct Your Address in GPS Devices, Apps, & Online Maps

Do GPS devices show your home or business in the wrong place? **The problem is not GPS!** It's the mapping software.

Report your issue to the software providers

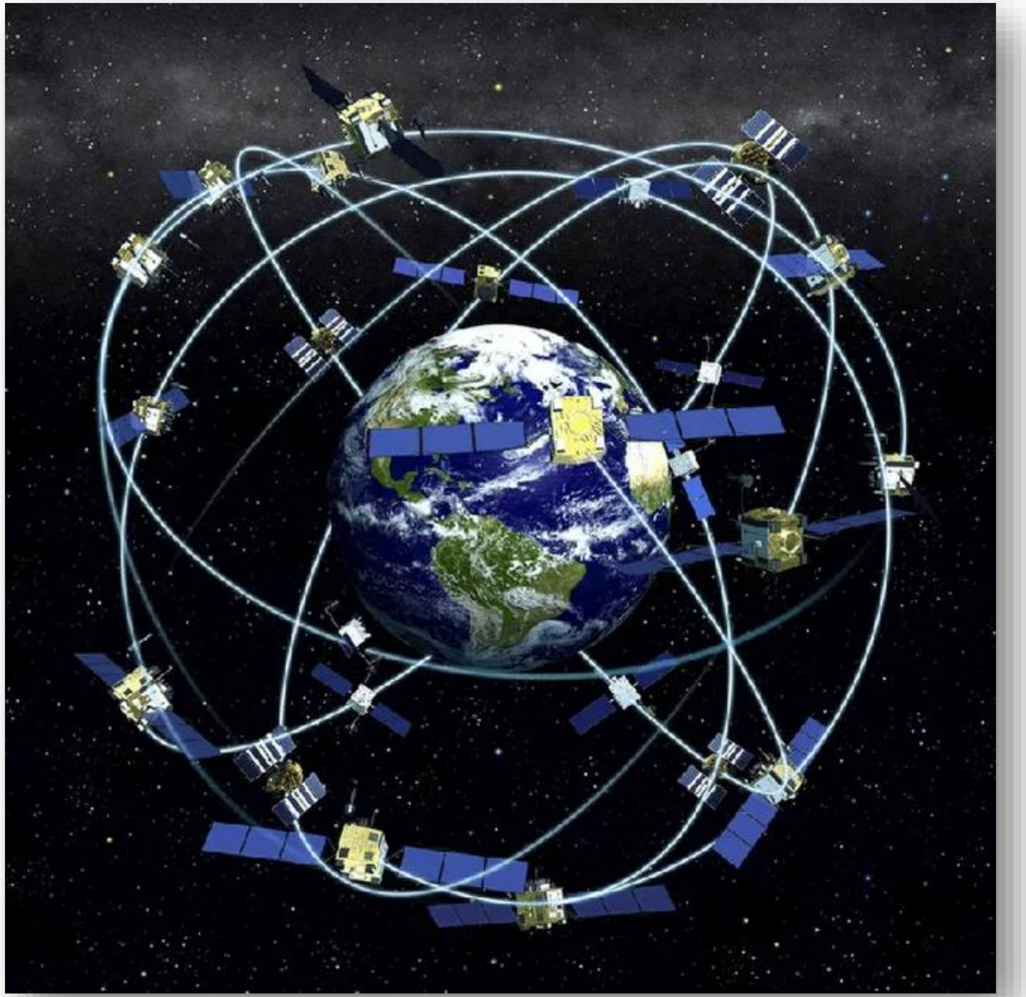
FOR GPS PROFESSIONALS

What's HOT for Pros

- Recent presentations
  - PNT Advisory Board, Dec 9-10
  - Japan GPS/GNSS Symposium, Oct 27
  - Public ICWG meeting, Sep 29
  - ICG-15 Vienna, Sep 27-Oct 1
  - ICG-15 Video: Multi-GNSS space service volume
- Technical documentation
  - Dec 2021 proposed change notices (comments due Jan 13, 2022)
  - ICD updates for 2021
  - PRN assignments, Jun 2021
- Ligado Networks and GPS

NAVSTAR GPS

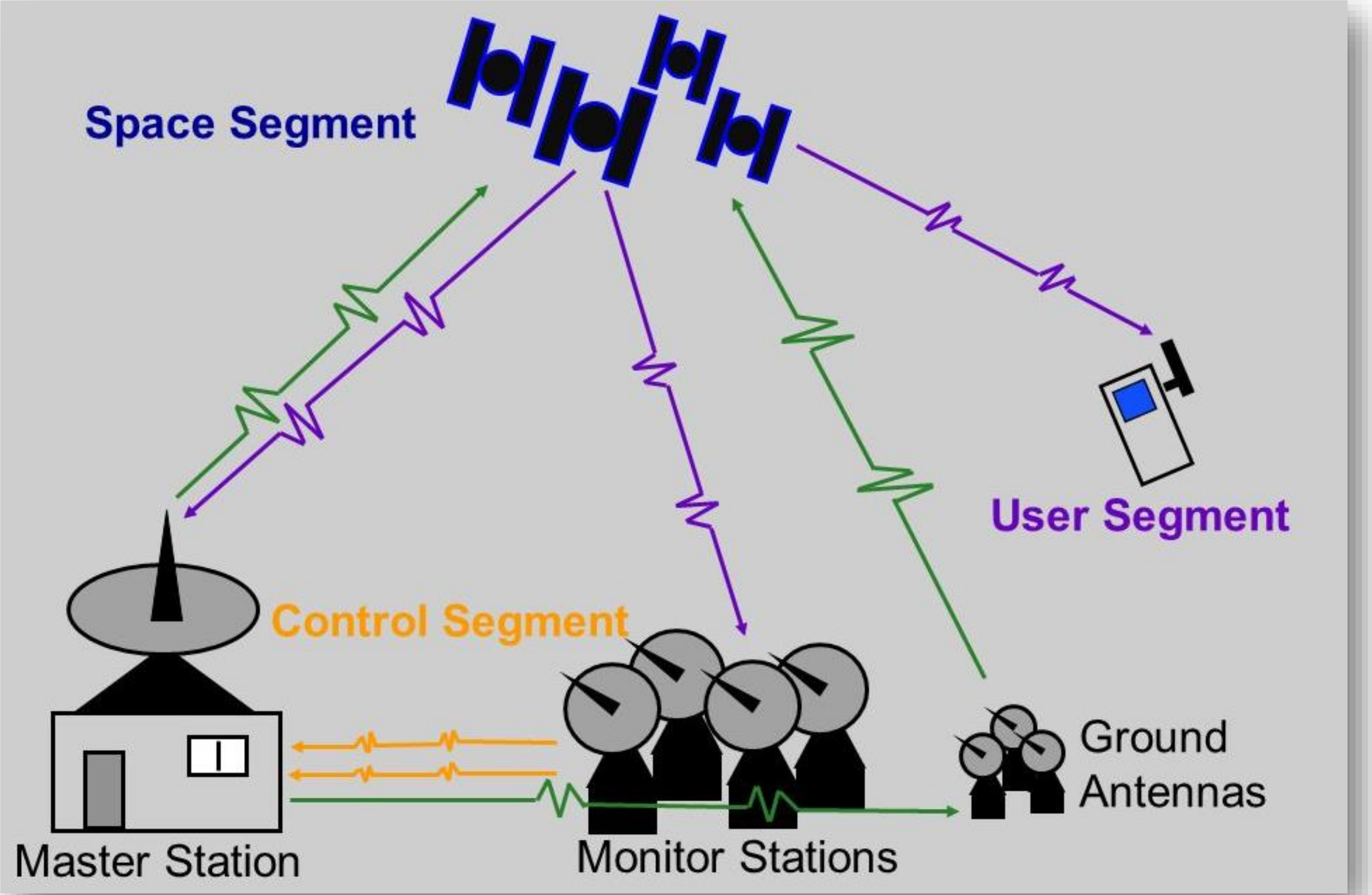
- Developed by the US Department of Defense (DOD)
- Constellation of 31 earth-orbiting satellites
- 3 Segments
  - Space
  - Control
  - User



Three Segments of the NAVSTAR GPS

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

https://slideplayer.com/slide/8801063/



Space Segment

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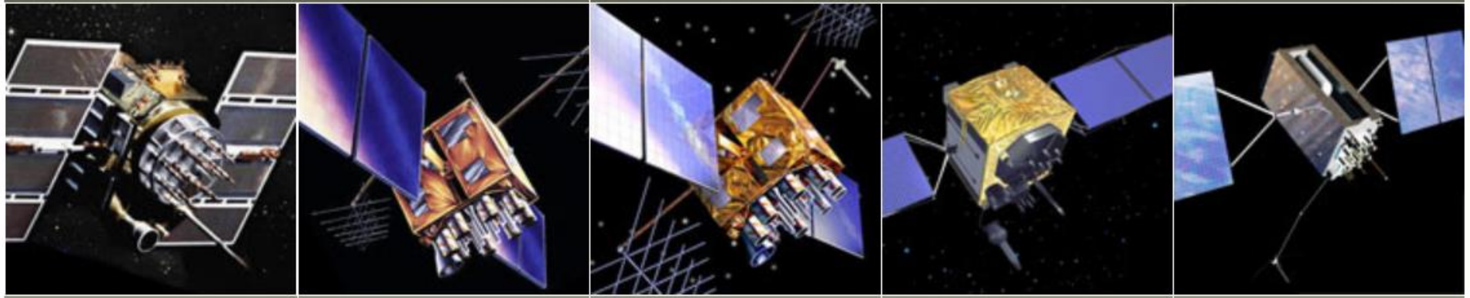
- NAVSTAR GPS
  - Navigation Satellite Timing and Ranging Global Positioning System
- NAVSTAR
  - Weighs 3000 – 4000 lbs
  - 2 complete rotations around the Earth per day
  - Transmit coded positional and timing info

NAVSTAR GPS Satellite Constellation

As of June 26, 2022, there were a total of **31 operational satellites** in the GPS constellation, not including the decommissioned, on-orbit spares.

Latest satellite launched was the GPS III SV05 in June of 2021.



LEGACY SATELLITES		MODERNIZED SATELLITES		
BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIF
0 operational	7 operational	7 operational	12 operational	5 operational
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997 ▪ Last one decommissioned in 2019	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) LEARN MORE ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009	▪ All Block IIR-M signals ▪ 3rd civil signal on L5 frequency (L5) LEARN MORE ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched in 2010-2016	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) LEARN MORE ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability LEARN MORE ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload ▪ First launch in 2018

NAVSTAR Launch

https://www.losangeles.spaceforce.mil/News/Photos/igphoto/2002744395/

GPS Control Segment

Source: GPS for Land Surveyors

User Segment

- A GPS receiver
  - locates at least 4 satellites
  - Calculates distance to each satellite it can “see”
  - Uses this information to calculate its location using the principle of trilateration
  - Gives location in latitude and longitude

GPS Receivers

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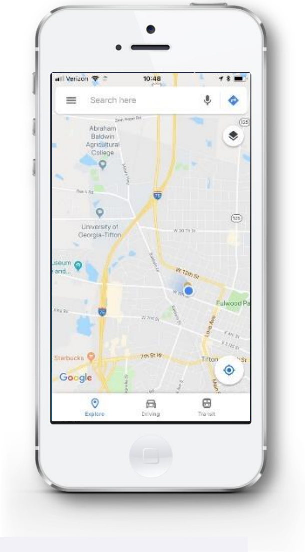
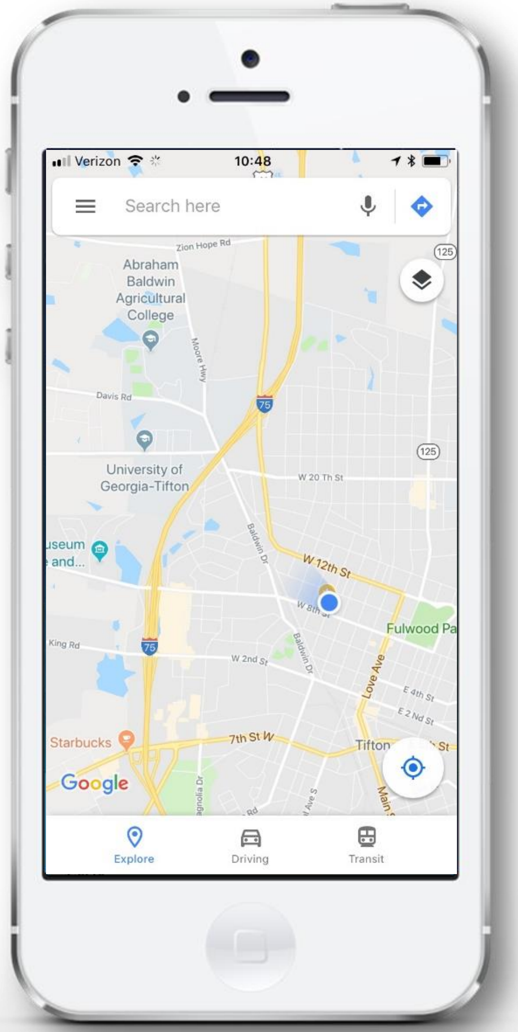


How Does GPS Work?

- A GPS receiver
  - locates at least 4 satellites
  - Calculates distance to each satellite it can "see"
  - Uses this information to calculate its location using the principle of trilateration



GPS Time

local	2020-09-09 14:37:04	Wednesday	day 253	timezone UTC-6
UTC	2020-09-09 20:37:04	Wednesday	day 253	MJD 59101.85907
GPS	2020-09-09 20:37:22	week 2122	333442 s	cycle 2 week 0074 day 3

- GPS Time is the time standard of the GPS system
- Also known as GPS System Time (GPST)
- UTC (Coordinated Universal Time) is the time standard for the world
- The rates of these two standards are virtually the same

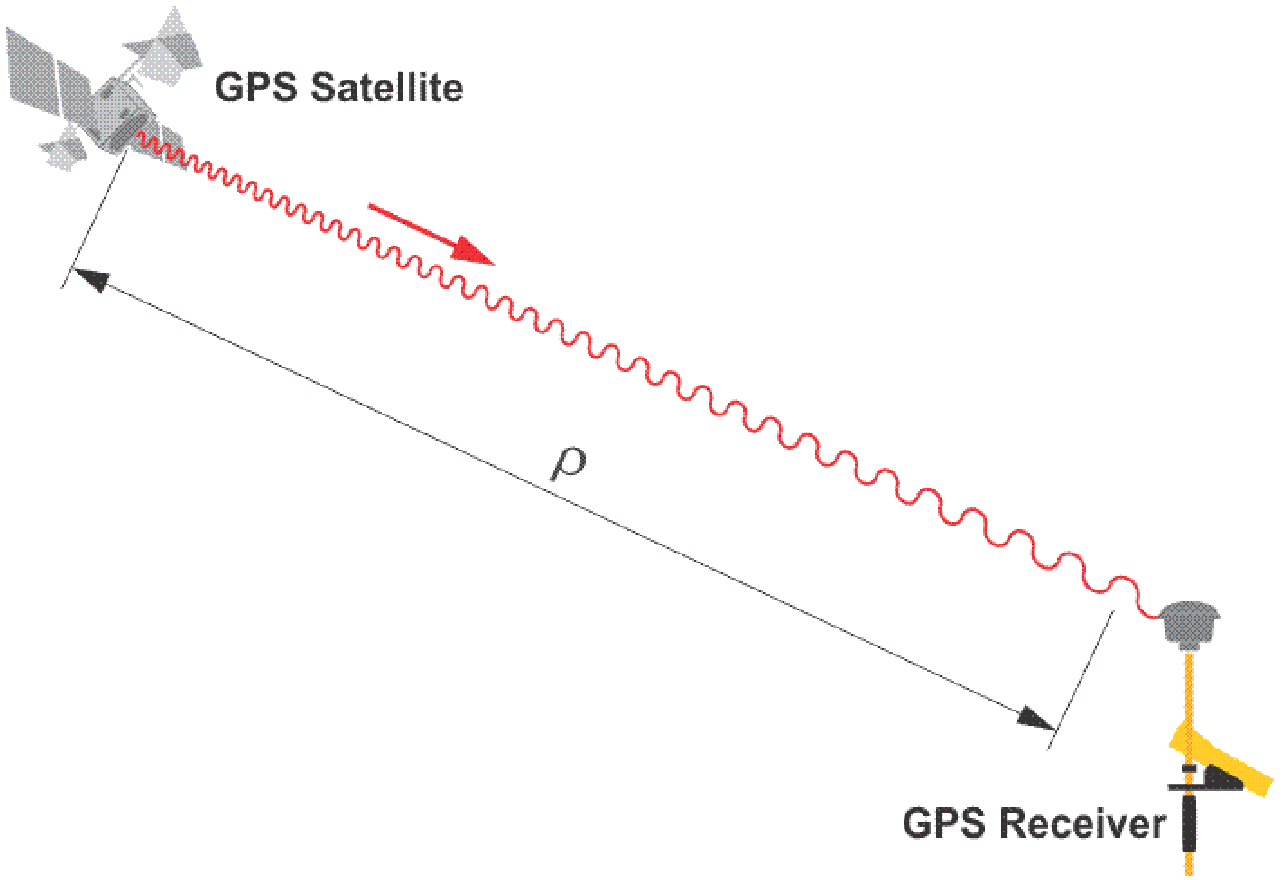
GPS Time

- Rate of UTC is determined by 65 timing laboratories and hundreds of atomic clocks around the world
  - Very stable
  - UTC and rotation of earth not perfectly synchronized
  - +/- Leap seconds applied periodically to UTC
  - Leap seconds NOT use in GPST
- UTC and GPST last identical at 00:00 06 January 1980
- GPST was 18 s ahead of UTC on September 11, 2020
- Receivers adjust for this offset from GPS time to calculate UTC and specific time zone values

One-way Ranging

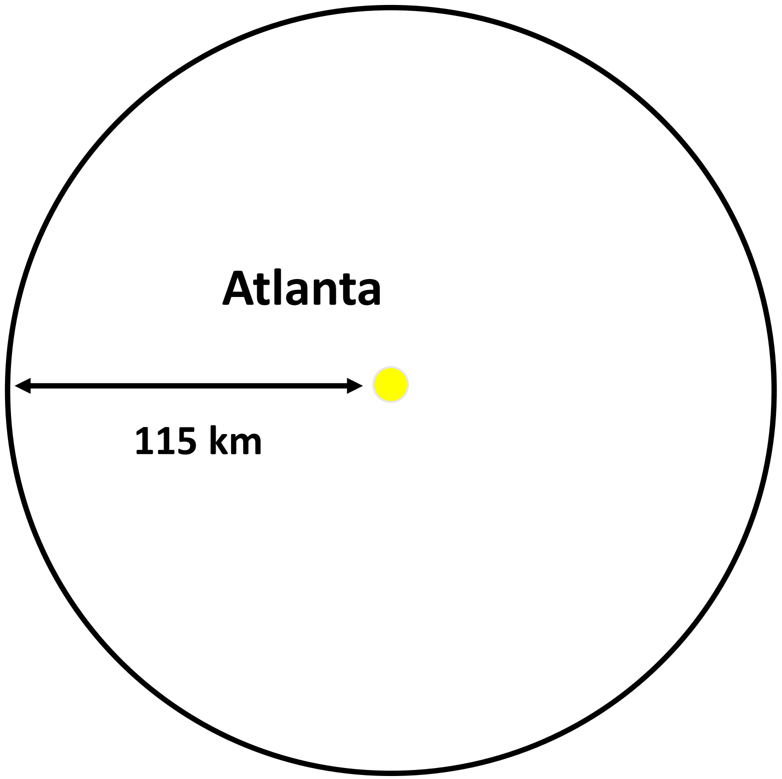
Information flows <u>one-way</u> from satellite to receiver

- What time it is on the satellite
- The instantaneous position of a moving satellite
- Information about necessary atmospheric corrections
- Satellite identification



https://www.e-education.psu.edu/geog862

Trilateration Basics



Trilateration Basics

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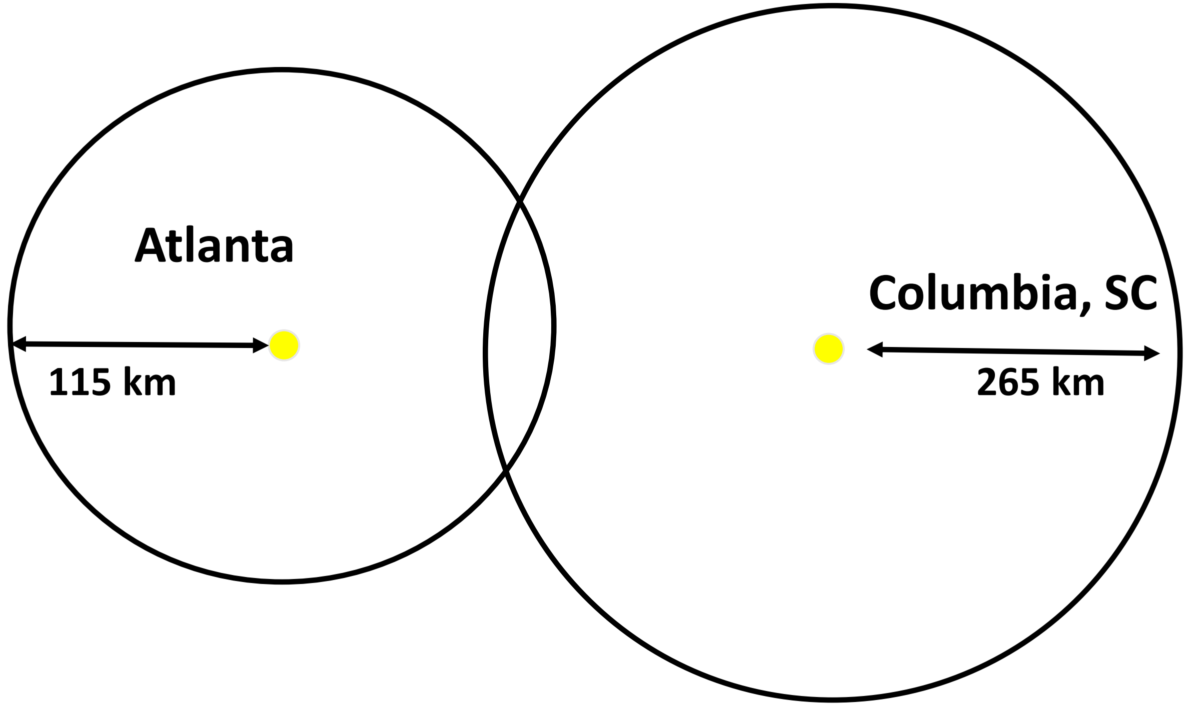
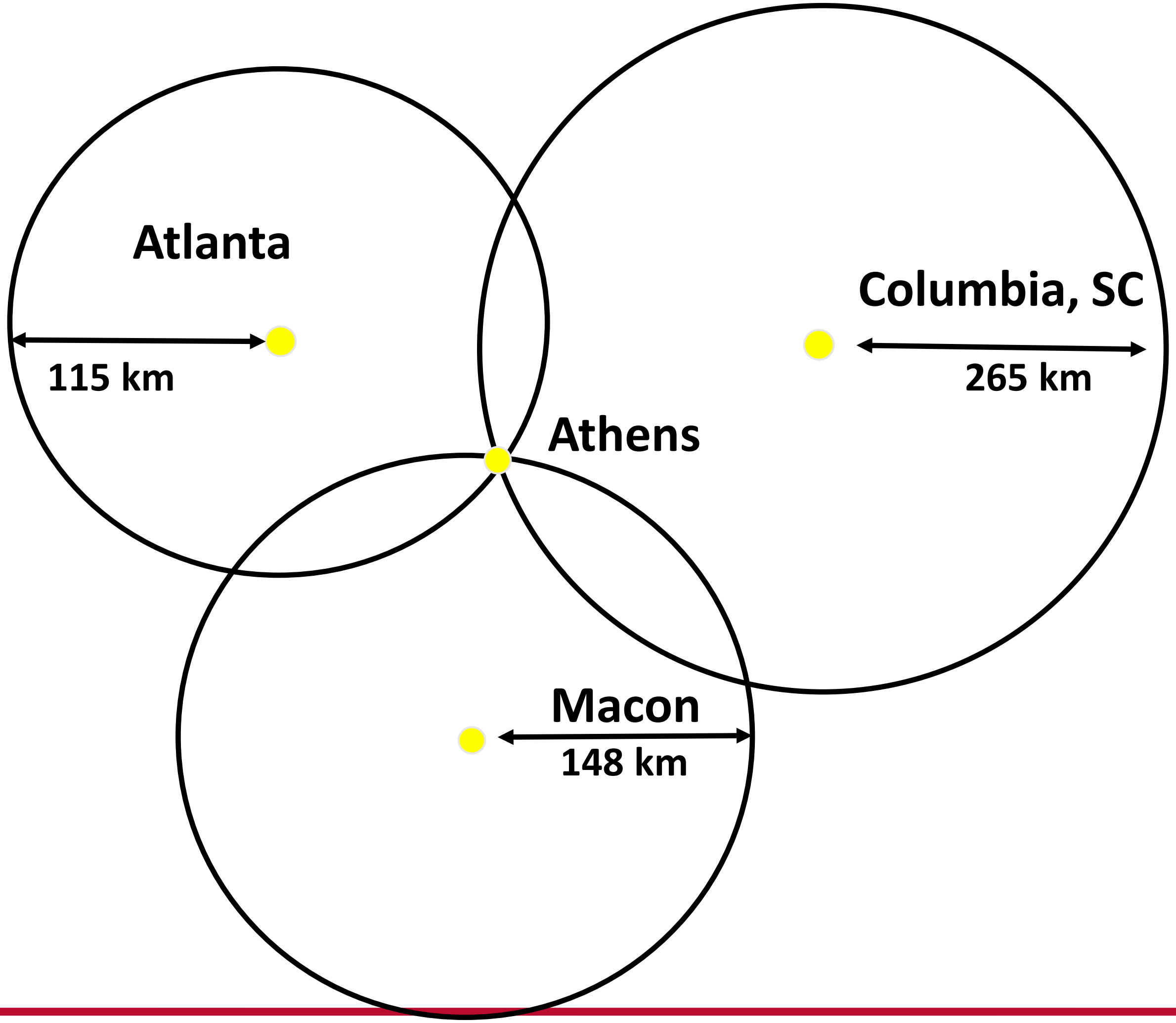
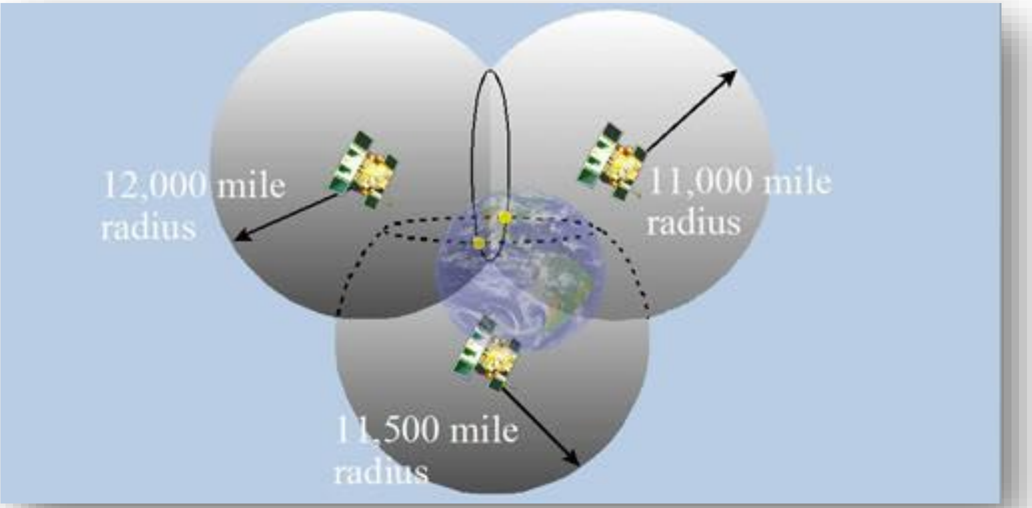


Trilateration Basics

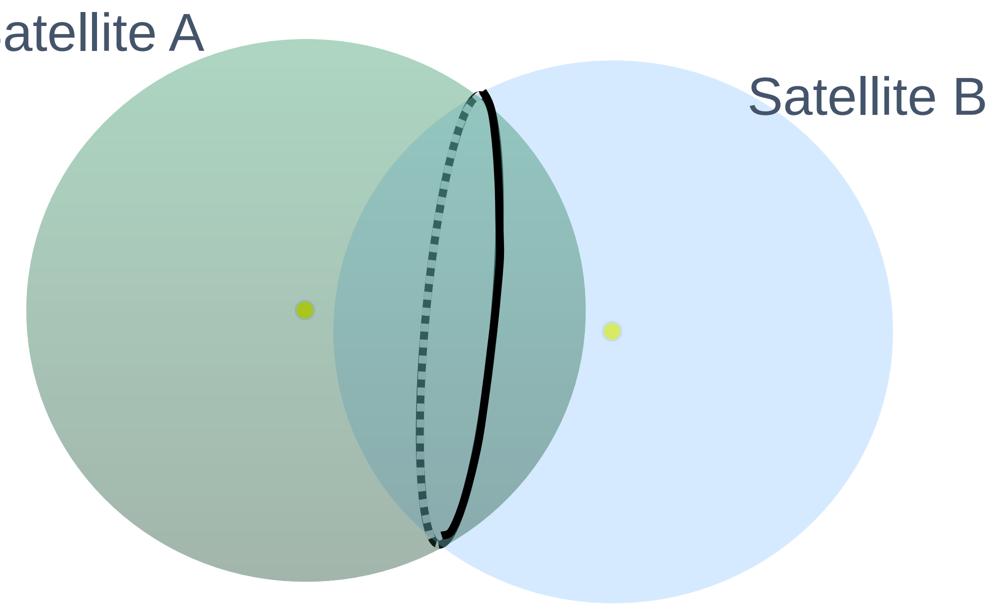


3-D Trilateration

In 3-D space, the circles we just discussed become spheres

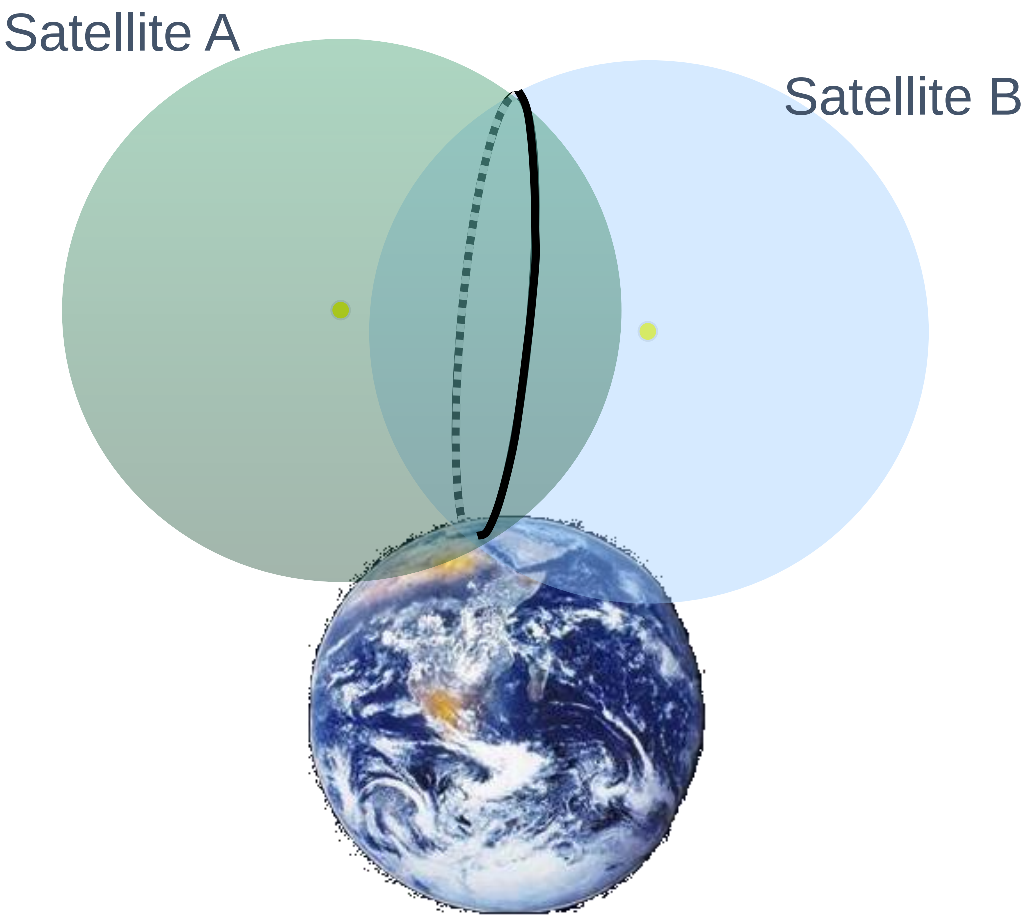


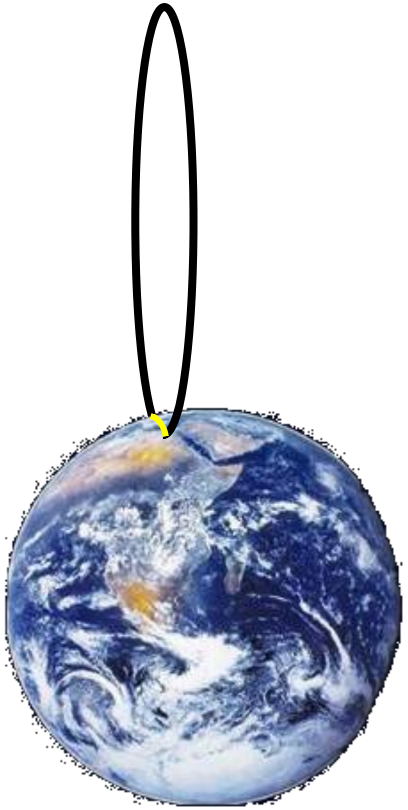
3-D Trilateration



What shape is the intersection of the two spheres?

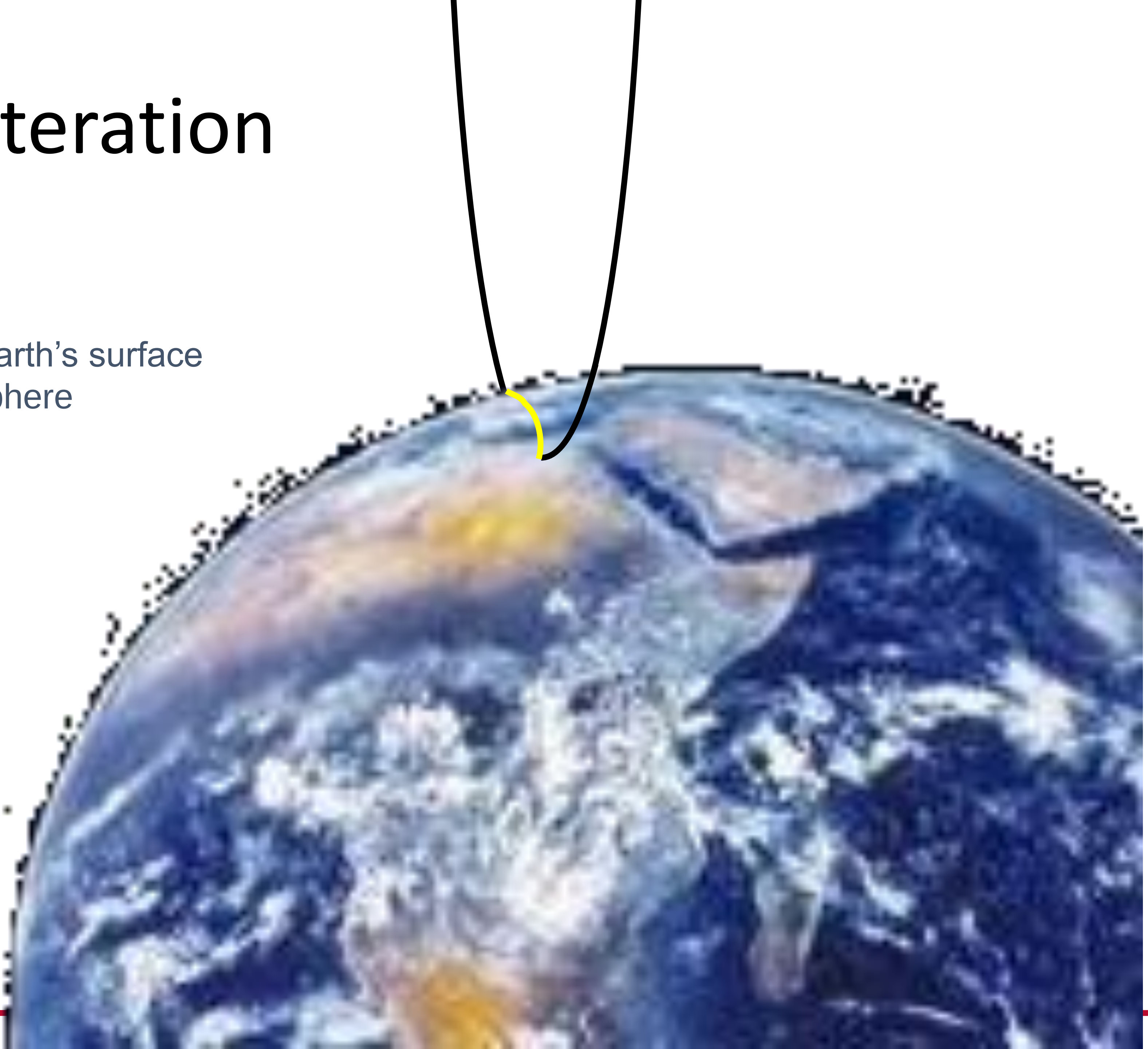
3-D Trilateration

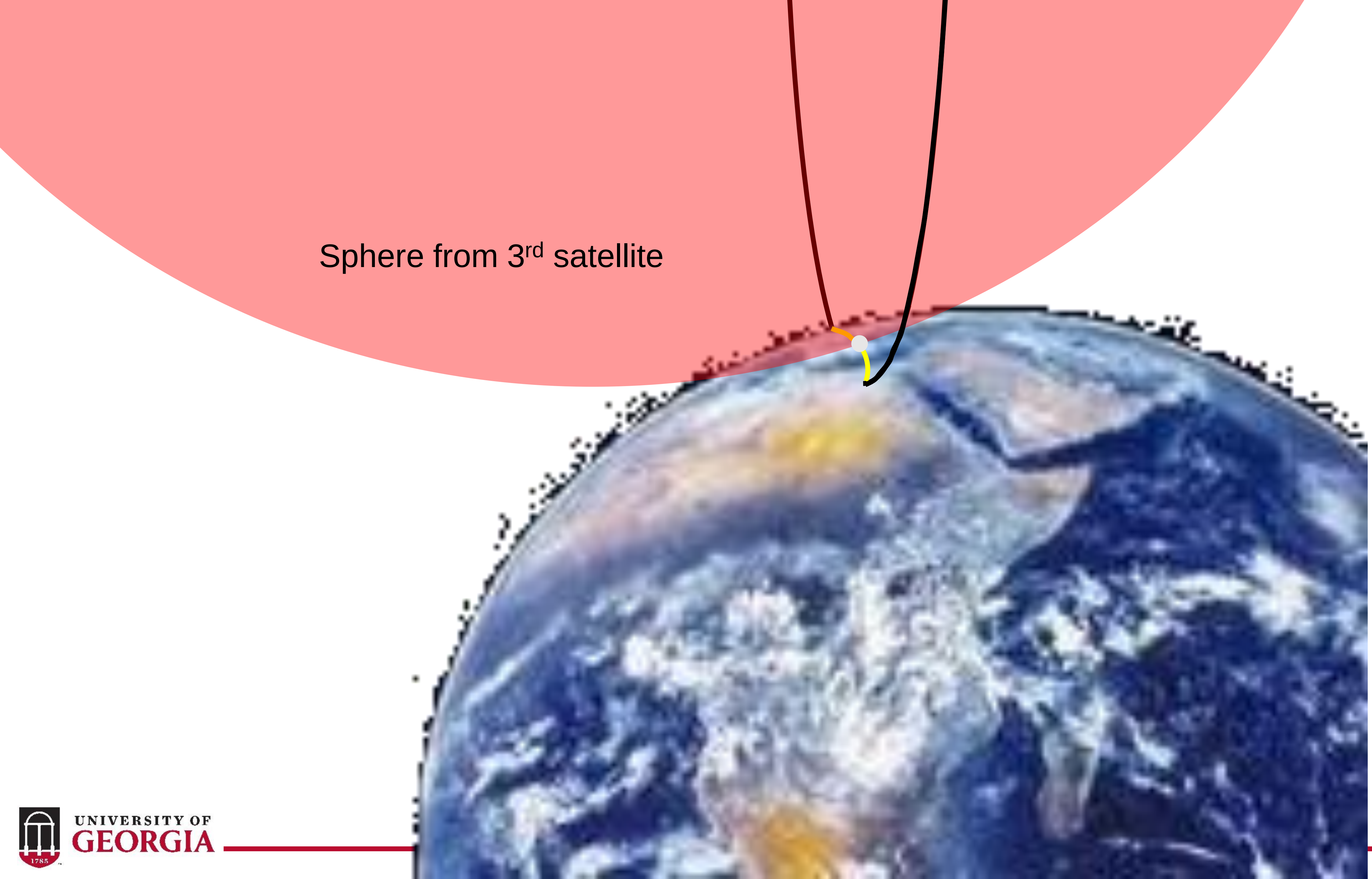




3-D Trilateration

Using the Earth's surface
as a third sphere




Sphere from 3rd satellite

3-D Trilateration

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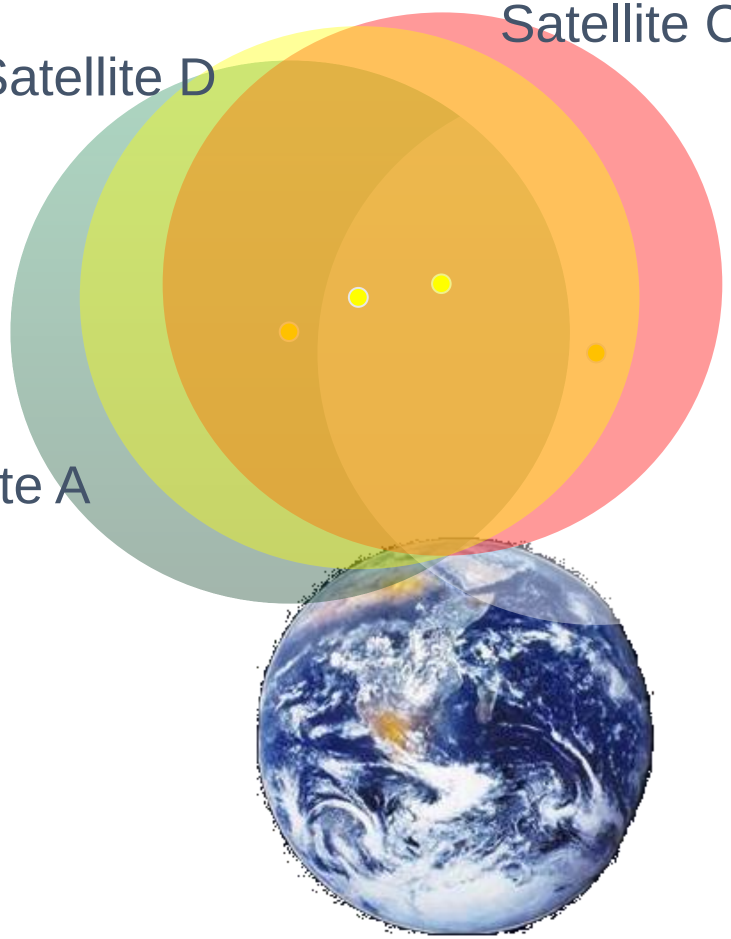

4 satellites are required to locate our position accurately.

How Far Away are those Satellites?

- GPS receiver must calculate distance to satellites. How?
- Radio waves are electromagnetic energy
  - Travel at $3x10^8$ m/s (186,000 miles/s)
- Receiver calculates how far the signal has traveled by timing how long it took the signal to arrive.

Synchronizing Clocks

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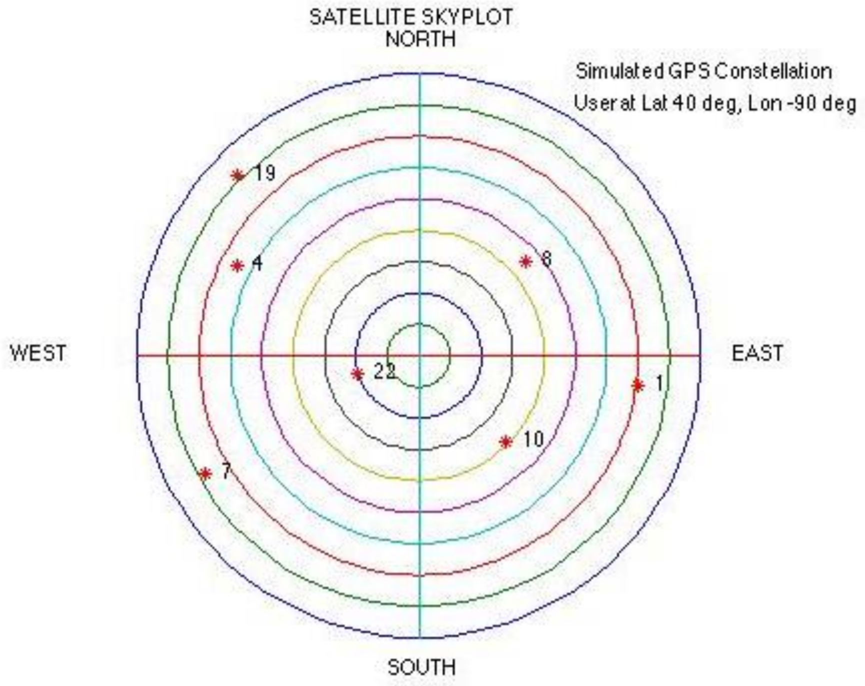
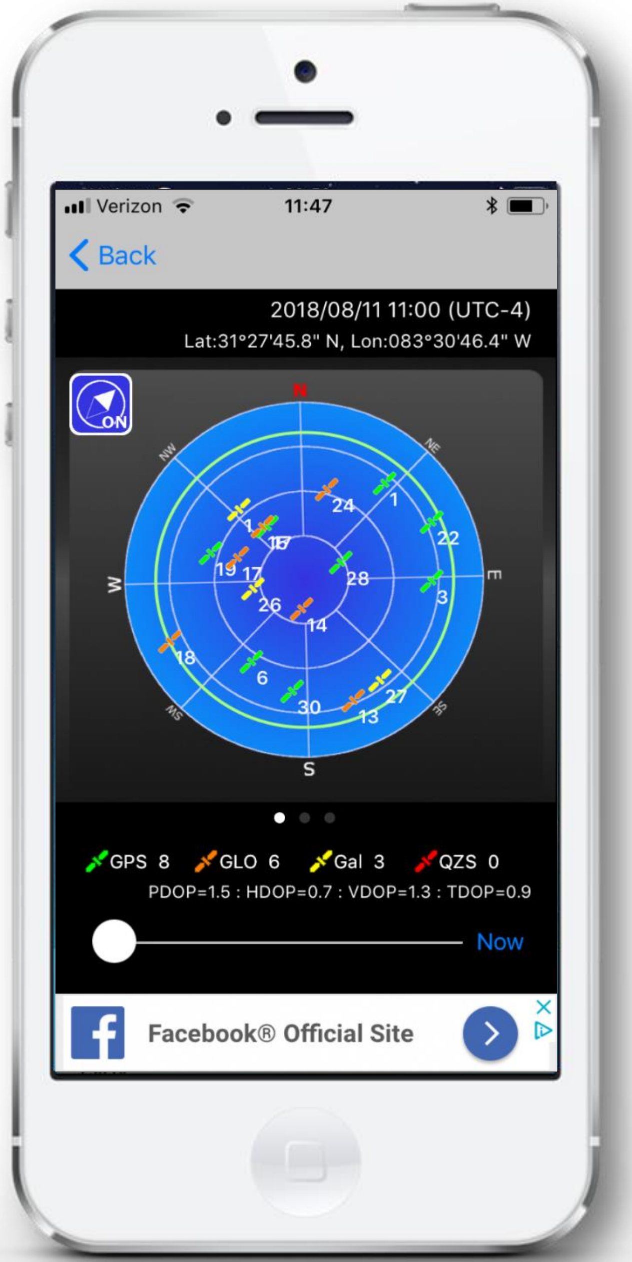
- To measure travel time, GPS receiver must know when the signal left the satellite
- To do this, clocks on GPS receiver and satellites must be synchronized
- Satellites have very accurate atomic clocks
- A GPS receiver, using the time broadcast by all the satellites it sees, constantly corrects its clock making it almost as accurate as an atomic clock

GPS Receiver also Needs…

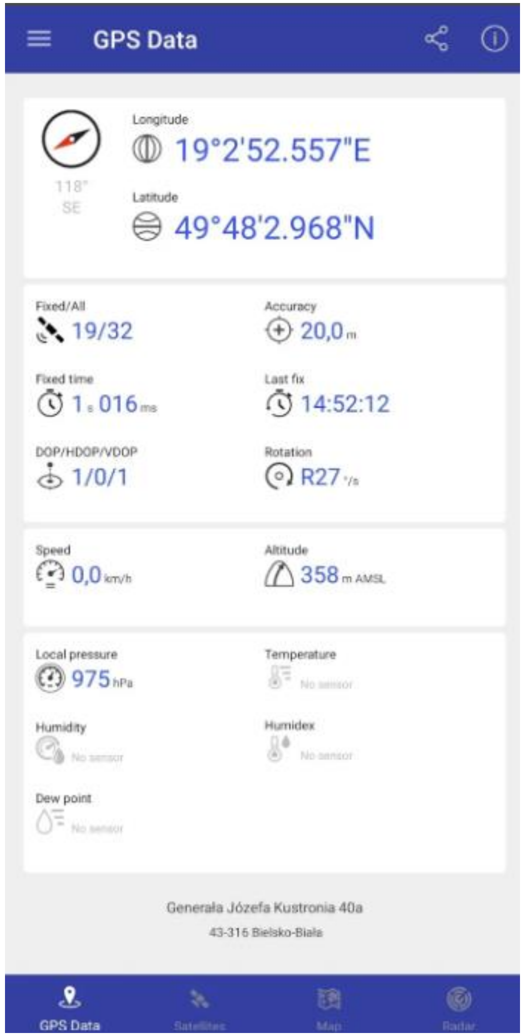
- Location of the satellites in the sky
- Almanac of satellites



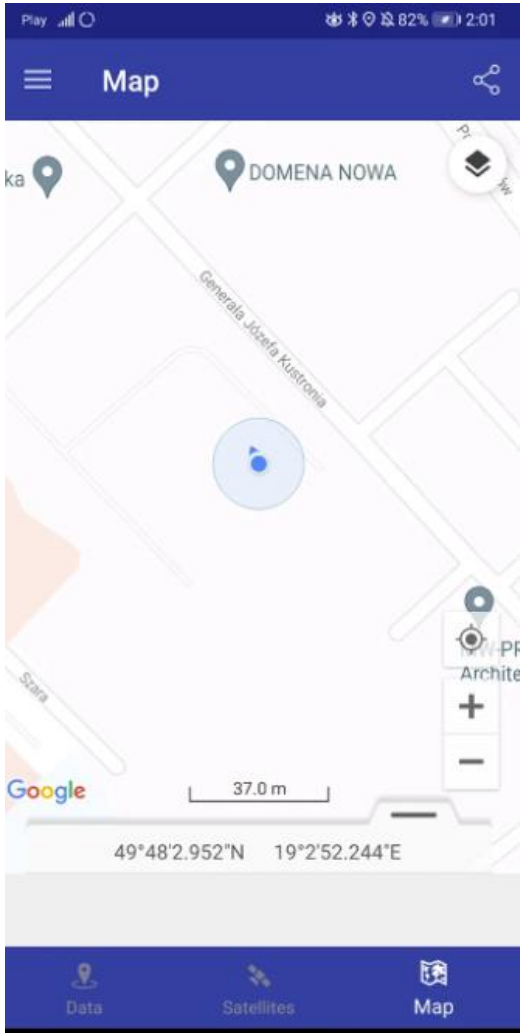


GPS Plan
iOS devices

GPS data- App


GPS Data
Longitude
19°2'52.557"E
Latitude
49°48'2.968"N
118°
SE
Fixed/All
19/32
Accuracy
20,0 m
Fixed time
1 s 016 ms
Last fix
14:52:12
DOP/HDOP/VDOP
1/0/1
Rotation
R27
Speed
0,0 km/h
Altitude
358 m AMSL
Local pressure
975 hPa
Temperature
Humidity
Humidex
Dew point
Generała Józefa Kustronia 40a
43-316 Bielsko-Biała
GPS Data


Radar
150
120
S
E
210
60
240
30
W
N
330
300
Jun 16, 2020 15:04:35
100 m
10 km
100 km
Accuracy
4,0 m
Target dist.
447
Jun 16, 2020 15:03:27
53°48'11"N 19°41'41"E
Jun 16, 2020 15:03:39
50°5'51"N 19°45'0"E
Jun 16, 2020 15:03:50
49°49'49"N 18°57'24"E
Jun 16, 2020 15:04:02
49°54'55"N 19°3'13"E
Jun 16, 2020 15:04:15
49°43'53"N 18°52'31"E
Radar


Map
DOMENA NOWA
Generała Józefa Kustronia
Google
37.0 m
49°48'2.952"N
19°2'52.244"E
Data
Satellites
Map

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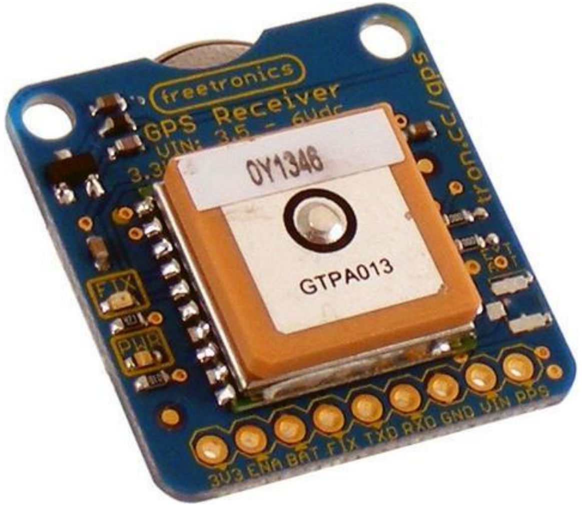
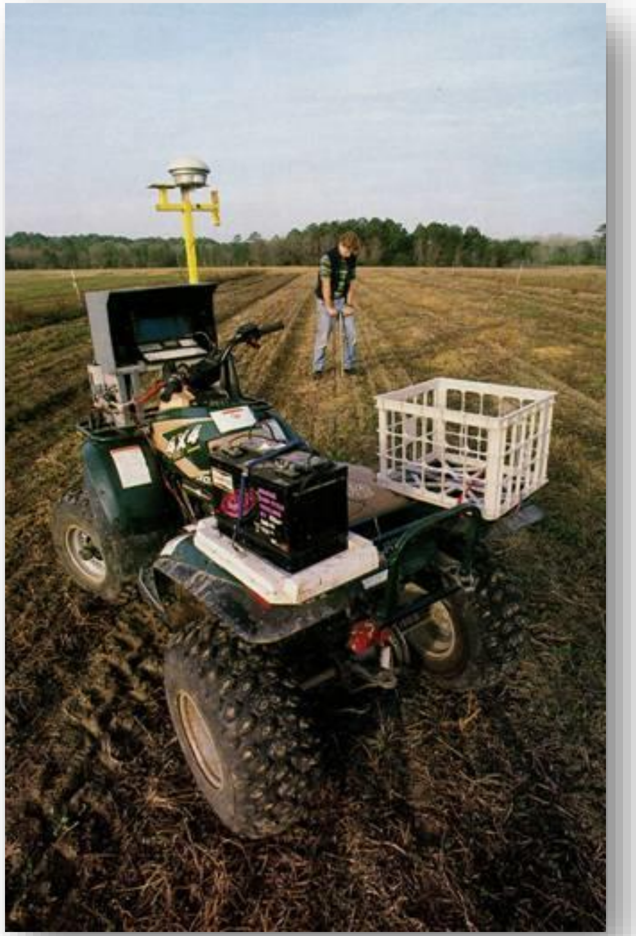
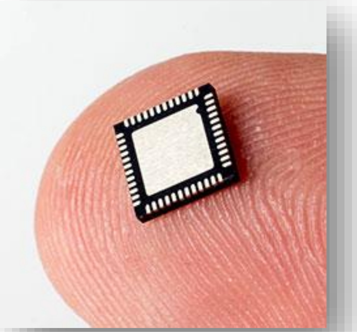
How Does GPS Work?





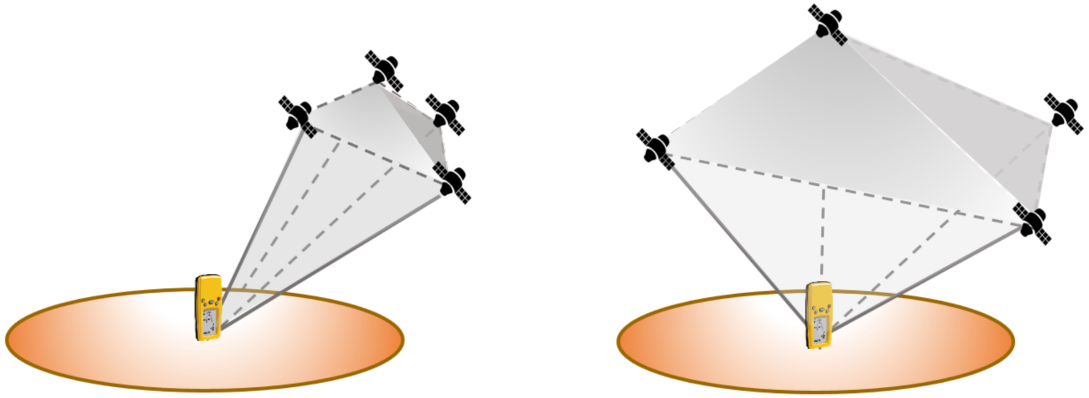


gpsworld.com

Errors

- Ionosphere and Troposphere induced delays of the radio signal
- GPS receiver clock error
- Signal multi-path
- Orbital errors – satellite's deviations from theoretical orbit due to gravitational pull of Earth and Moon, solar wind, etc.
- Dilution of precision (DOP)

Satellite Geometry and Dilution of Precision (DOP)



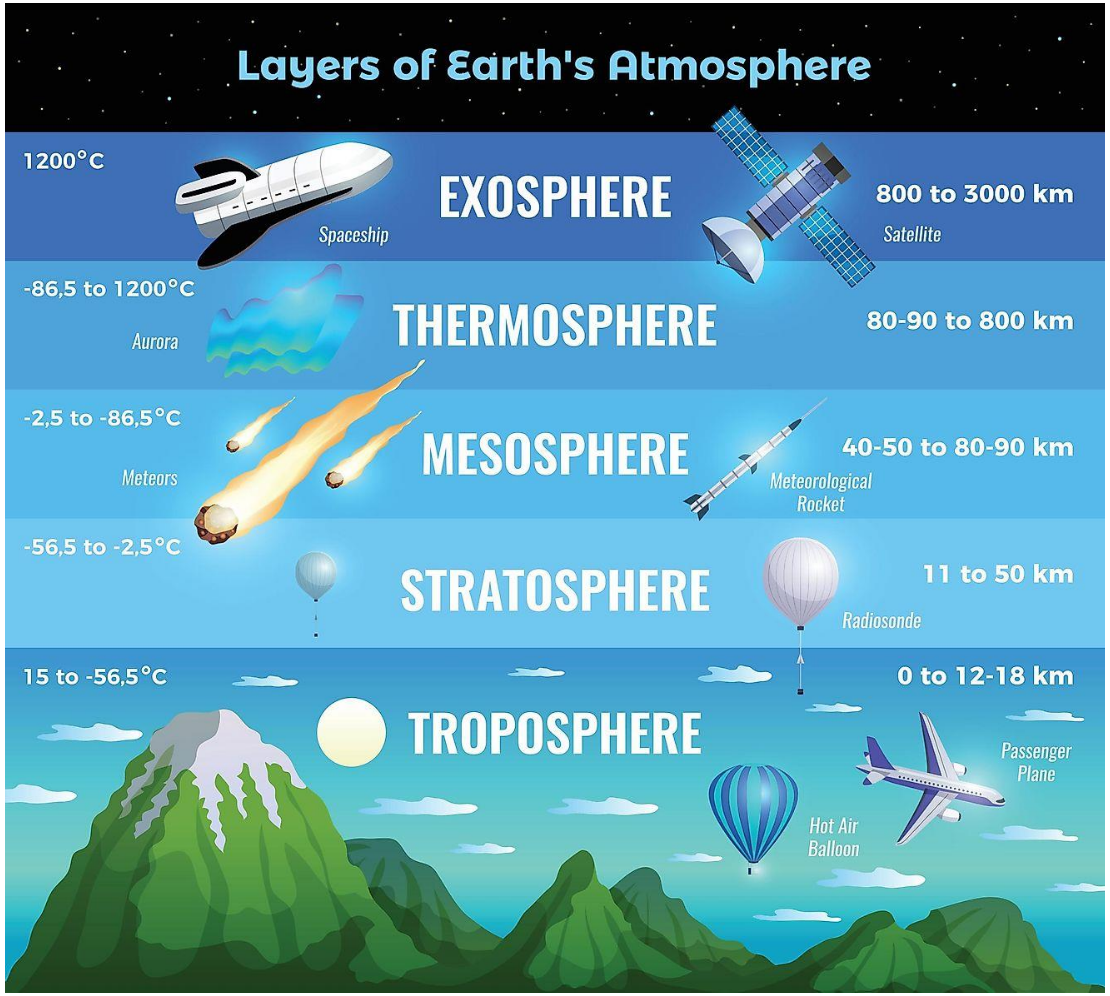
(a) Satellites clustered together
Satellite geometry enclosing less volume
BAD DOP (HIGH DOP VALUE)

(b) Satellites far apart in the sky
Satellite geometry enclosing more volume
GOOD DOP (LOW DOP VALUE)

Chinmaya S Rathore, CoG, IIFM

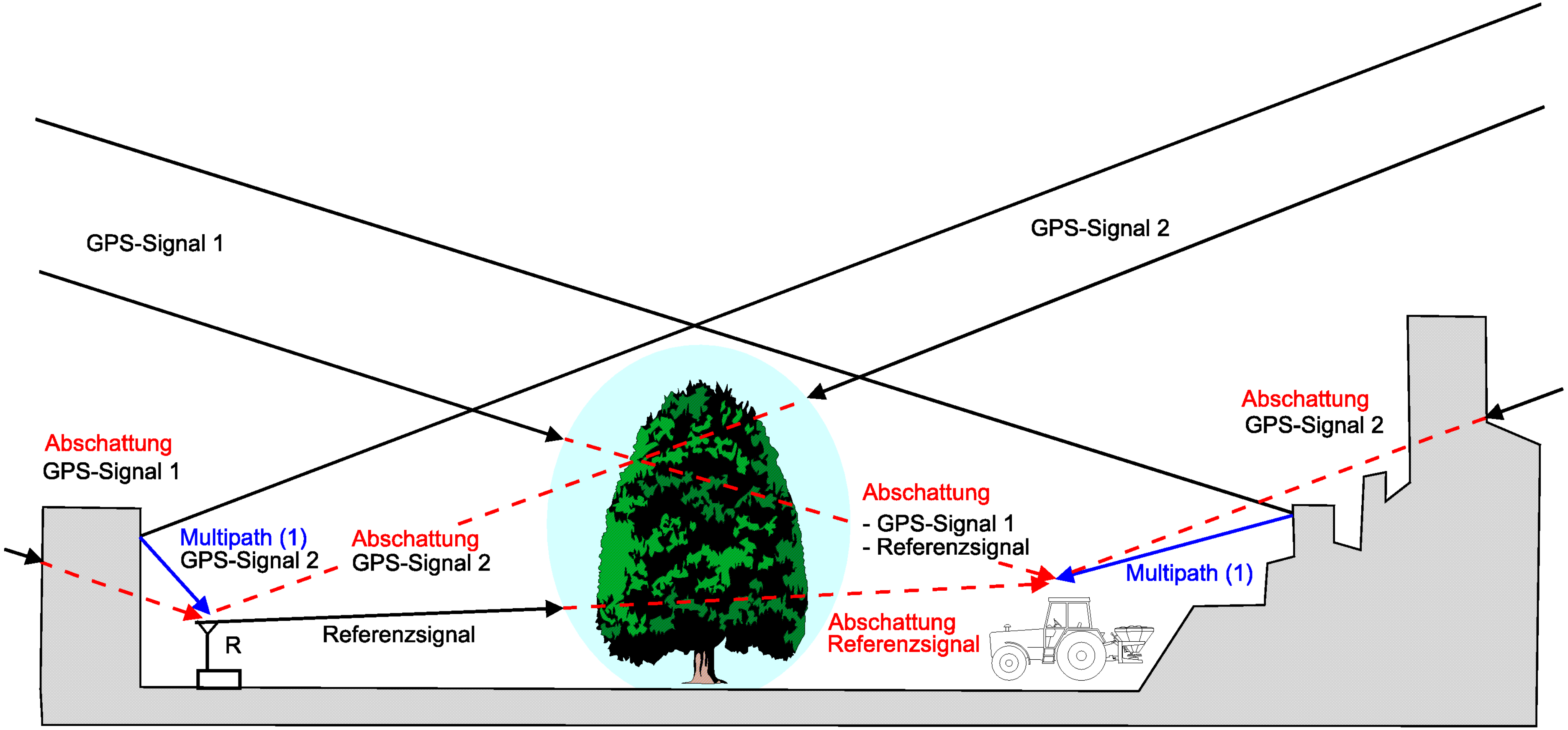
Ionosphere and Troposphere

- Radio signals travel at the speed of light in space
- Their propagation in the ionosphere and troposphere is slower
- Electrons and positive charged ions are formed by the ionizing force of the sun in the ionosphere
- These refract the electromagnetic waves resulting in an elongated signal runtime
- Different concentrations of water vapor in the troposphere refract the waves also resulting in elongated signal runtime



https://www.worldatlas.com/

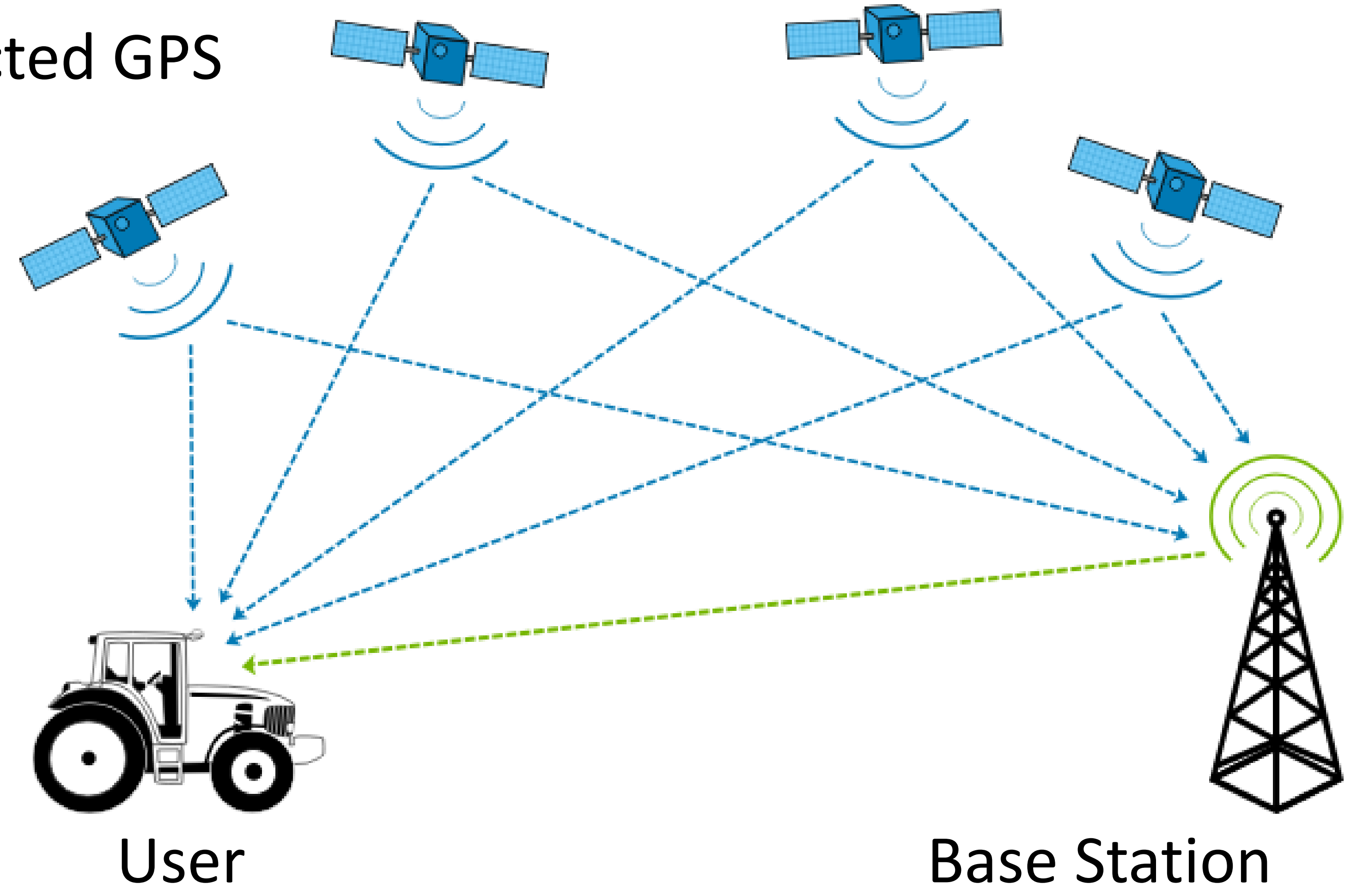
GPS Errors – Signal Multi-Path



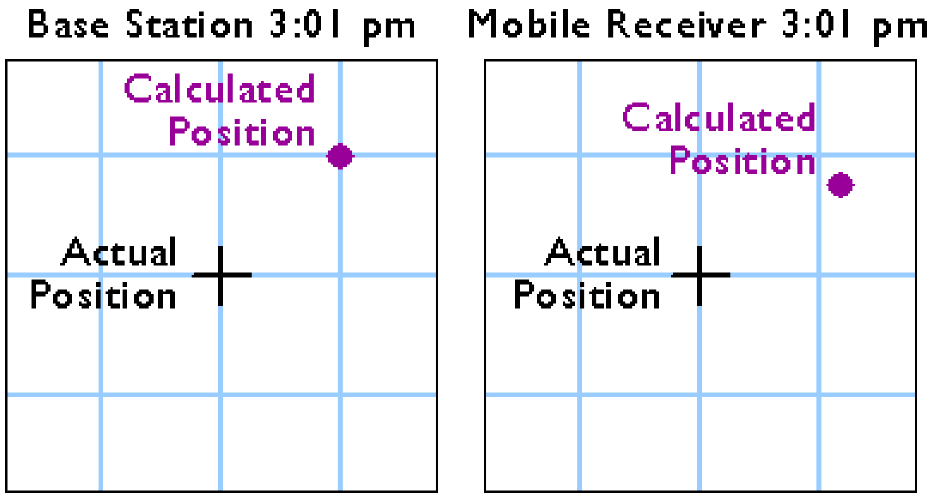
Quelle: Seebauer, C.: Diplomarbeit Weihenstephan, 1995, S. 46

How to Correct for Errors? – DGPS

DGPS – Differentially corrected GPS



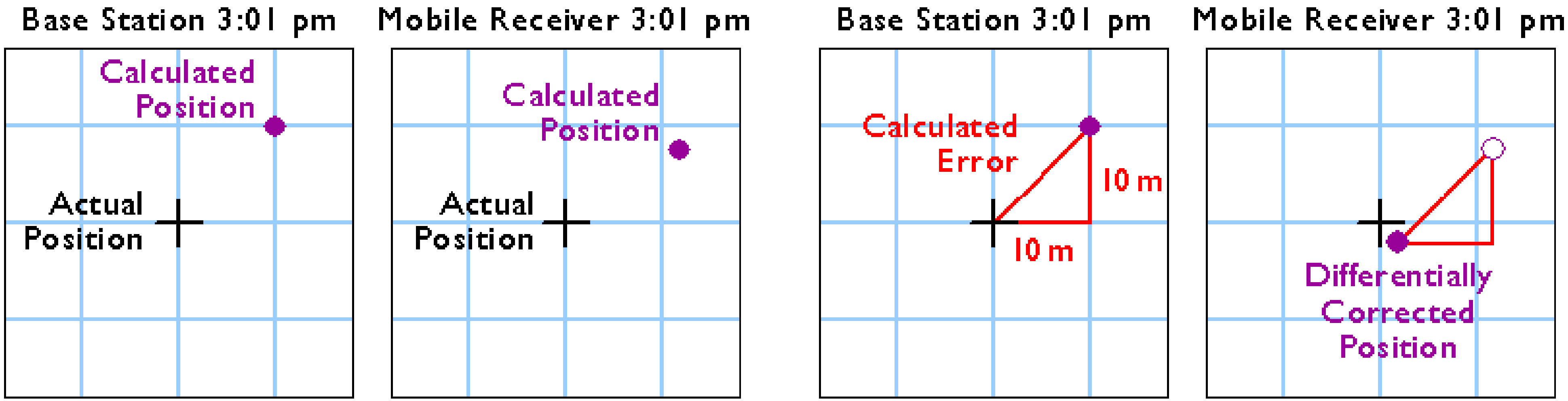
How to Correct for Errors? – DGPS



Before differential correction

https://www.e-education.psu.edu/natureofgeoinfo

How to Correct for Errors? – DGPS



Before differential correction

After differential correction

https://www.e-education.psu.edu/natureofgeoinfo

Sources of DGPS Correction

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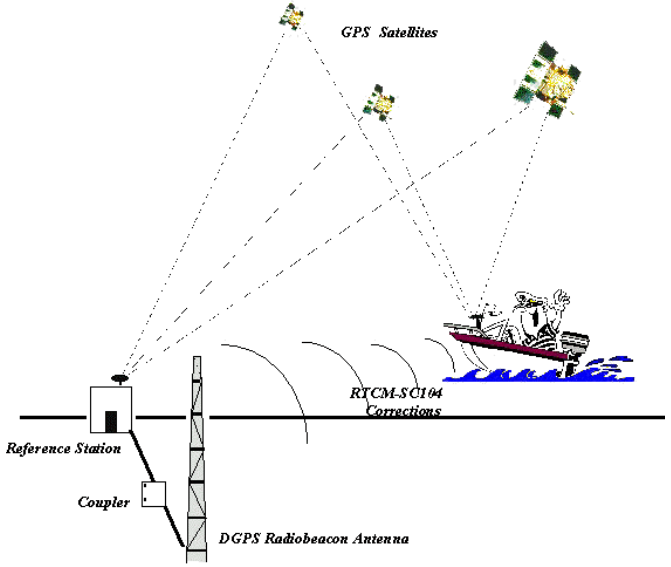
- Subscription to private providers via satellite broadcast
  - Omnistar, FUGRO, etc.
  - Most accurate signal (depending on receiver quality)
- WAAS – Wide Area Augmentation System (FAA)
- EGNOS – European Geostationary Navigation Overlay Service
- State Departments of Transportation (DOT) beacons
- Real time kinematic (RTK)
- Cellular modem, internet, etc.

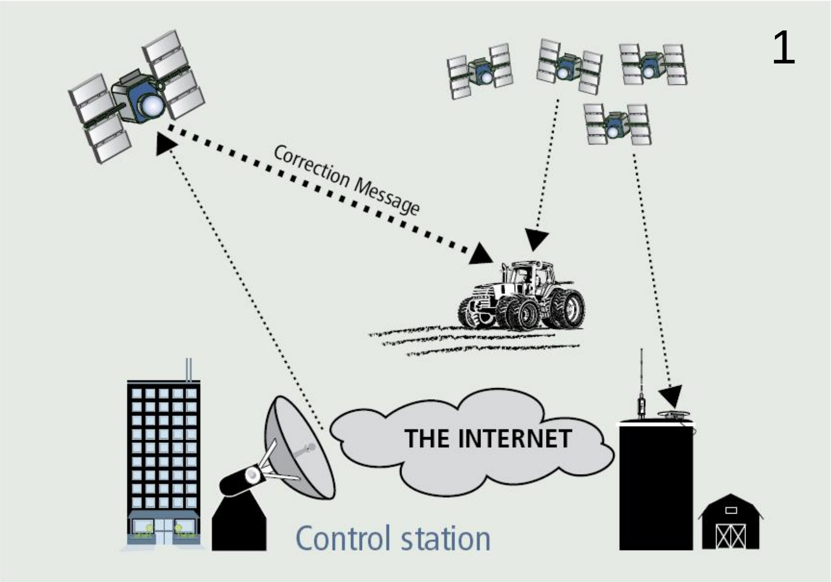
Coast Guard, US DOT, & Corps of Engineer Beacons

- Original public source of DGPS
- Discontinued by 2020

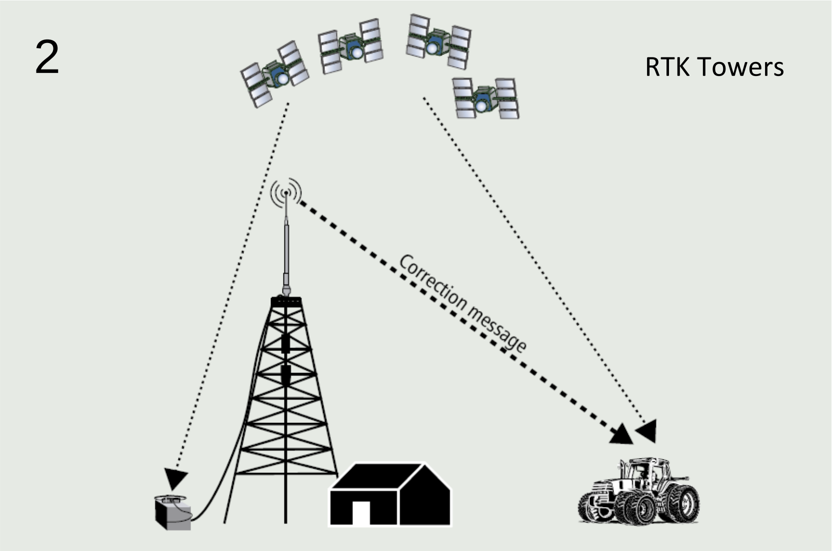


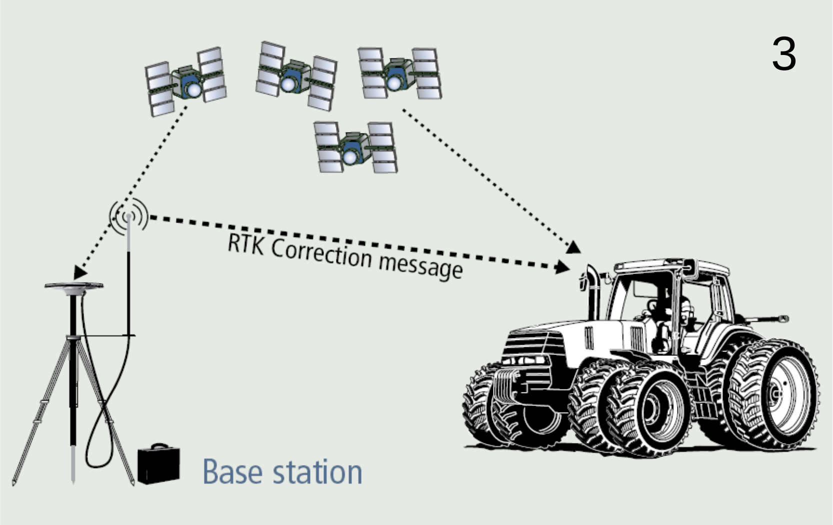
navcen.uscg.gov

Differential Correction Signals



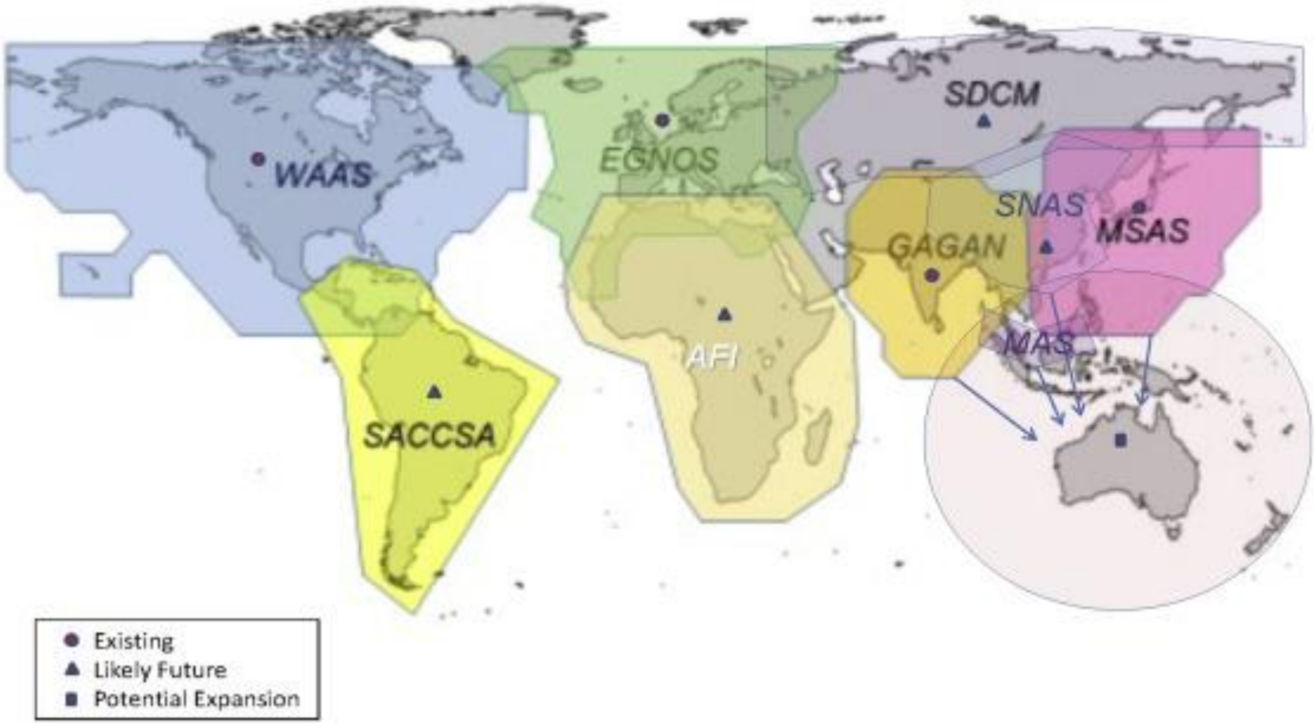
1. Differential GPS (DGPS) with WAAS, EGNOS, OmniSTAR, or StarFire Correction
2. RTK (Real Time Kinematic) subscription service from towers
3. RTK with personal base station





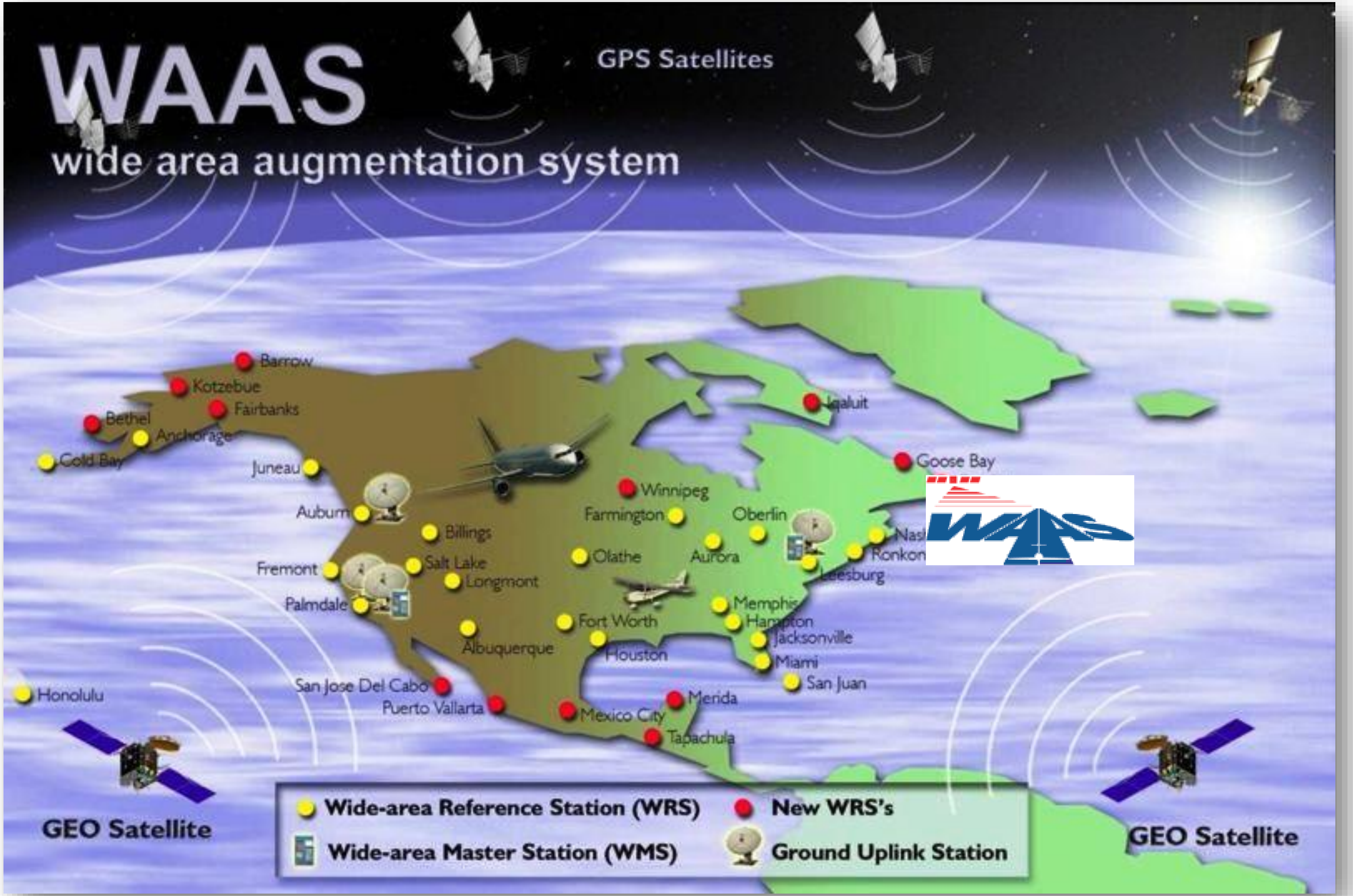
source: www.trimble.com

Differential Correction Signals



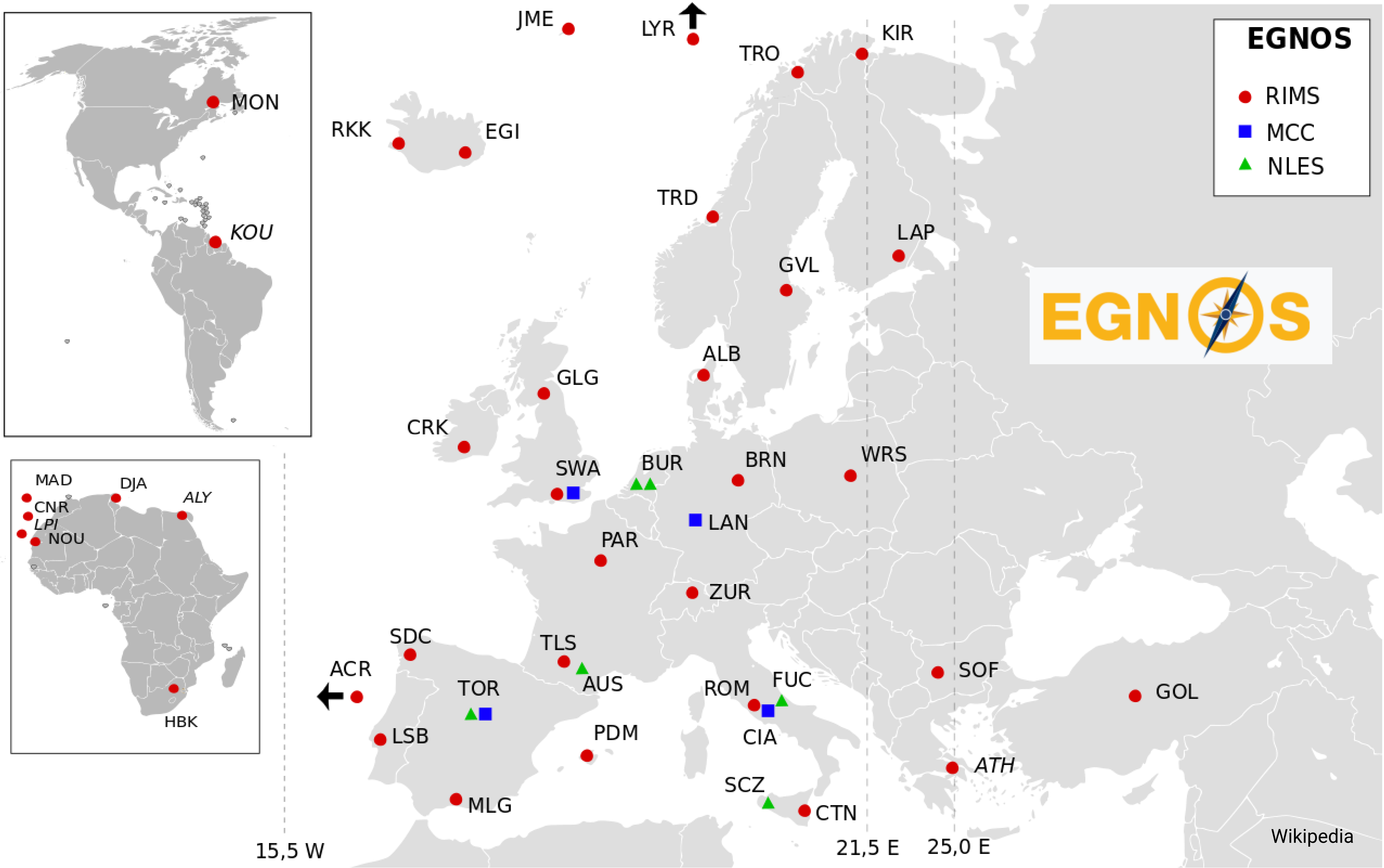
R. Sabatini, T. Moore, S. Ramasamy. 2017. Global navigation satellite systems performance analysis and augmentation strategies in aviation. *Progress in Aerospace Sc*iences. 95:45-98. https://doi.org/10.1016/j.paerosci.2017.10.002

38 (Wide Area Reference Stations) WRSs:
20 in the contiguous USA, 7 in Alaska, 1 in Hawaii, 1 in Puerto Rico, 5 in Mexico, and 4 in Canada. 3 WMS, 4 Uplinks



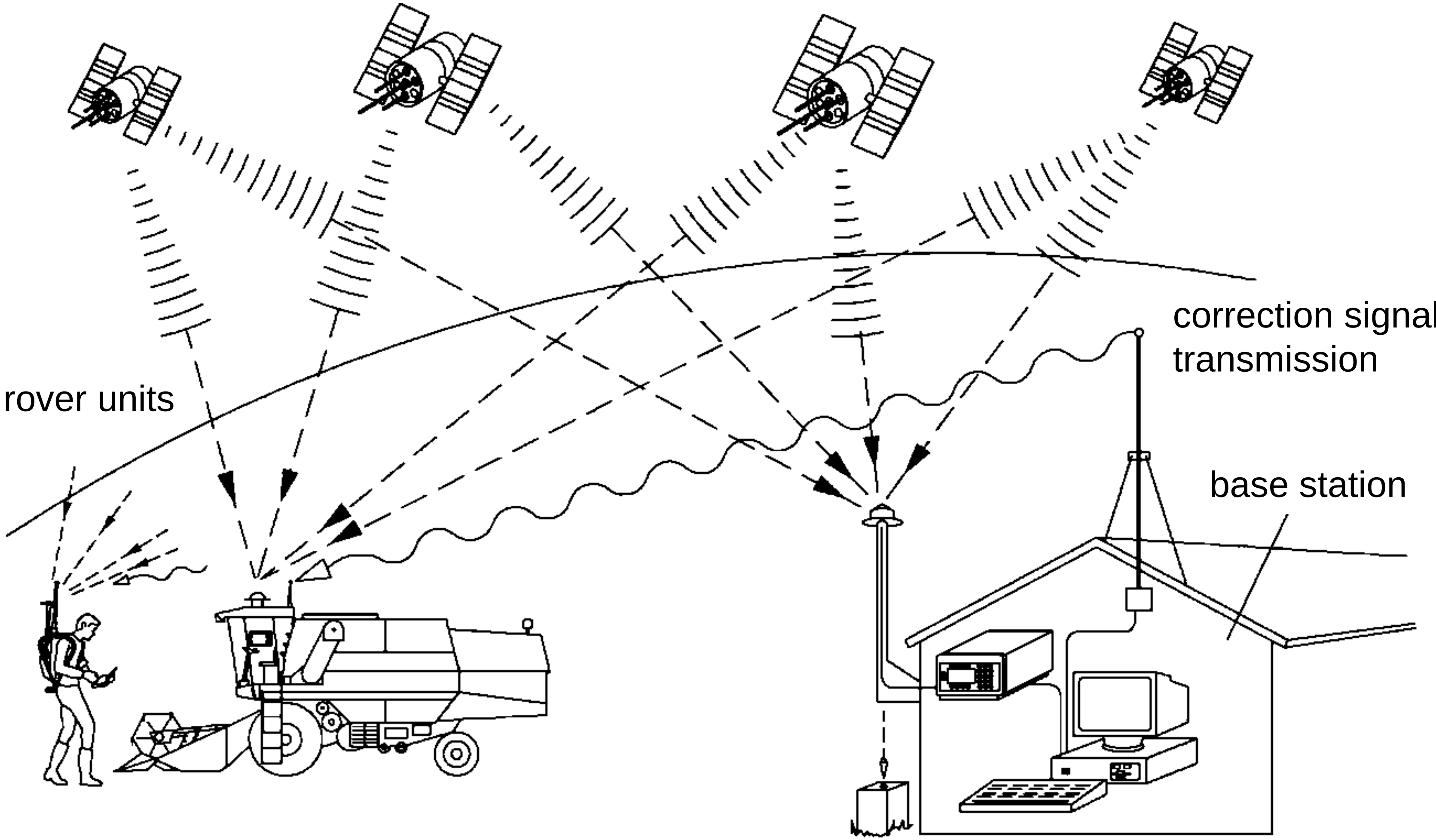
Wikipedia

- European Geostationary Navigation Overlay Service (EGNOS)
- Satellite based augmentation system (SBAS) developed by the European Space Agency, the European Commission and EUROCONTROL.
- Supplements the GPS, GLONASS and Galileo satellite navigation systems
- 40 ground stations and 3 geostationary satellites.



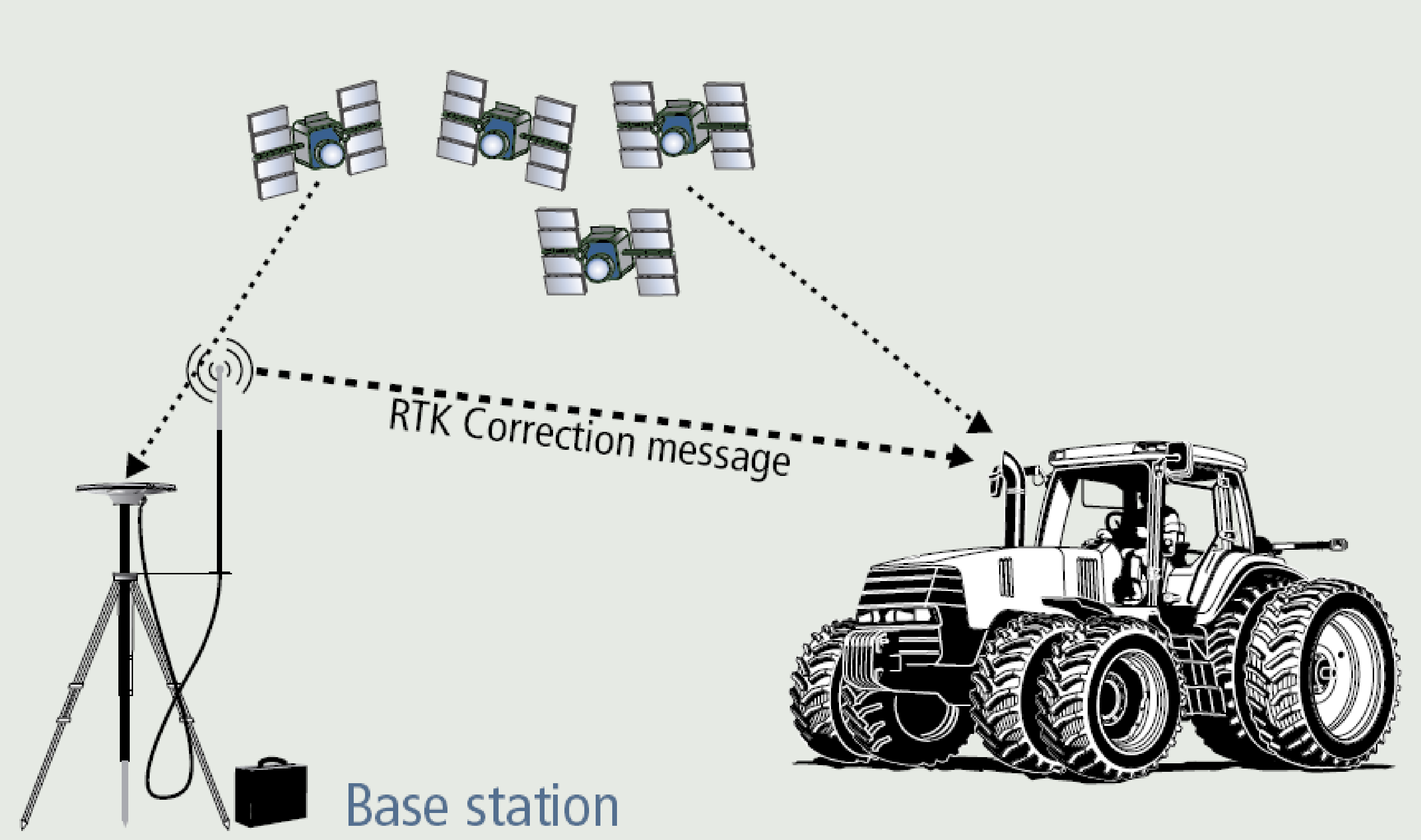
34 RIMS (**R**anging and **I**ntegrity **M**onitoring **S**tations): receiving signals from GPS satellites
4 MCC (**M**ission **C**ontrol **C**enters): data processing and differential corrections counting
6 NLES (**N**avigation **L**and **E**arth **S**tations): accuracy and reliability data sending to three geostationary satellite transponders to allow end-user devices to receive them.

RTK – Real Time Kinematic DGPS



Basics of RTK GPS

- At least 2 receivers are needed (one base, one rover).
- Both receivers observe data from at least 4 SVs.
- The radio link between the base and rover **must** be available in order to process data in real-time. This is a line-of-sight signal on 900 MHz.
- One base can supply data to multiple rovers.



source: www.trimble.com

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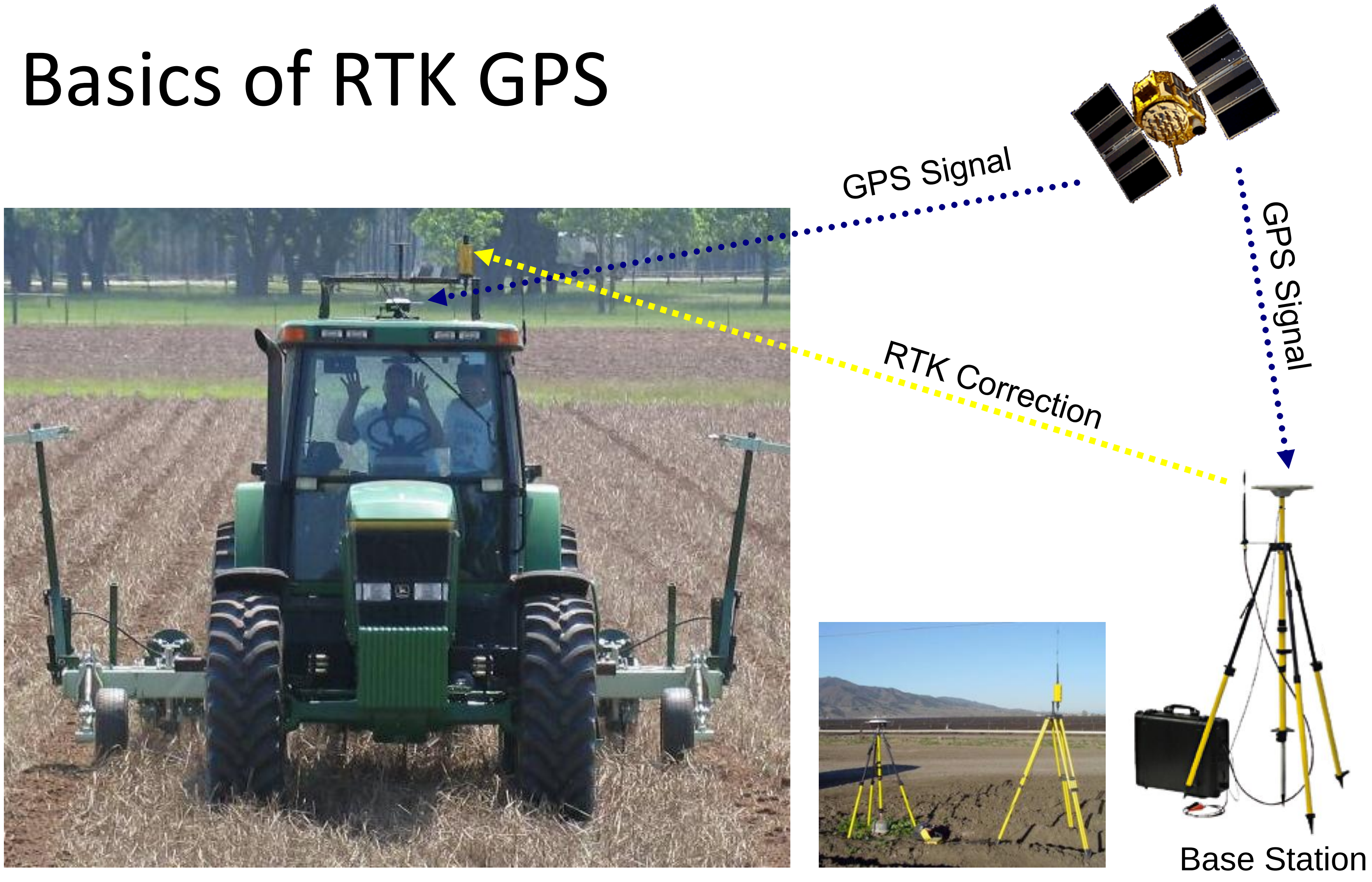
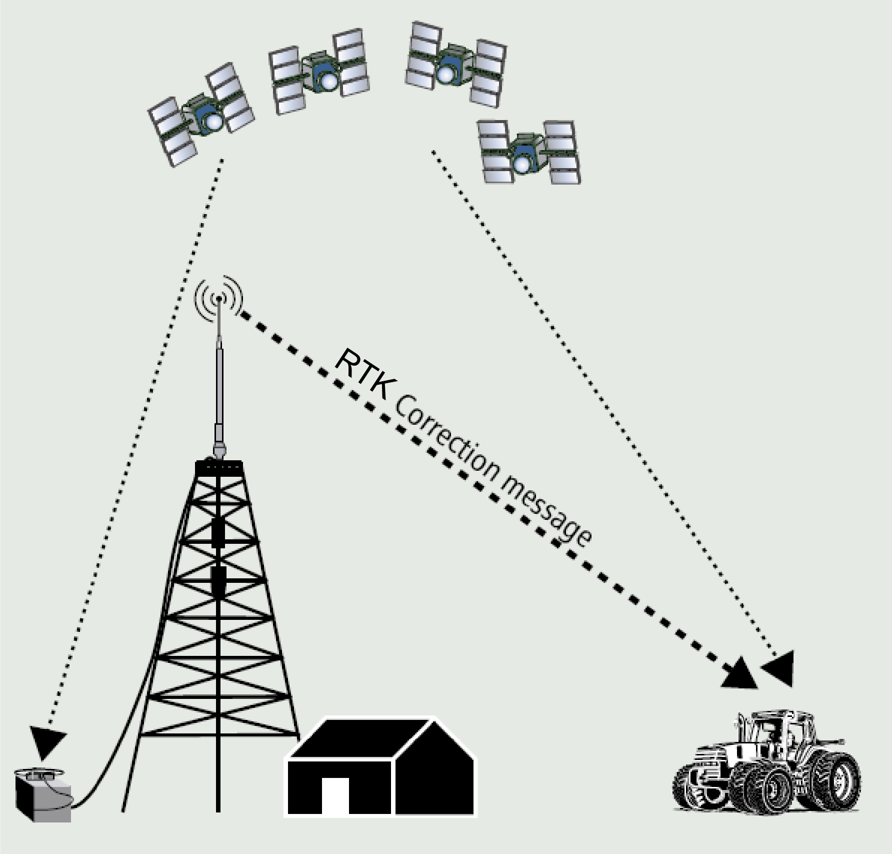
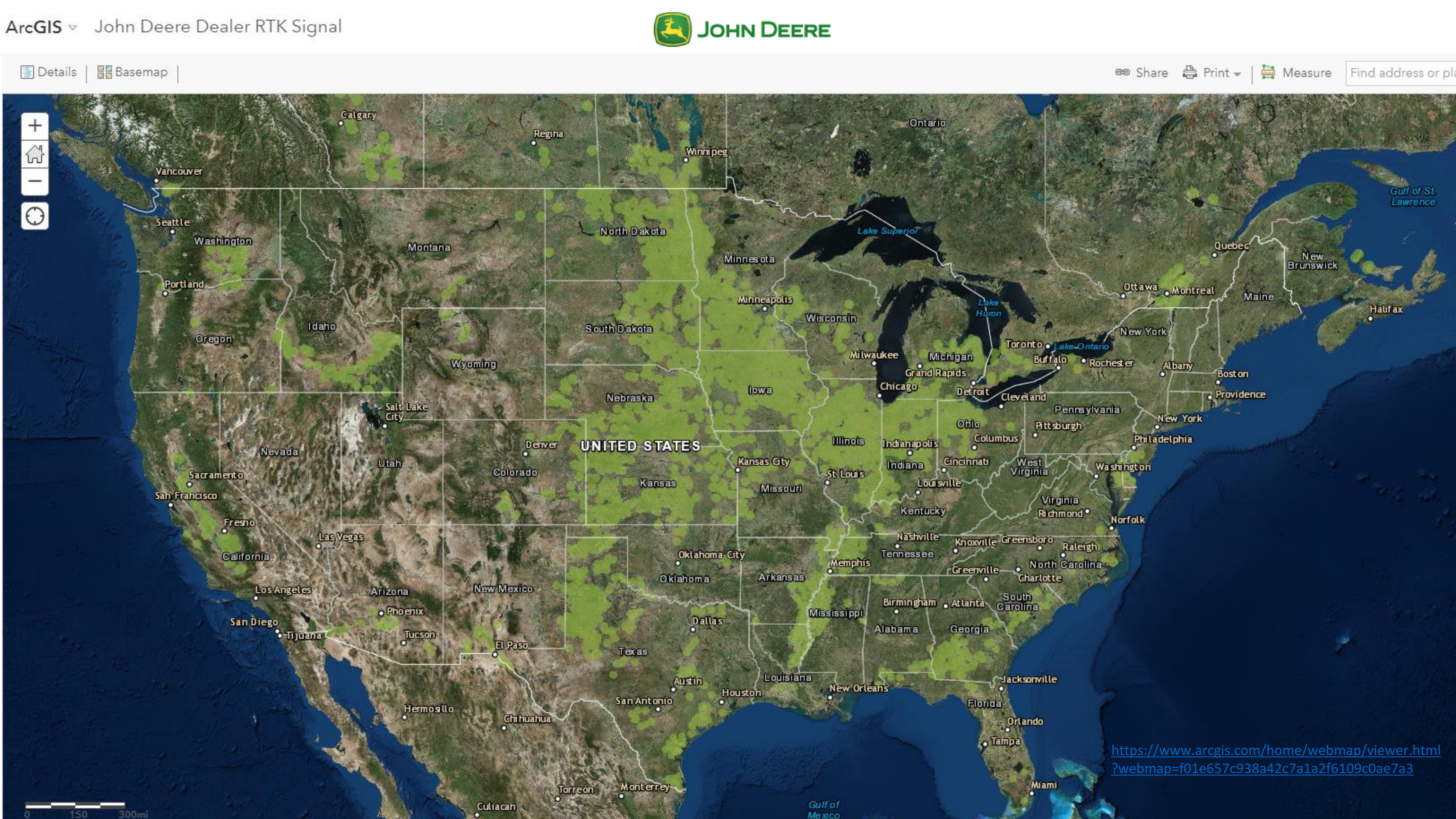
Basics of RTK GPS



Tower-Based RTK GPS



- Private companies have now established a network of densely-spaced base stations.
- Users can access RTK quality correction without establishing their own base stations.



https://www.arcgis.com/home/webmap/viewer.html?webmap=f01e657c938a42c7a1a2f6109c0ae7a3

Virtual Reference (Base) Station (VRS)

- A VRS is virtual reference station near the RTK user
- It is created from the data of surrounding reference stations
- The data from several reference stations are interpolated to obtain the correction data for the approximate location of the rover
- An RTK correction based on a VRS may be more accurate than an RTK correction based on a tower which is relatively far away

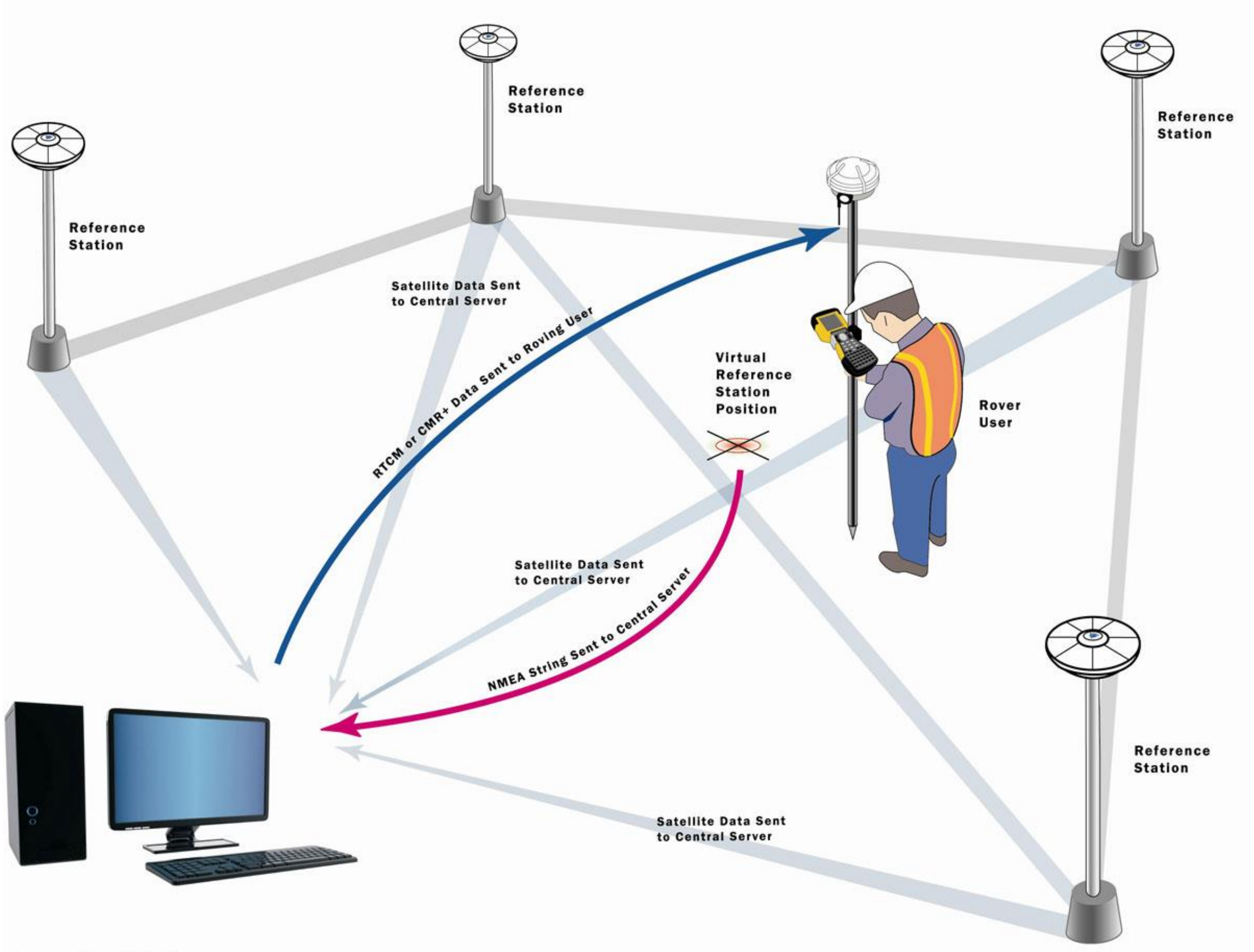
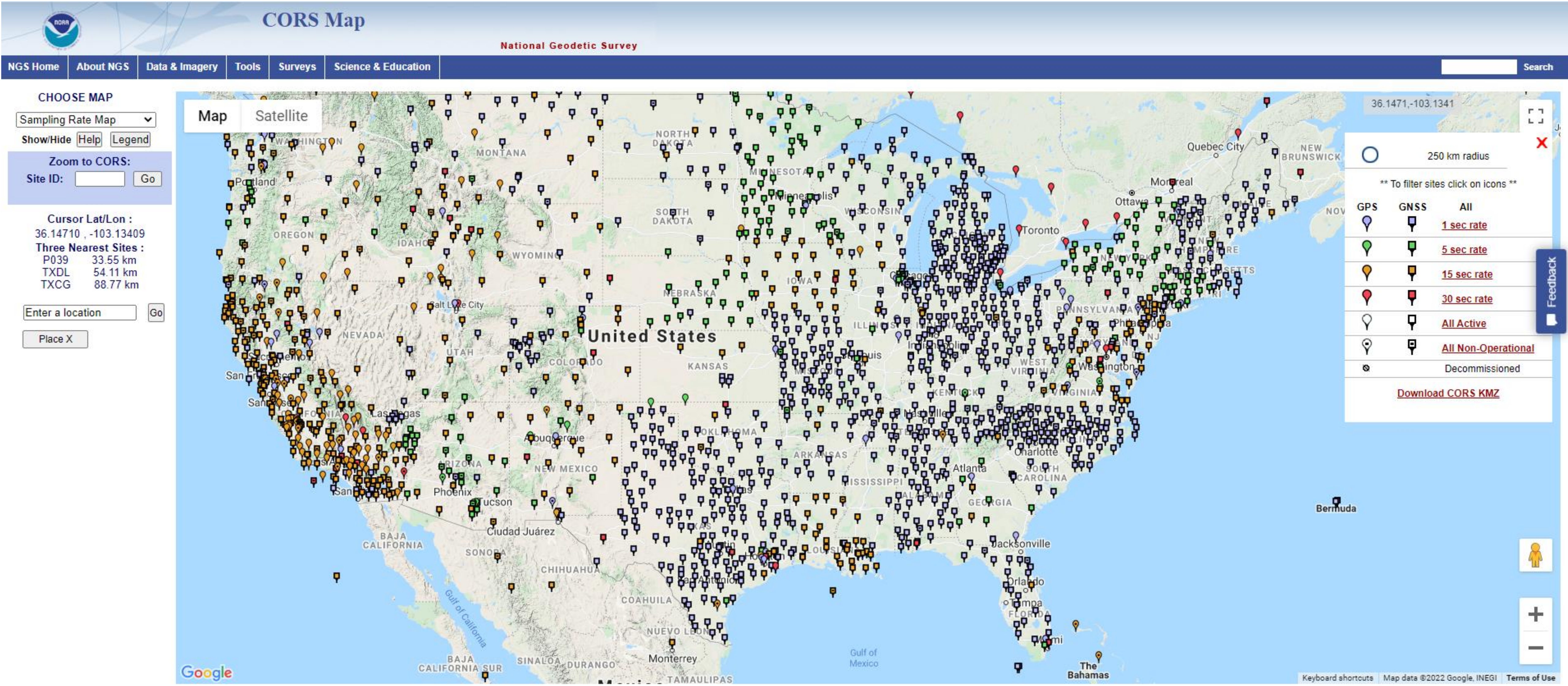
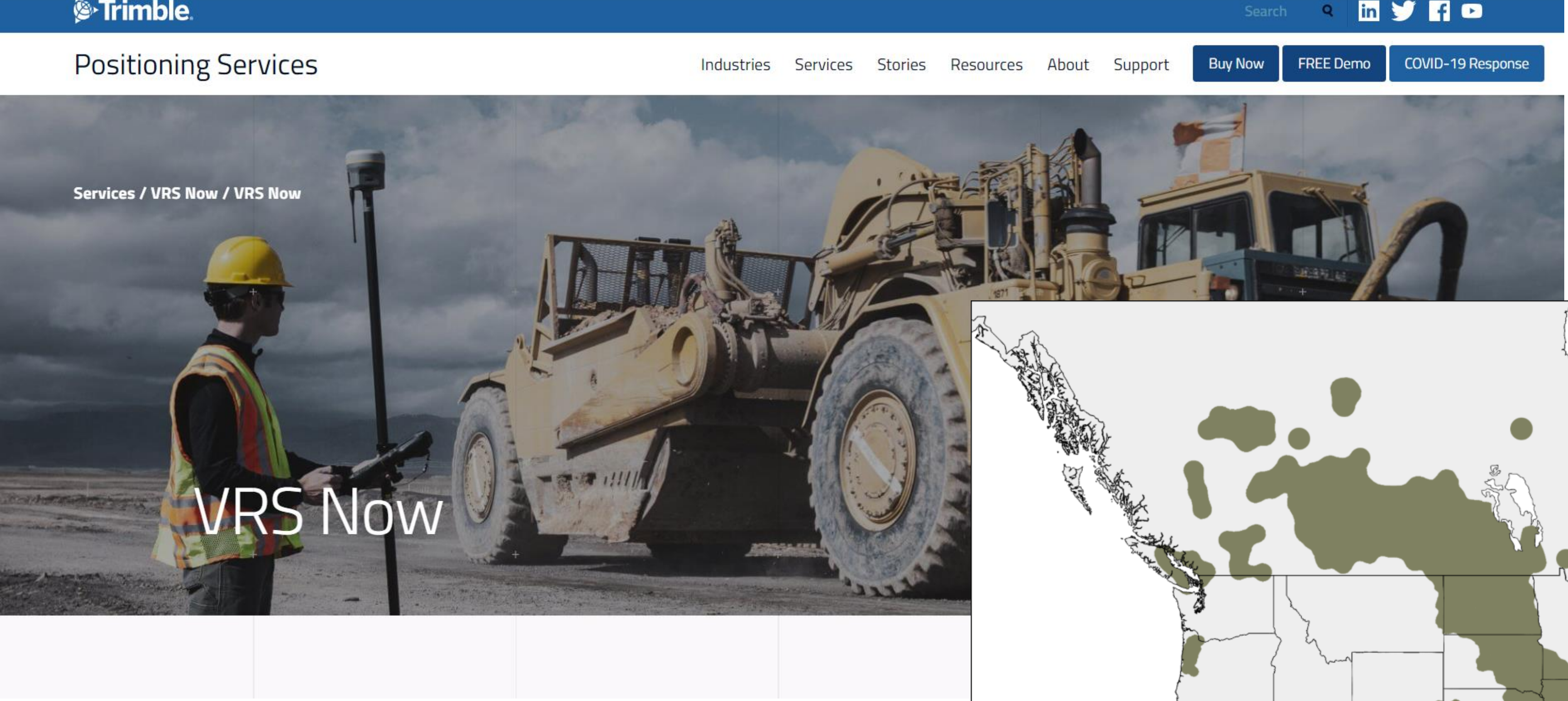
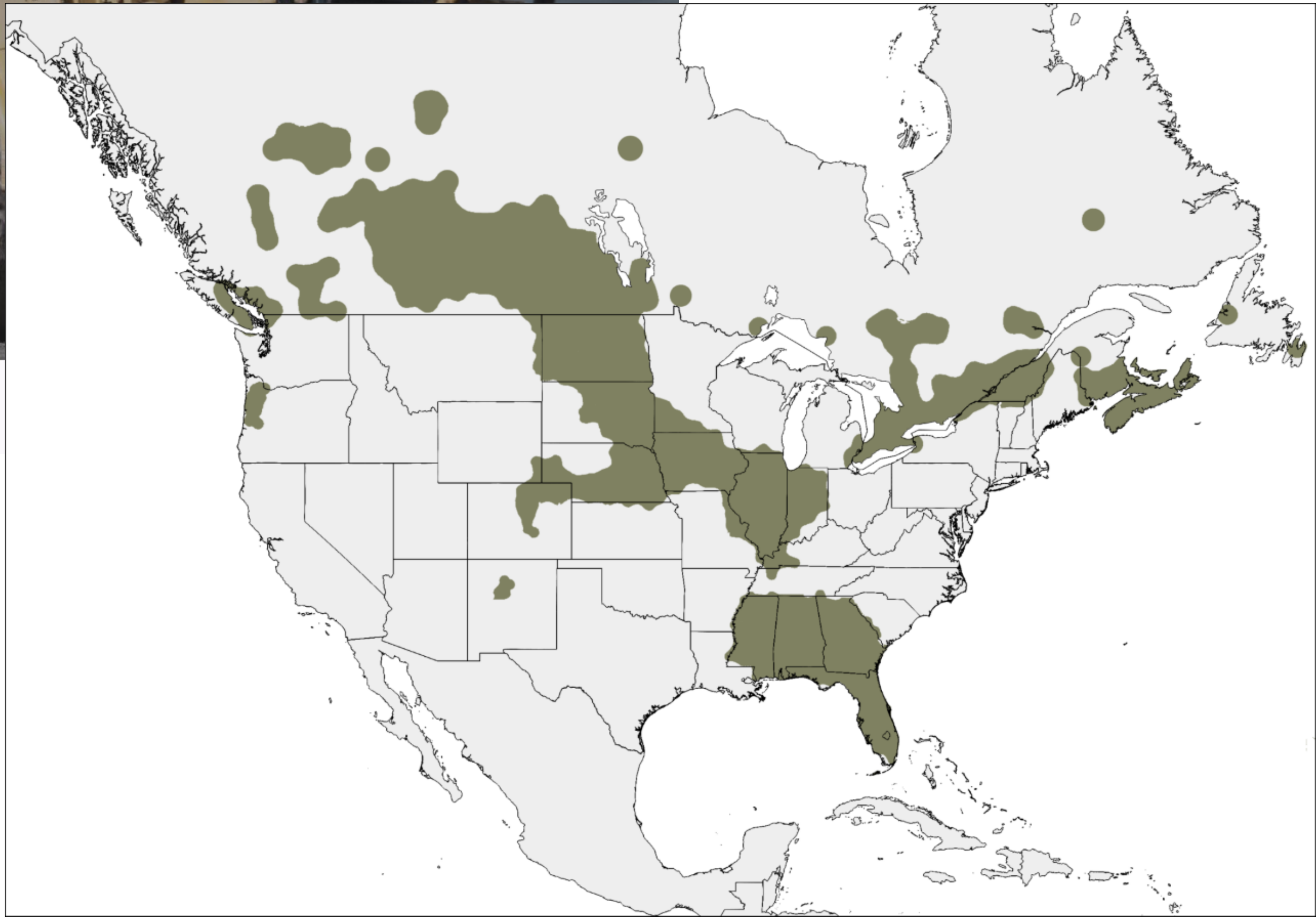


Image courtesy of Trimble

Continuously Operating Reference Station (CORS)







- Trimble VRS coverage

Catalyst 1

Centimeter accuracy
(1 cm)

Starting at
$390/mo

(per user, on a monthly plan)*

- Hourly On-demand Plans
- Monthly Plans
- Annual Plans

How to Buy ›

Catalyst 10

Decimeter accuracy
(10 cm)

Starting at
$225/mo

(per user, on a monthly plan)*

- Monthly Plans
- Annual Plans

How to Buy ›

Catalyst 30

Sub-foot accuracy
(30 cm)

Starting at
$135/mo

(per user, on a monthly plan)*

- Monthly Plans
- Annual Plans

How to Buy ›

Catalyst 60

Sub-meter accuracy
(60 cm)

Starting at
$45/mo

(per user, on a monthly plan)*

- Monthly Plans
- Annual Plans

How to Buy ›

Uses of RTK DGPS

- Topographic mapping
  - hand held units
  - vehicle mounted units
- Autosteer

Autosteer

- Planting / strip tillage
  - cotton
  - peanuts
- Bed shaping
  - vegetables
- Harvesting
  - peanuts
  - grains

NMEA 0183 Sentences

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Sentence	Sentence Contents
ALM	GPS week number, SV health, and complete almanac data for one SV
GBS	GNSS Satellite Fault Detection
GGA	Time, position, and fix related data
GLL	Position fix, time of position fix, and status
GRS	GPS Range Residuals
GSA	GPS position fix mode, SVs used for navigation and DOP values
GST	GPS Pseudo Range Noise Statistics
GSV	Number of SVs visible, PRN numbers, elevation, azimuth and SNR values
MSS	Signal strength, signal-to-noise ratio, beacon frequency, and beacon bit rate
RMC	UTC time, status, latitude, longitude, speed over ground, date, and magnetic variation
VTG	Actual track made good and speed over ground
XTE	Cross-track error
ZDA	UTC time, day, month, and year, local zone number and local zone minutes

http://www.trimble.com/OEM_ReceiverHelp/V4.44/en/NMEA-0183messages_MessageOverview.html

NMEA 0183 Sentences

- Garmin GPS-38, NMEA-0183 V. 2.0 mode Standard:
  - GLL, RMB, RMC, WPL, BOD, GSA, GSV, RTE, GGA
  - Proprietary: PGRME (estimated error), PGRMM, PGRMZ, PSLIB
- Garmin GPS-45 (and probably GPS-40 and GPS-90) Standard:
  - BOD, GLL, RTE, RMB, RMC, GGA, GSA, GSV
  - Proprietary: PGRME, PGRMM, PGRMZ
- Magellan Trailblazer Standard:
  - APB, BWC, GGA, GLL, RMB, RMC, VTG
- Trimble Ensign XL Standard:
  - APA, BWC, BWR, GGA, GLL, RMB
- Trimble Flightmate Pro and Scoutmaster Standard:
  - APA, APB, BWC, GGA, GLL, GSA, GSV, RMB, RMC, VTG, WCV, XTE, ZTC

GGA Sentence

- **GPS fix data**
  The GGA sentence contains the time, position, and fix related data:

```
$GPGGA,151924,3723.454444,N,12202.269777,W,2,09,1.9,
-17.49,M,-25.67,M,1,0000*57
```

Field	Description
1	UTC of position fix in HHMMSS.SS format
2	Latitude in DD MM,MMMM format (0-7decimal places)
3	Direction of Latitude: N = North, S = South
4	Longitude in DD MM,MMMM format (0-7decimal places)
5	Direction of Longitude: E = East, W = West
6	GPS quality indicator: 0 = fix not valid, 1 = GPS fix, 2 = DGPS fix, 4 = RTKDGPS fix 8 = Simulation mode
7	Number of SVs in use, 00 – 12
8	Horizontal dilution of precision (HDOP)

http://www.gpsinformation.org/dale/nmea.htm

GGA Sentence

- **GPS fix data**
  The GGA sentence contains the time, position, and fix related data:

```
$GPGGA,151924,3723.454444,N,12202.269777,W,2,09,1.9,
-17.49,M,-25.67,M,1,0000*57
```

Field	Description
9	Antenna height, MSL reference
10	‘M’ indicates that the altitude is in meters
11	Geoidal separation
12	‘M’ indicates that the geoidal separation is in meters
13	Age of differential GPS data record, Type 1. Null when DGPS not used
14	Base station ID, 0000 – 1023

$GPGGA,161229.487,3723.2475,N,12158.3416,W,1,07,1.0,9.0,M, , , ,0000*18

Name	Example	Units	Description
Message ID	$GPGGA		GGA protocol header
UTC Time	161229.487		hhmmss.sss
Latitude	3723.2475		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12158.3416		dddmm.mmmm
E/W Indicator	W		E=east or W=west
Position Fix Indicator	1		See
Satellites Used	07		Range 0 to 12
HDOP	1.0		Horizontal Dilution of Precision
MSL Altitude	9.0	meters	
Units	M	meters	
Geoid Separation		meters	
Units	M	meters	
Age of Diff. Corr.		second	Null fields when DGPS is not used
Diff. Ref. Station ID	0000		
Checksum	*18		
<CR> <LF>			End of message termination

0 = Invalid
1 = Valid SPS
2 = Valid DGPS
3 = Valid PPS
4 = RTK fixed
5 = RTK float
6 = Estimated fix
7 = Manual input mode
8 = Simulation mode
9 = WAAS fix (not NMEA standard)

SPS = Standard Positioning Service
PPS = Precise Positioning Service

Precision Ag Uses of GPS

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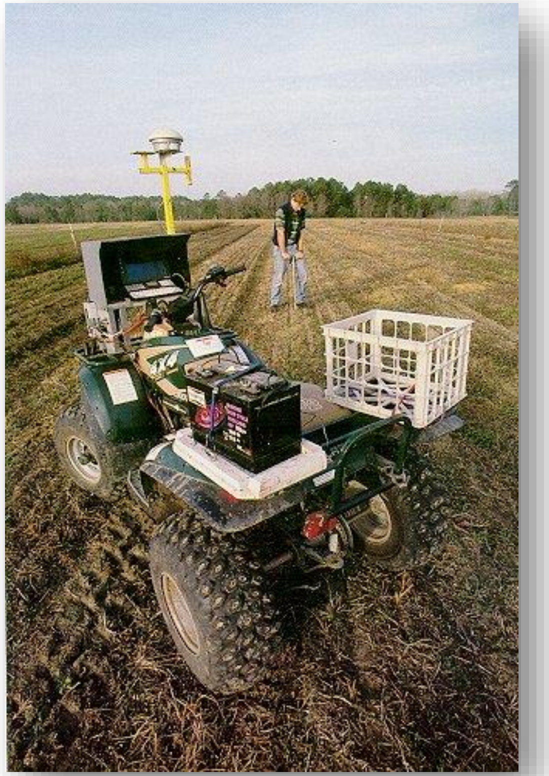
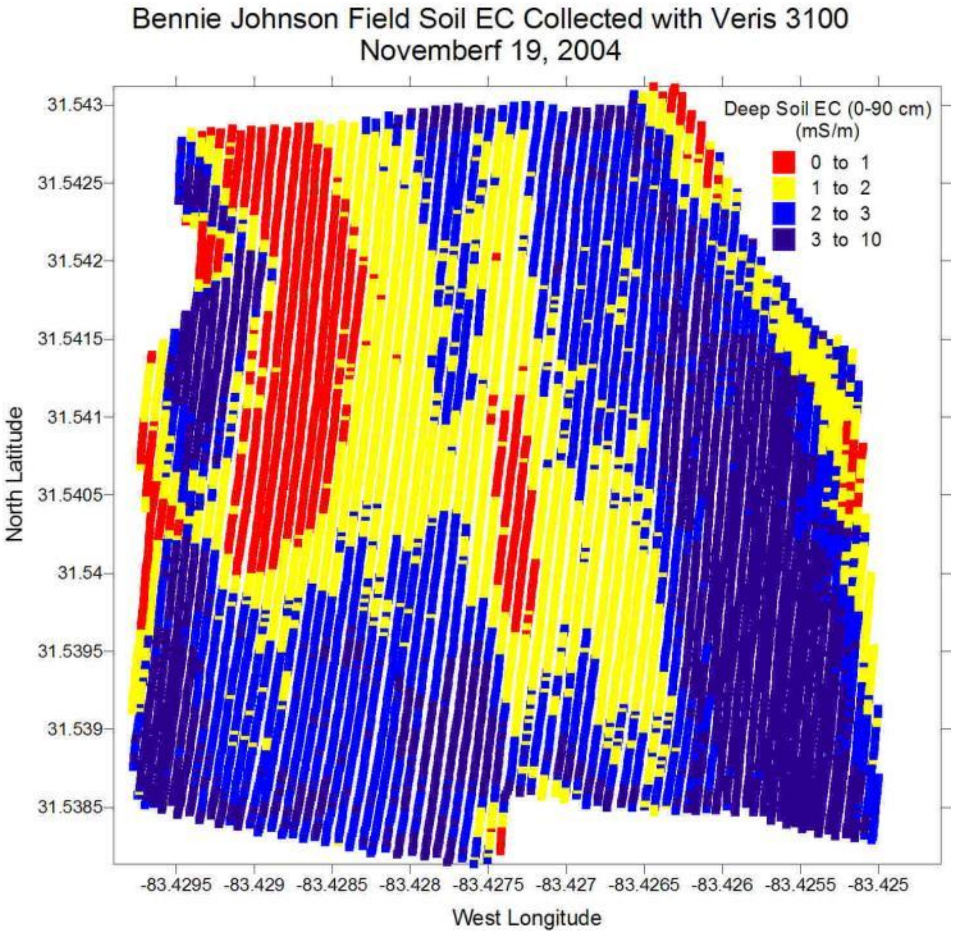


Data Collection

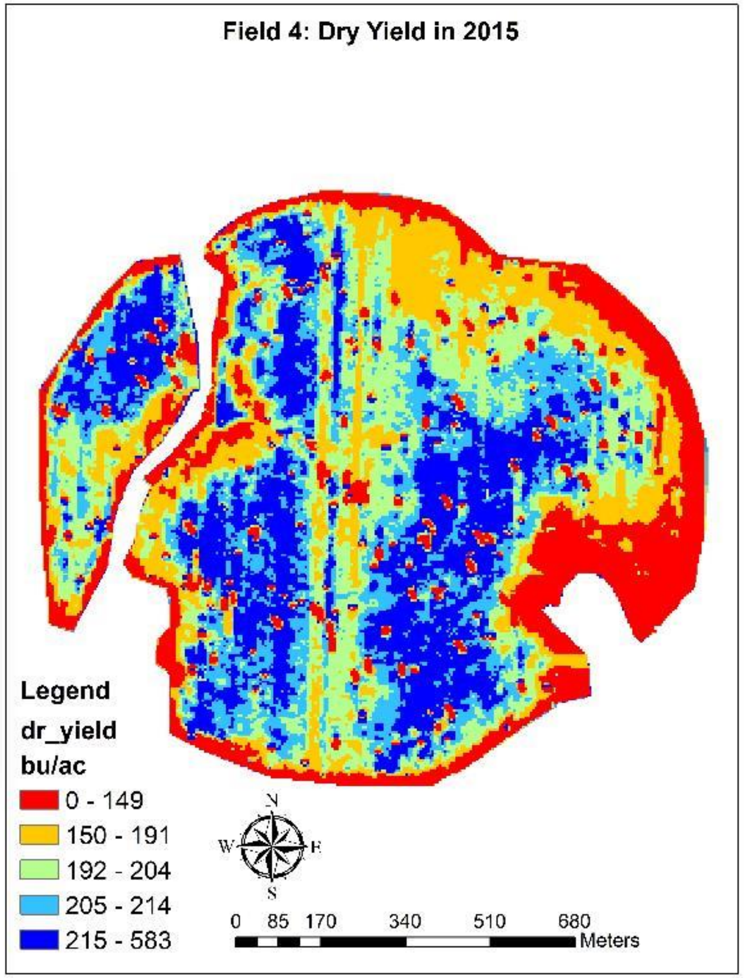
Precision Ag Uses of GPS



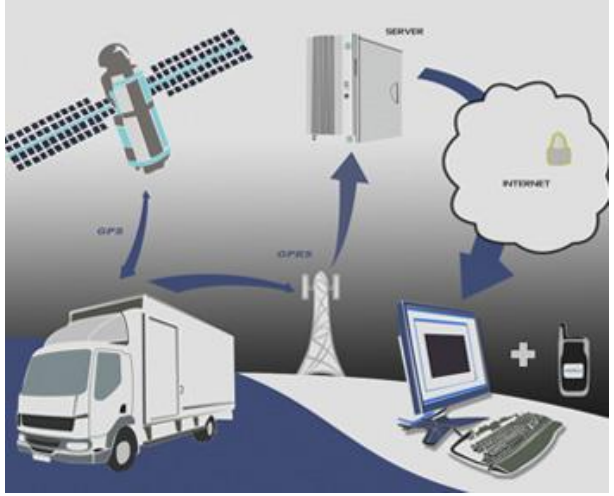
Soil Mapping

Precision Ag Uses of GPS

Yield Mapping



Precision Ag Uses of GPS



www.alarmsetc.com

www.gpsinsight.com

Vehicle or Fleet Tracking

Connected Farm - Apps |

https://www.connectedfarm.com/#apps

Getting Started | Imported From IE

Connected Farm™

Log In or Register

How It Works | Features | Apps | Customer Stories

Apps

Connected Farm Fleet App

Monitor your entire fleet from any location with a smartphone or tablet. The fleet app is a powerful management tool to increase fleet efficiency and productivity.

- View fleet positions and status overlaid on background imagery.
- Navigate to equipment from your current position using turn-by-turn directions.
- Receive geo-fence and curfew alerts.
- View historical positions.

Scan to download the Fleet App

ANDROID APP ON Google play

Available on the App Store

Connected Farm Scout App

Change the way you use GPS for field mapping and scouting applications in agriculture. The scout app utilizes your smartphone or tablet for mapping field boundaries, marking flags, and entering scouting information.

- Map areas, flags, and field boundaries.
- Enter scouting information and capture images of pests, weeds or diseases while charting the severity of problems and crop conditions.
- View crop health imagery in the background to help with targeted scouting
- Calculate nitrogen rates by using crop readings from the GreenSeeker handheld crop sensor.

Scan to download the Scout App

ANDROID APP ON Google play

Available on the App Store


Trimble *Ag*GPS® Autopilot™
Precision Ag Uses of RTK GPS

Precision Ag Uses of RTK GPS

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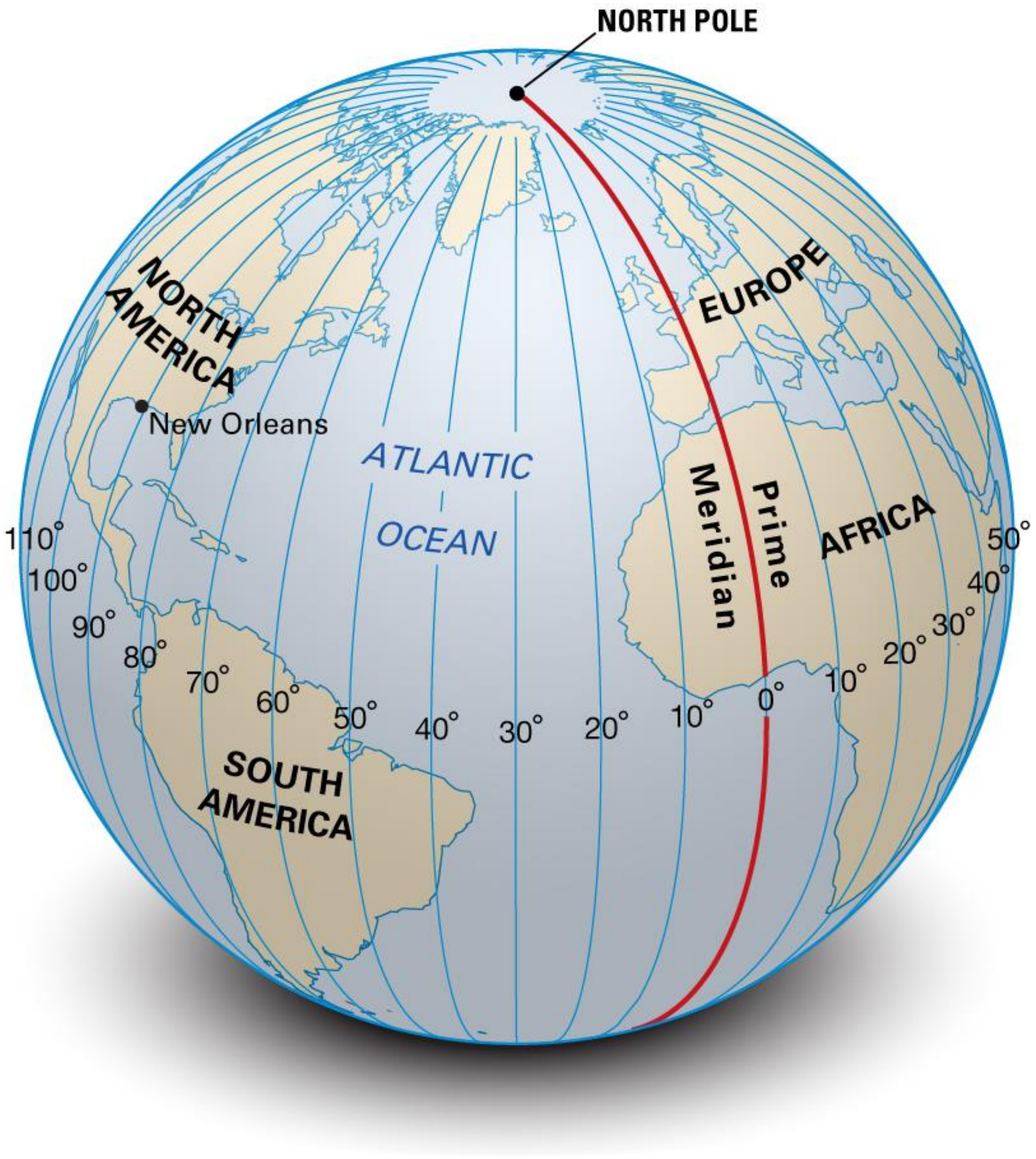
Consumer GPS

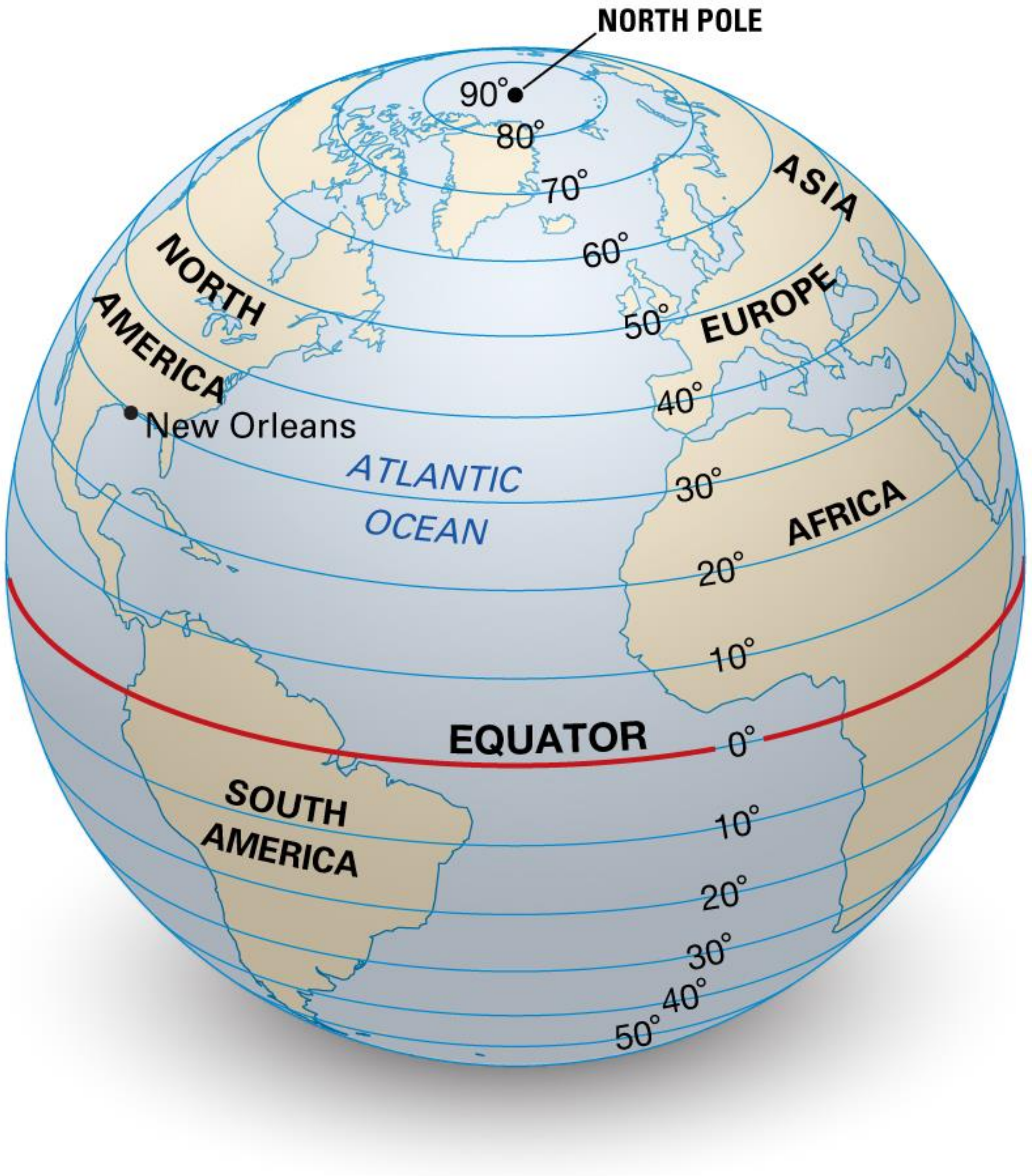
BlueChart compatible WAAS enabled

OnStar by GM



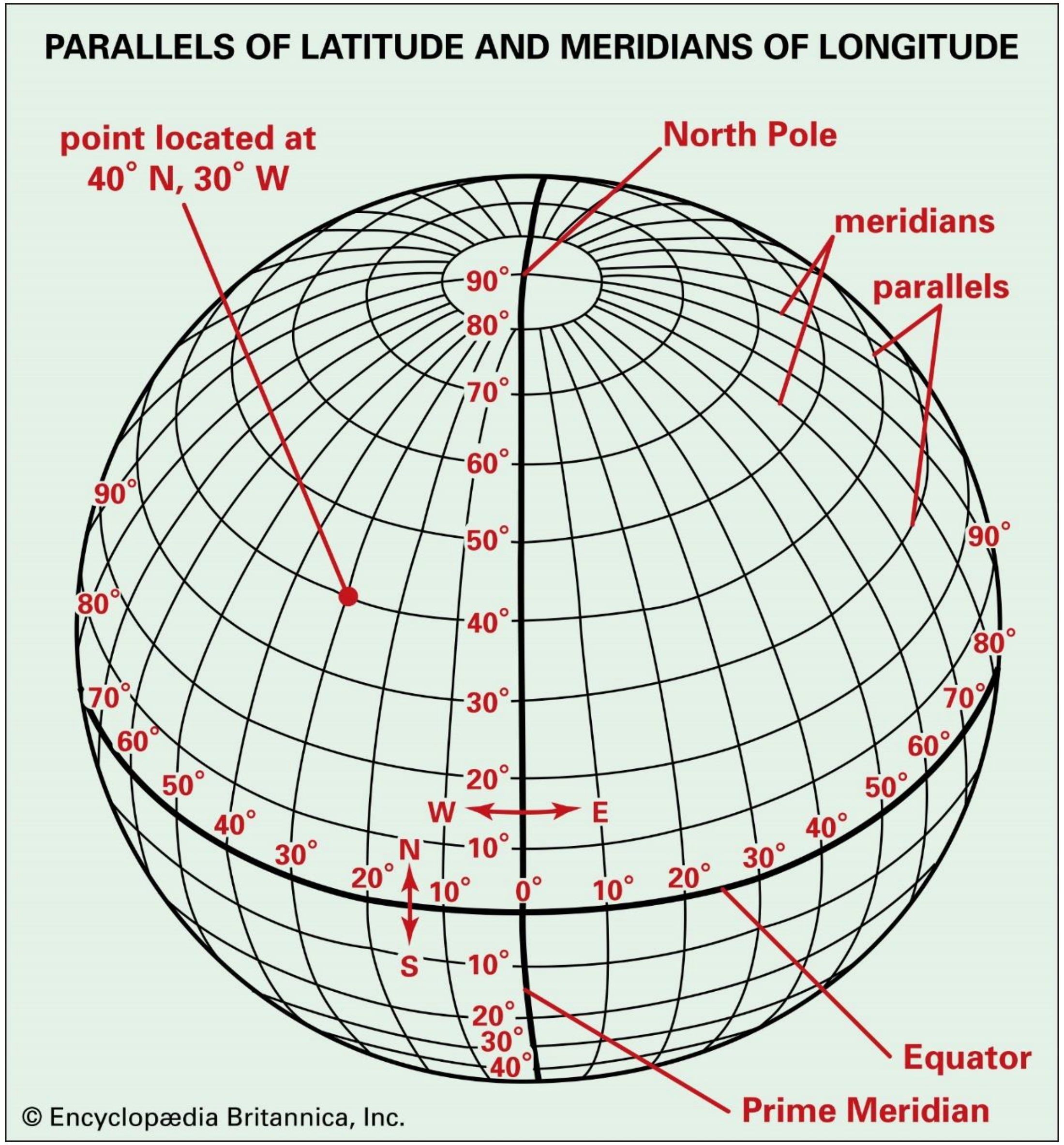
FACTS ABOUT LINES OF LONGITUDE

- Are known as meridians.
- Run in a north-south direction.
- Measure distance east or west of the prime meridian.
- Are farthest apart at the Equator and meet at the poles.
- Cross the Equator at right angles.
- Lie in planes that pass through the Earth's axis.
- Are equal in length.
- Are halves of great circles.



FACTS ABOUT LINES OF LATITUDE

- Are known as parallels.
- Run in an east-west direction.
- Measure distance north or south from the Equator.
- Are parallel to one another and never meet.
- Cross the prime meridian at right angles.
- Lie in planes that cross the Earth's axis at right angles.
- Get shorter toward the poles, with only the Equator, the longest, a great circle.


PARALLELS OF LATITUDE AND MERIDIANS OF LONGITUDE
point located at 40° N, 30° W
North Pole
meridians
parallels
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
W
E
N
S
Equator
Prime Meridian
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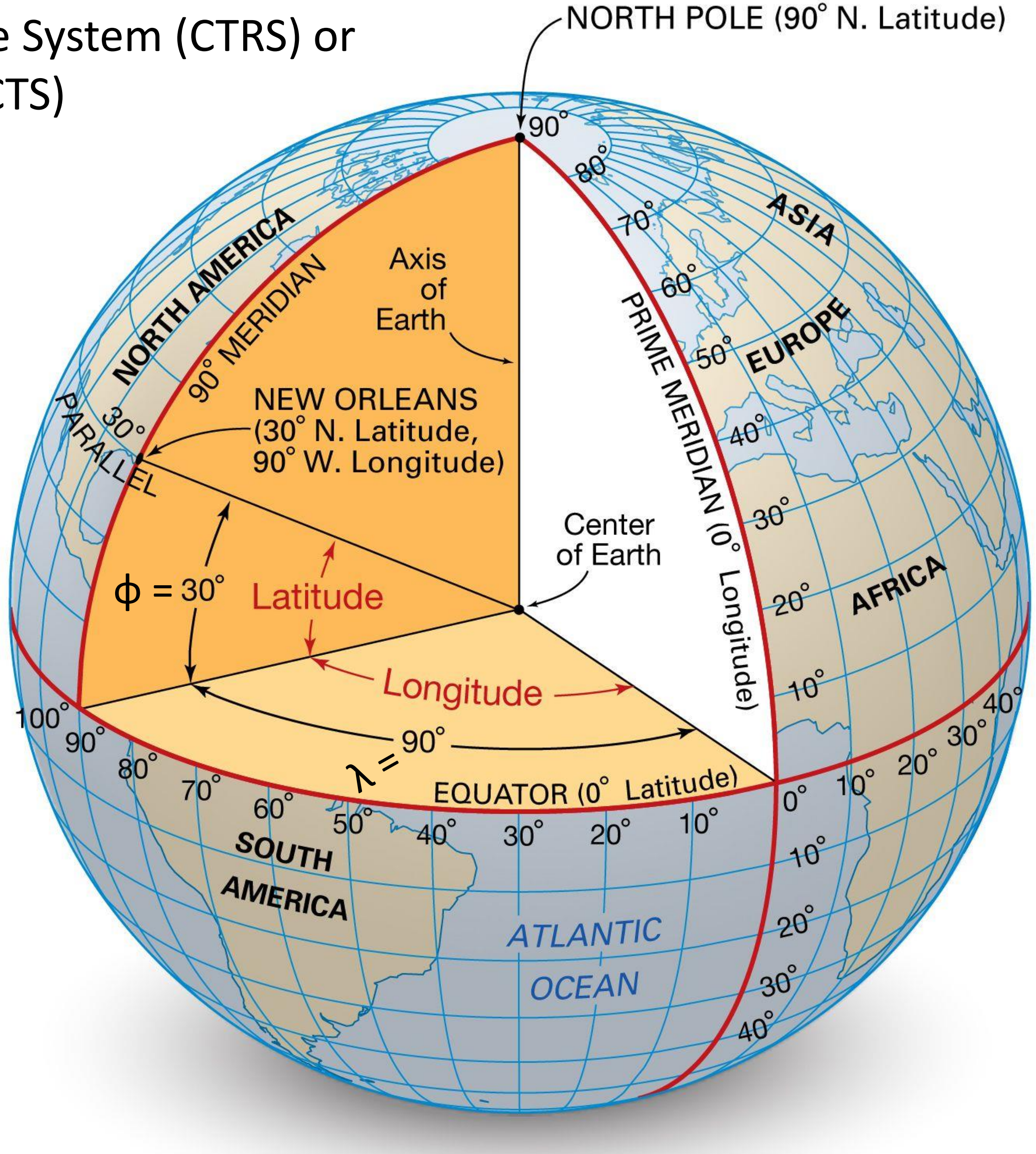
ASIA
NORTH POLE
90°
PRIME MERIDIAN
60°
EUROPE
39° PARALLEL
30°
NORTH AMERICA
AFRICA
PACIFIC OCEAN
WASHINGTON, D.C.
39° North Latitude
77° West Longitude
0°
ATLANTIC OCEAN
150°
EQUATOR
120°
30°
90°
60°
77° MERIDIAN
SOUTH AMERICA

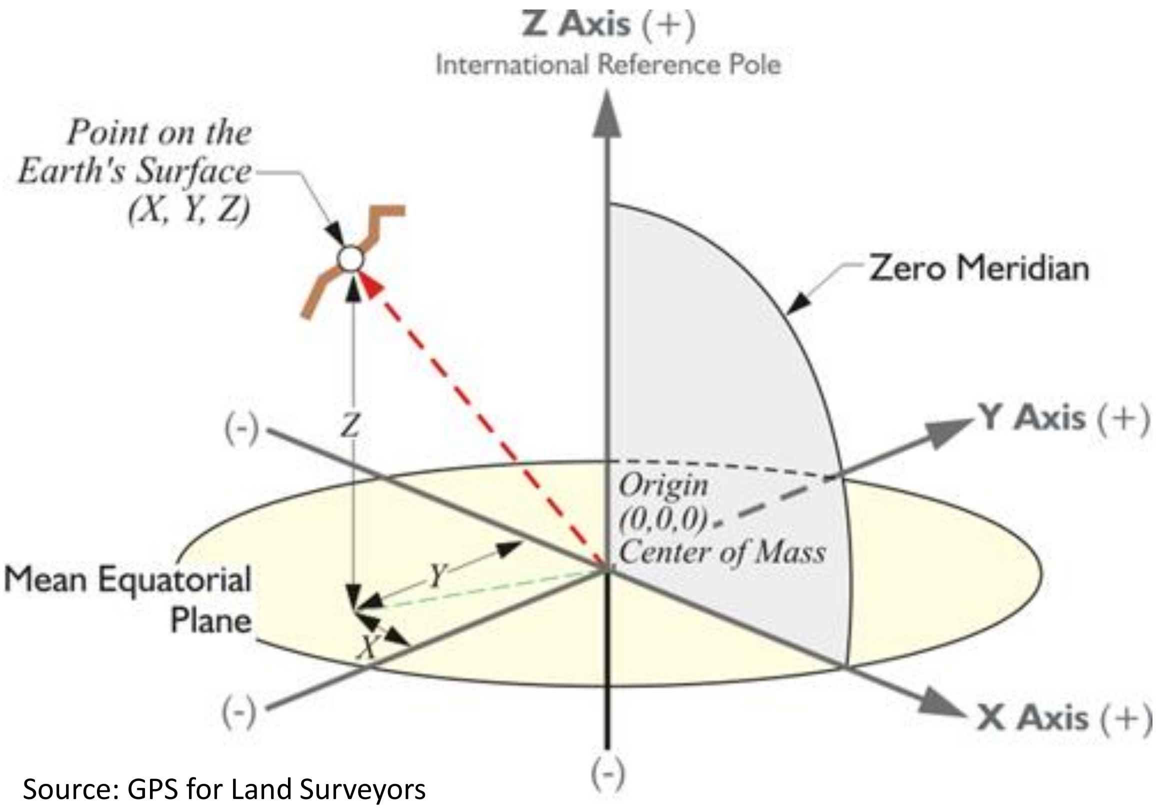
Conventional Terrestrial Reference System (CTRS) or Conventional Terrestrial System (CTS)



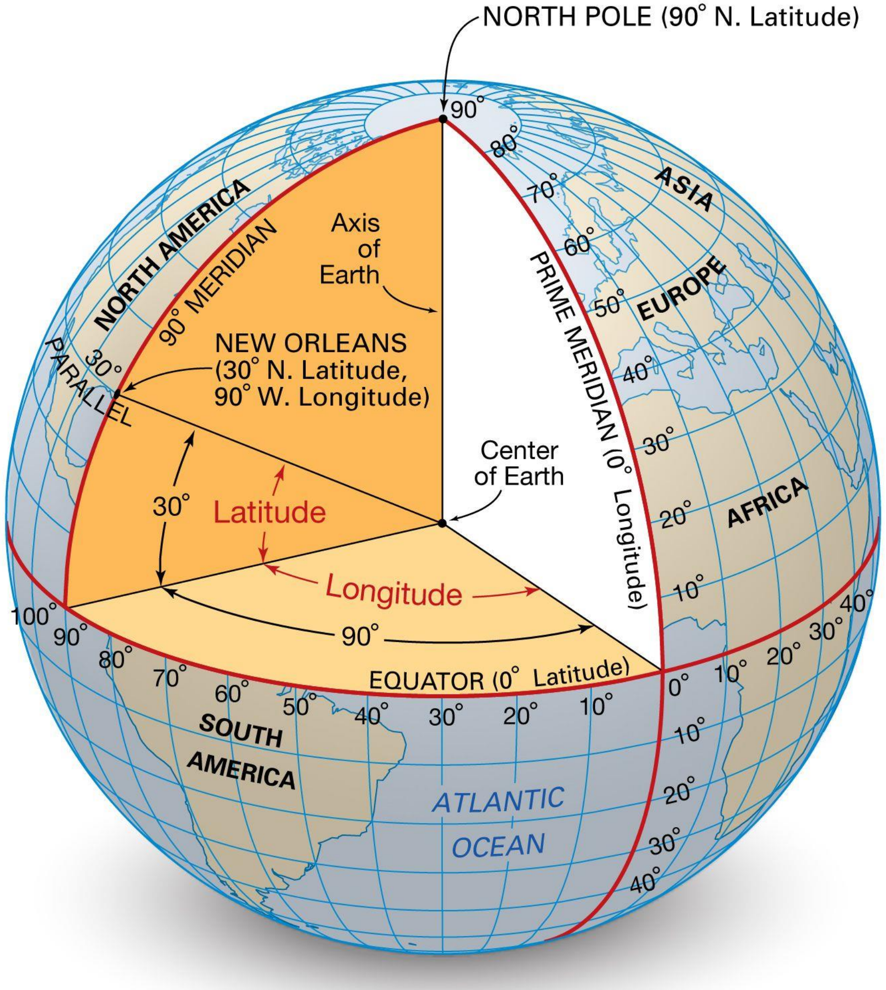
ϕ = degrees latitude

λ = degrees longitude

Three-Dimensional Cartesian Earth-Centered-Earth-Fixed (ECEF) Coordinates



Source: GPS for Land Surveyors



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ECEF is the system in which GNSS coordinates are expressed

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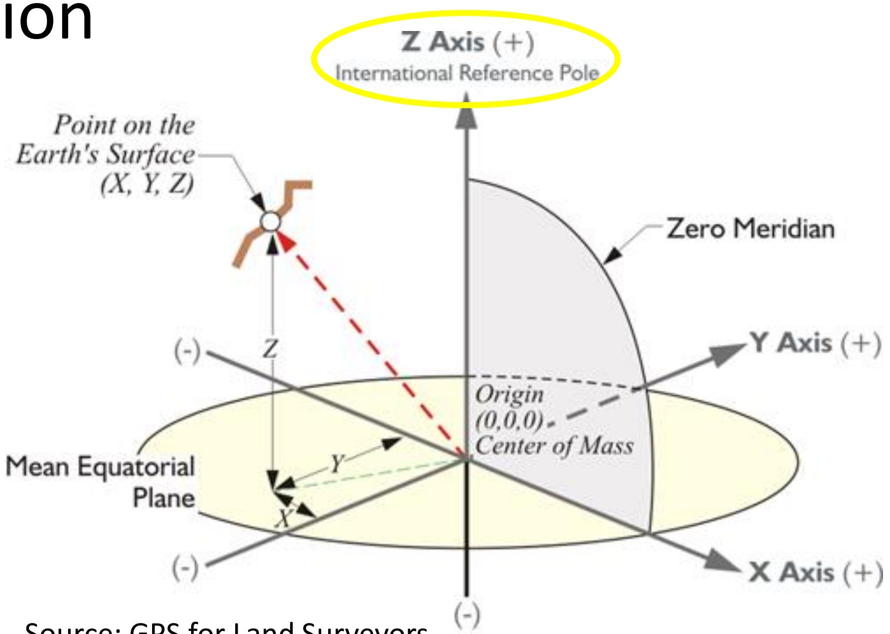
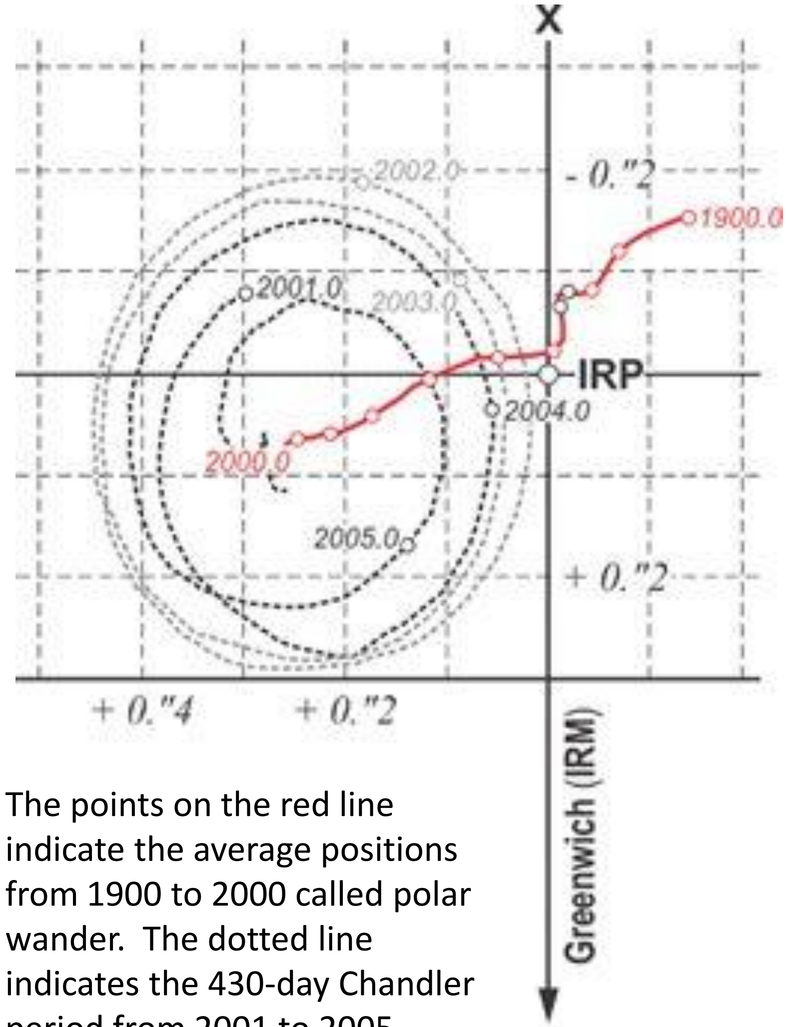
Polar Motion

- Earth's rotational axis wanders
  - Polar motion
- International Reference Pole (IRP) fixed by international convention



Source: GPS for Land Surveyors



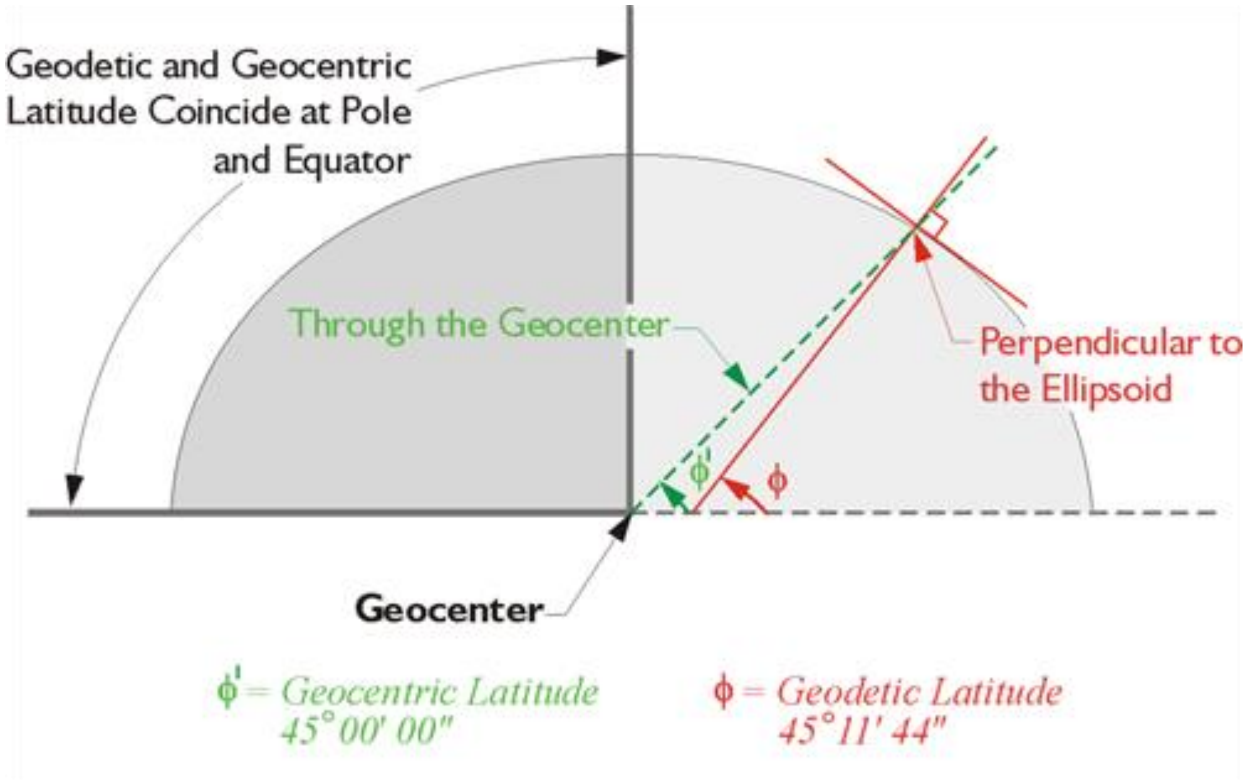
The points on the red line indicate the average positions from 1900 to 2000 called polar wander. The dotted line indicates the 430-day Chandler period from 2001 to 2005.

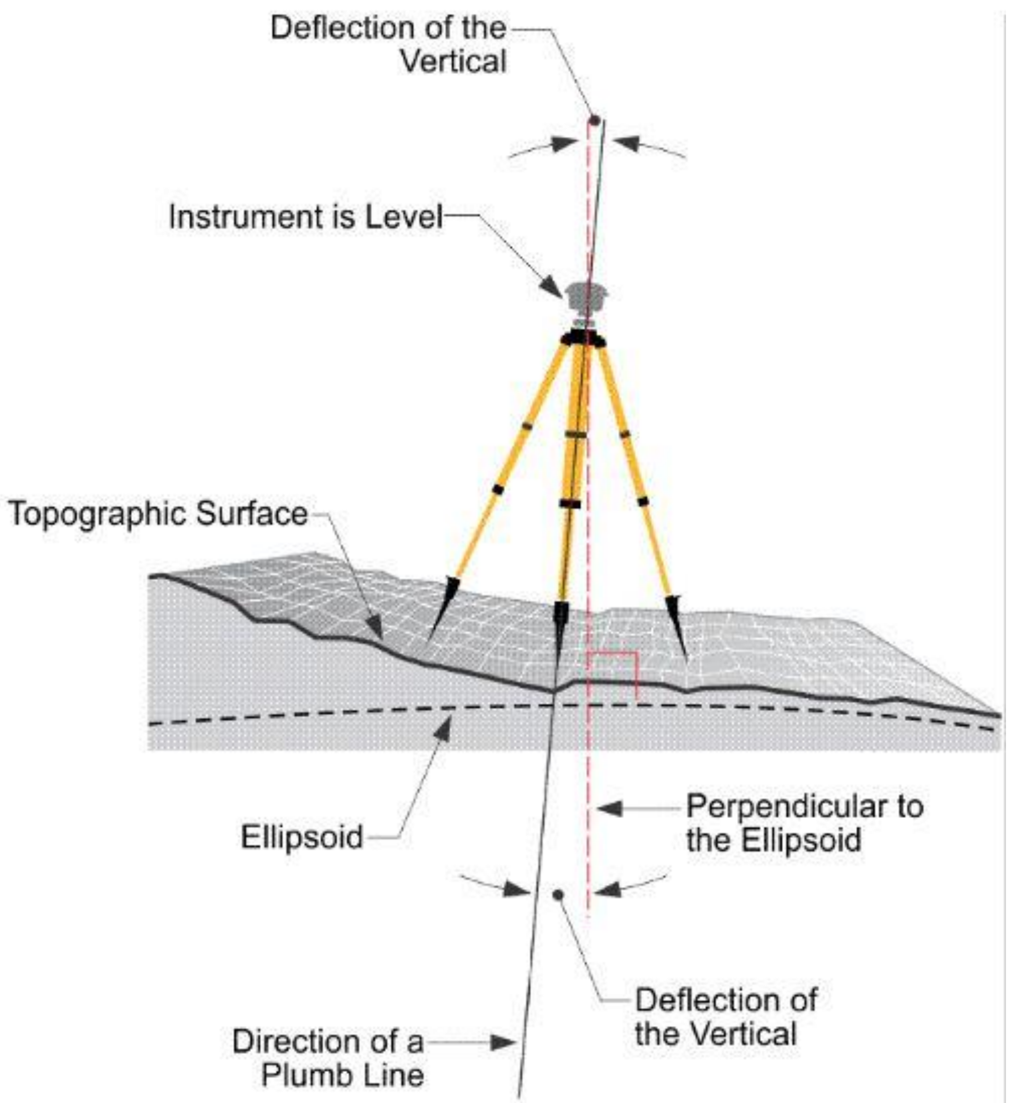
Coordinate Systems

- GPS Control Segment generates the position and velocity of the satellites themselves in ECEF coordinates
- Position data resulting from GPS in the XYZ coordinates of the ECEF system can be converted to other coordinate systems
  - Universal Transfers Mercater System coordinates
  - State Plane coordinates
  - latitude and longitude (multiple systems)
  - Etc.

Coordinate Systems

Ellipsoid model of Earth

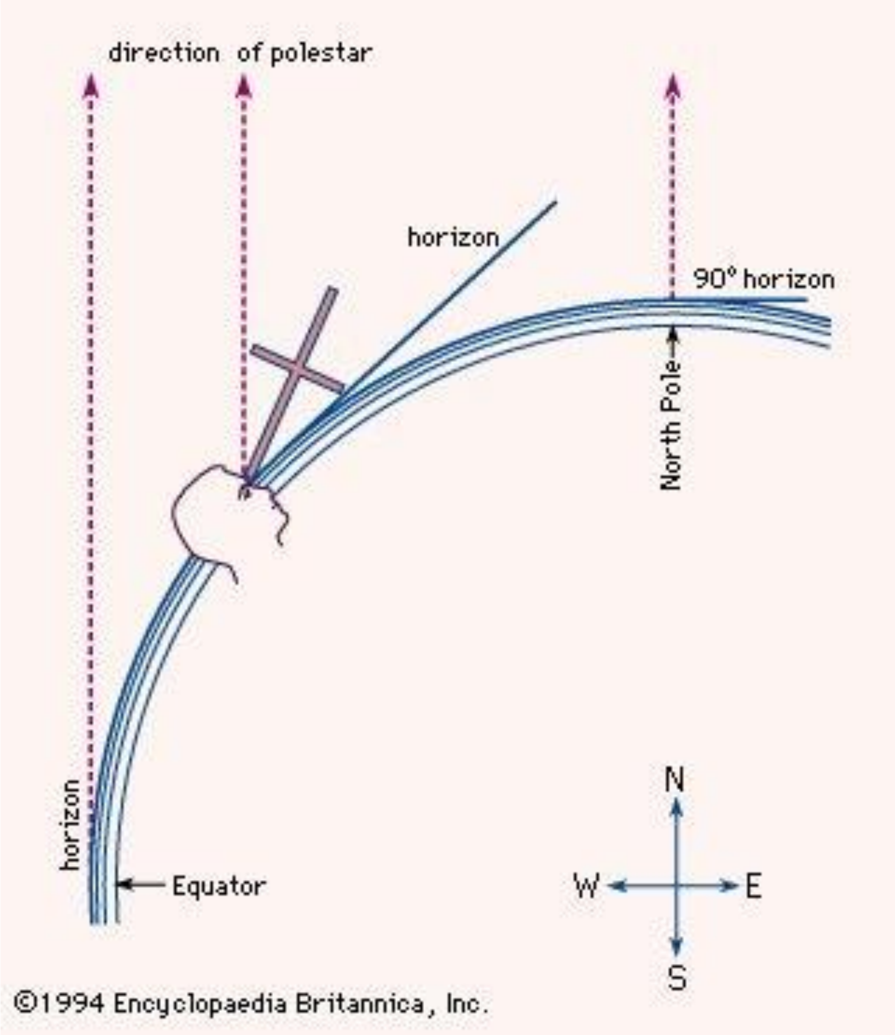




Source: GPS for Land Surveyors

Coordinate Systems

- Geodetic coordinate system for latitude and longitude is the most commonly used
- ECEF coordinates are initially converted to the Geocentric coordinate system by GPS receivers and then converted to Geodetic
- Software packages like ArcGIS, QGIS easily convert between systems



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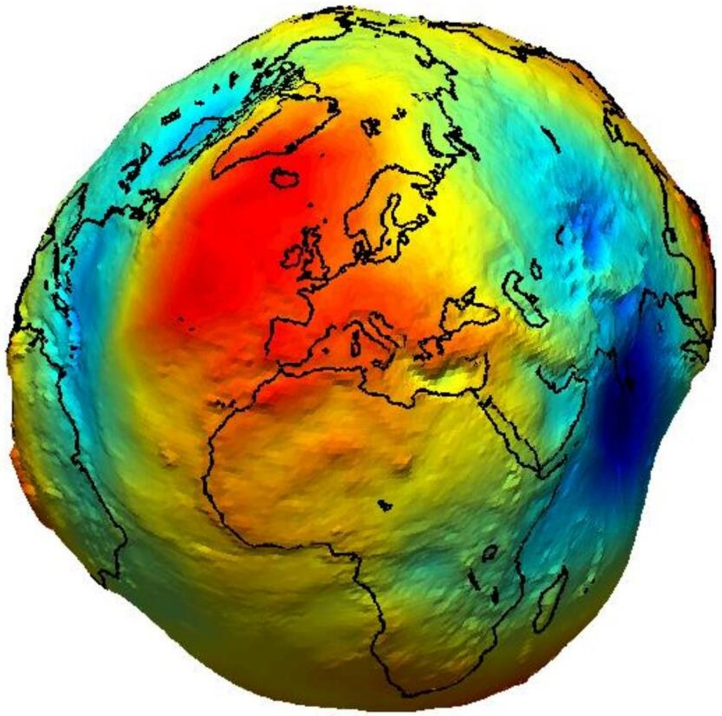
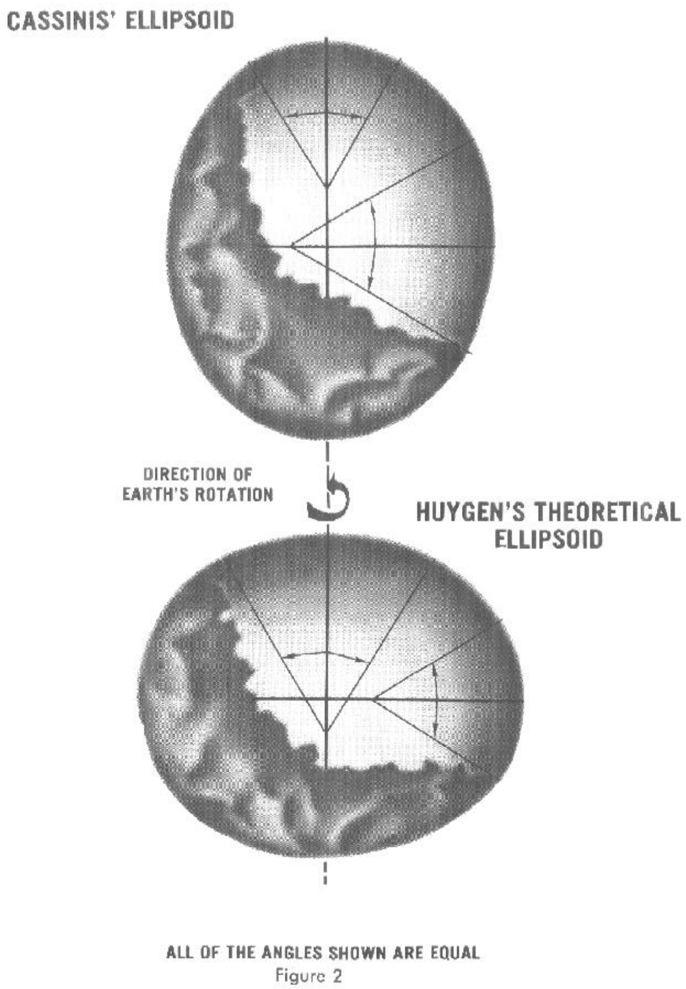
Ellipsoid Model of the Earth

- Earth is not a perfect sphere



Exaggerated model of the Earth's true shape known as a Geoid.
Colors indicate intensity of gravitational field.

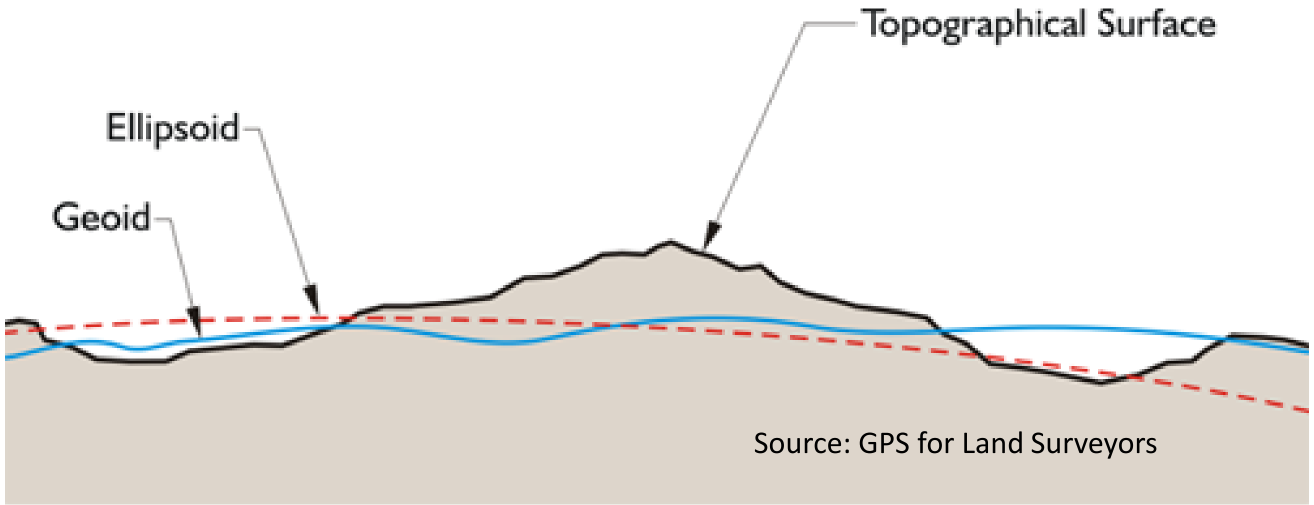
Source: European Space Agency



Source: NOAA
https://commons.wikimedia.org/w/index.php?curid=10522135

Ellipsoid Model of the Earth

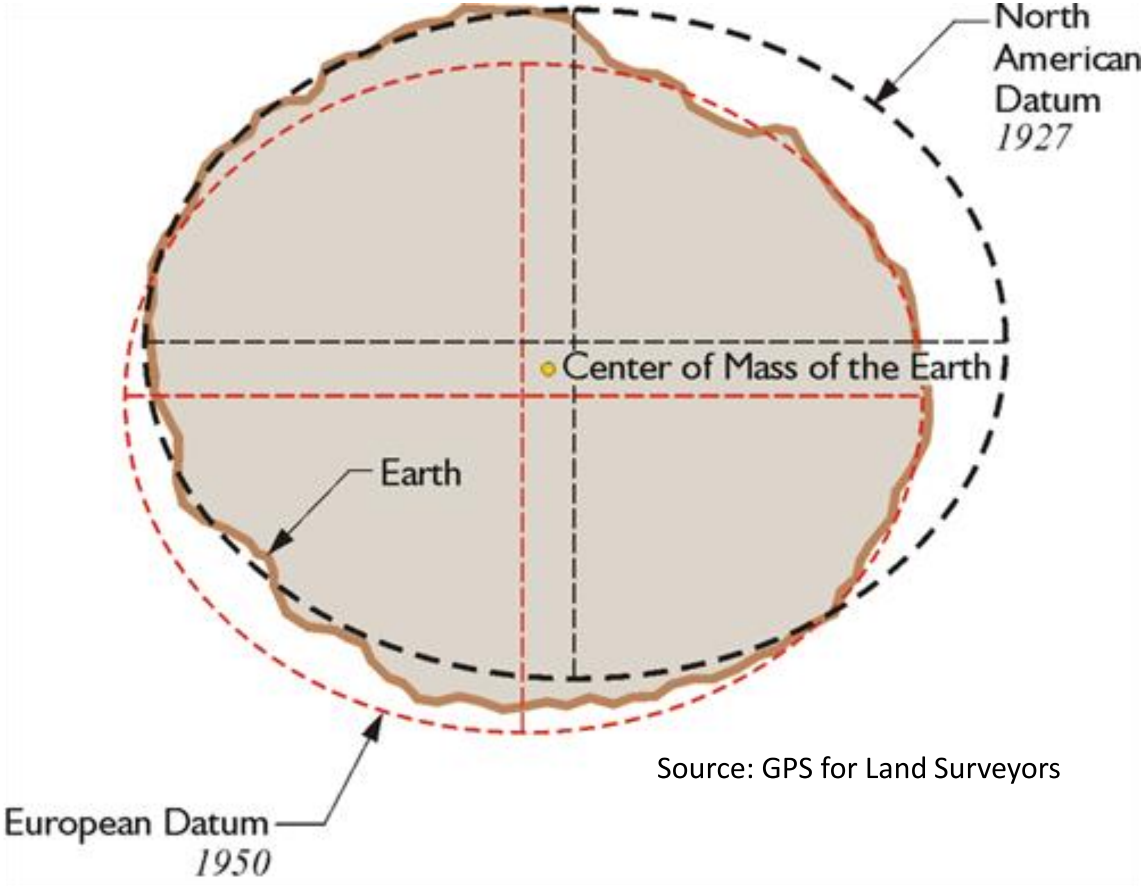
- Topographical surface
- Ellipsoid
- Geoid



Source: GPS for Land Surveyors

Ellipsoid Model of the Earth

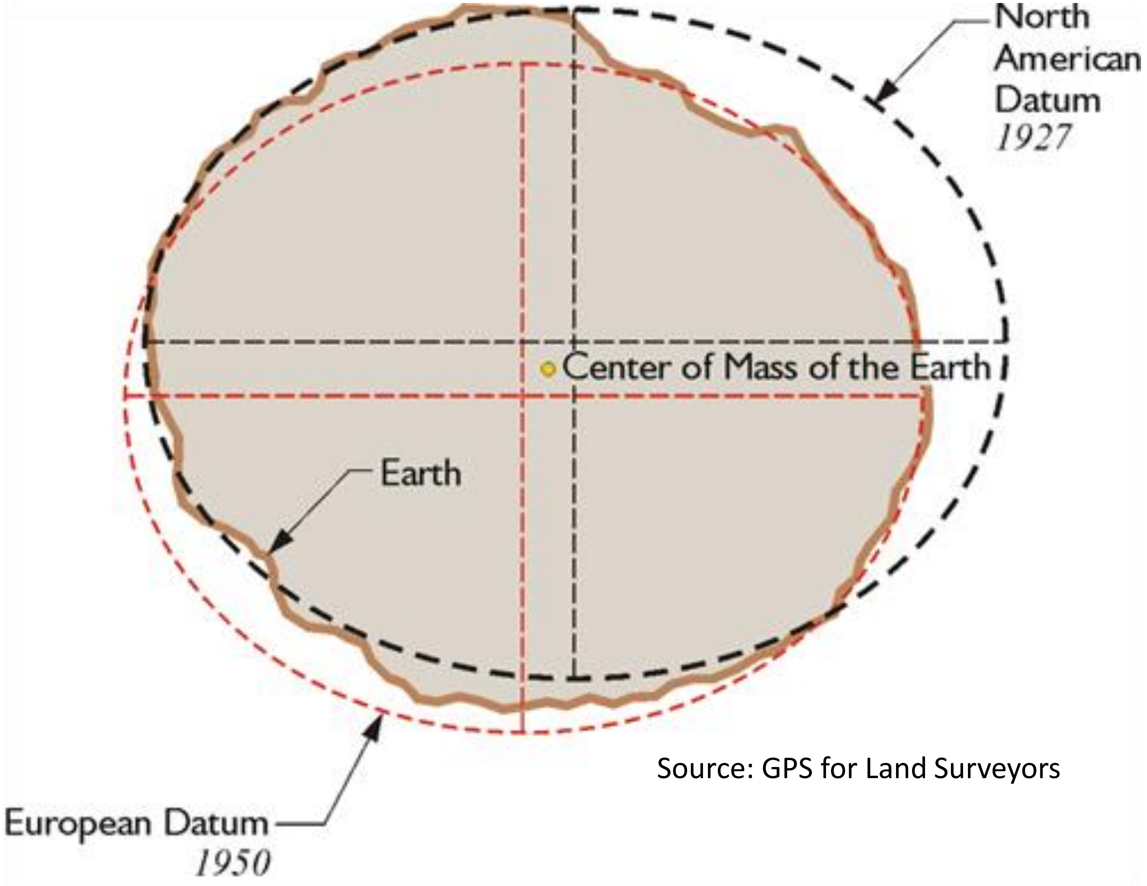
- Geographers have used different ellipsoid models
- Models match specific cartographic needs resulting in regional datums
- The same latitude and longitude numbers do not show the same place on maps of different geodetic datums



Source: GPS for Land Surveyors

Ellipsoids and Datums

- Ellipsoids define size and shape
- The datum fixes that ellipsoid to the Earth
- Depending on who develops the datum, they are fixed to different parts of the Earth



Source: GPS for Land Surveyors

Historical Earth Ellipsoids

- With space-based measurements, we have moved to ellipsoids attached to the center of mass of the Earth
  - GRS80
  - WGS84

Reference ellipsoid name	Equatorial radius (m)	Polar radius (m)	Inverse flattening	Where used
Maupertuis (1738)	6,397,300	6,363,806.283	191	France
Plessis (1817)	6,376,523.0	6,355,862.9333	308.64	France
Everest (1830)	6,377,299.365	6,356,098.359	300.80172554	India
Everest 1830 Modified (1967)	6,377,304.063	6,356,103.0390	300.8017	West Malaysia & Singapore
Everest 1830 (1967 Definition)	6,377,298.556	6,356,097.550	300.8017	Brunei & East Malaysia
Airy (1830)	6,377,563.396	6,356,256.909	299.3249646	Britain
Bessel (1841)	6,377,397.155	6,356,078.963	299.1528128	Europe, Japan
Clarke (1866)	6,378,206.4	6,356,583.8	294.9786982	North America
Clarke (1878)	6,378,190	6,356,456	293.4659980	North America
Clarke (1880)	6,378,249.145	6,356,514.870	293.465	France, Africa
Helmert (1906)	6,378,200	6,356,818.17	298.3	Egypt
Hayford (1910)	6,378,388	6,356,911.946	297	USA
International (1924)	6,378,388	6,356,911.946	297	Europe
Krassovsky (1940)	6,378,245	6,356,863.019	298.3	USSR, Russia, Romania
WGS66 (1966)	6,378,145	6,356,759.769	298.25	USA/DoD
Australian National (1966)	6,378,160	6,356,774.719	298.25	Australia
New International (1967)	6,378,157.5	6,356,772.2	298.24961539	
GRS-67 (1967)	6,378,160	6,356,774.516	298.247167427	
South American (1969)	6,378,160	6,356,774.719	298.25	South America
WGS-72 (1972)	6,378,135	6,356,750.52	298.26	USA/DoD
GRS-80 (1979)	6,378,137	6,356,752.3141	298.257222101	Global ITRS[4]
WGS-84 (1984)	6,378,137	6,356,752.3142	298.257223563	Global GPS
IERS (1989)	6,378,136	6,356,751.302	298.257	
IERS (2003)[5]	6,378,136.6	6,356,751.9	298.25642	[4]

Geocentric Ellipsoids

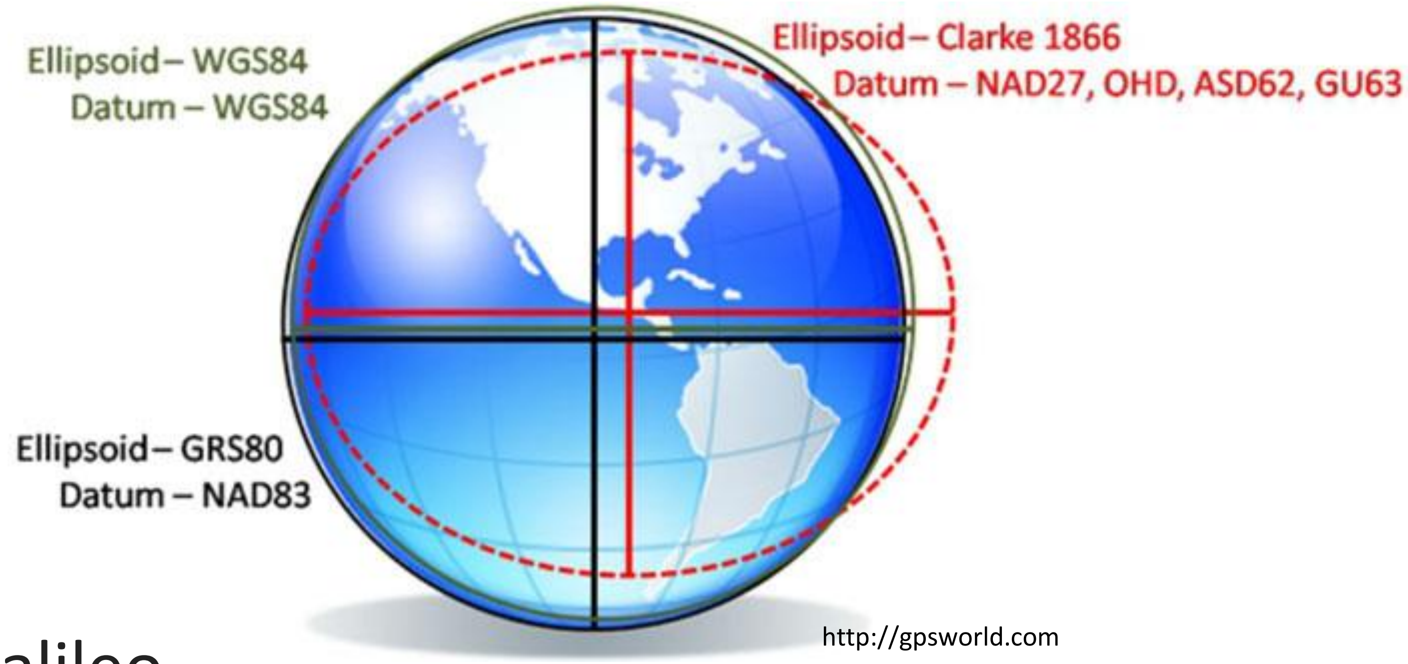
Ellipsoid	Semi-major axis	inverse flattening
GRS80	6,378,137 m	298.257222101
WGS84	6,378,137 m	298.257223563

- GRS80 – Geodetic Reference System 1980
- WGS84 – World Geodetic System 1984
  - Used by the GPS System and some other GNSS
  - Regularly updated
  - Currently using WGS84 (G1762) which is the sixth update to WGS84

Year	Realization (Epoch)
1987	WGS 1984 (ORIG)
1994	WGS84 (G730)
1997	WGS84 (G873)
2002	WGS84 (G1150)
2012	WGS (G1674)
2013	WGS (G1762)

Source: GPS for Land Surveyors

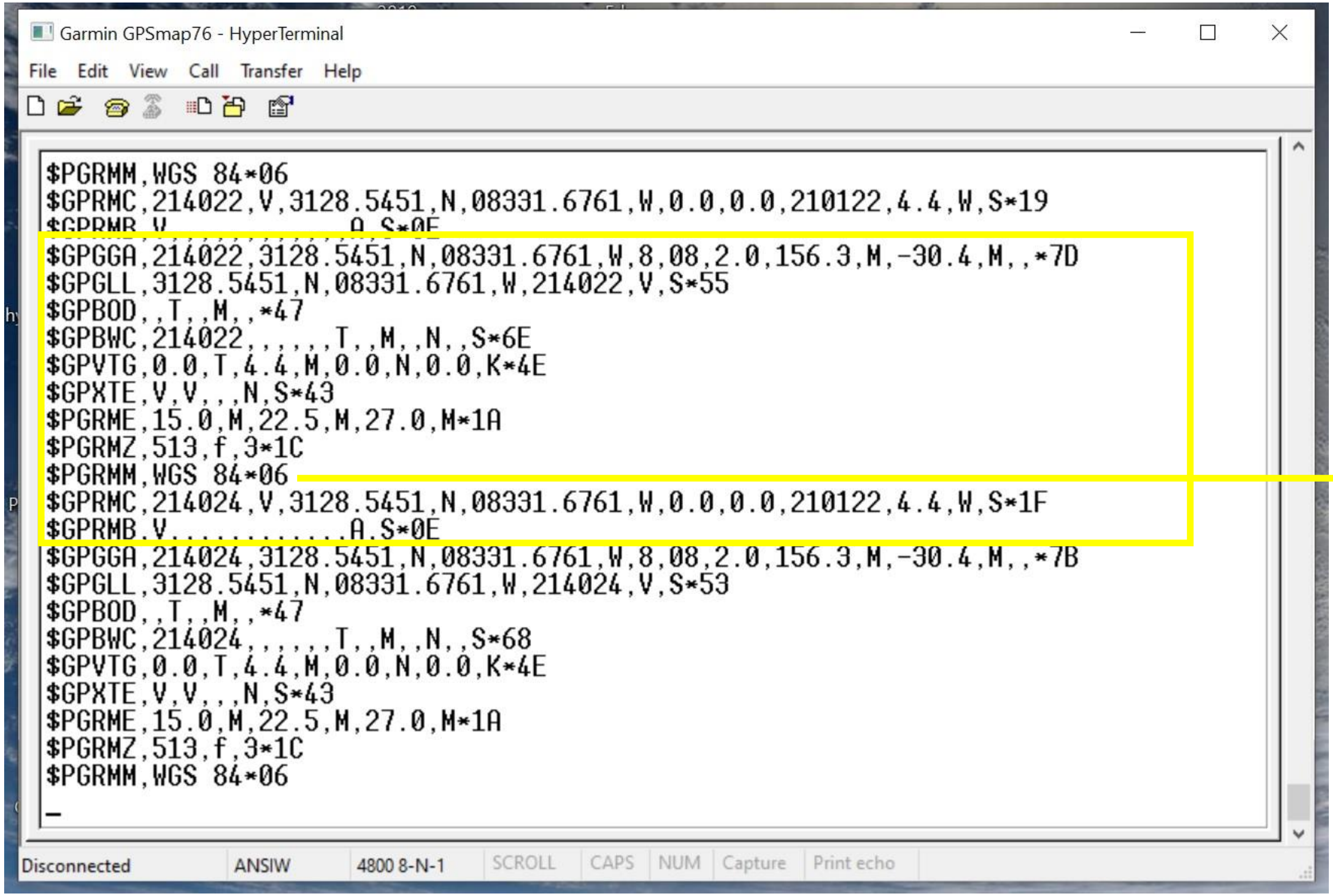
Ellipsoids and Datums used by GNSS

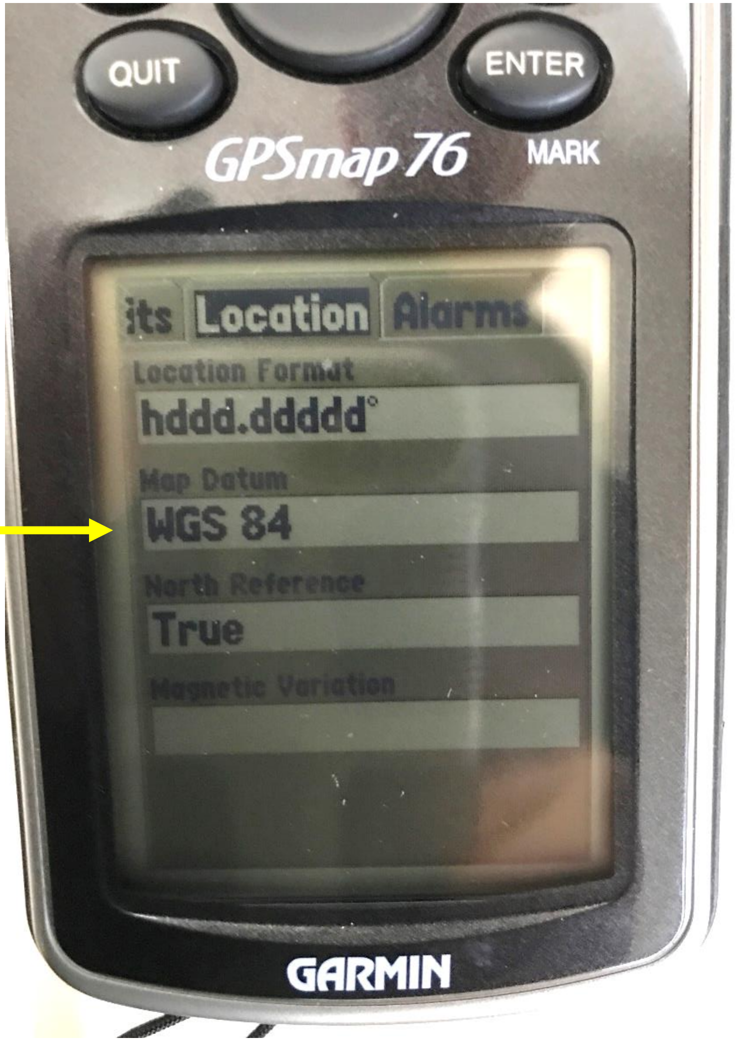


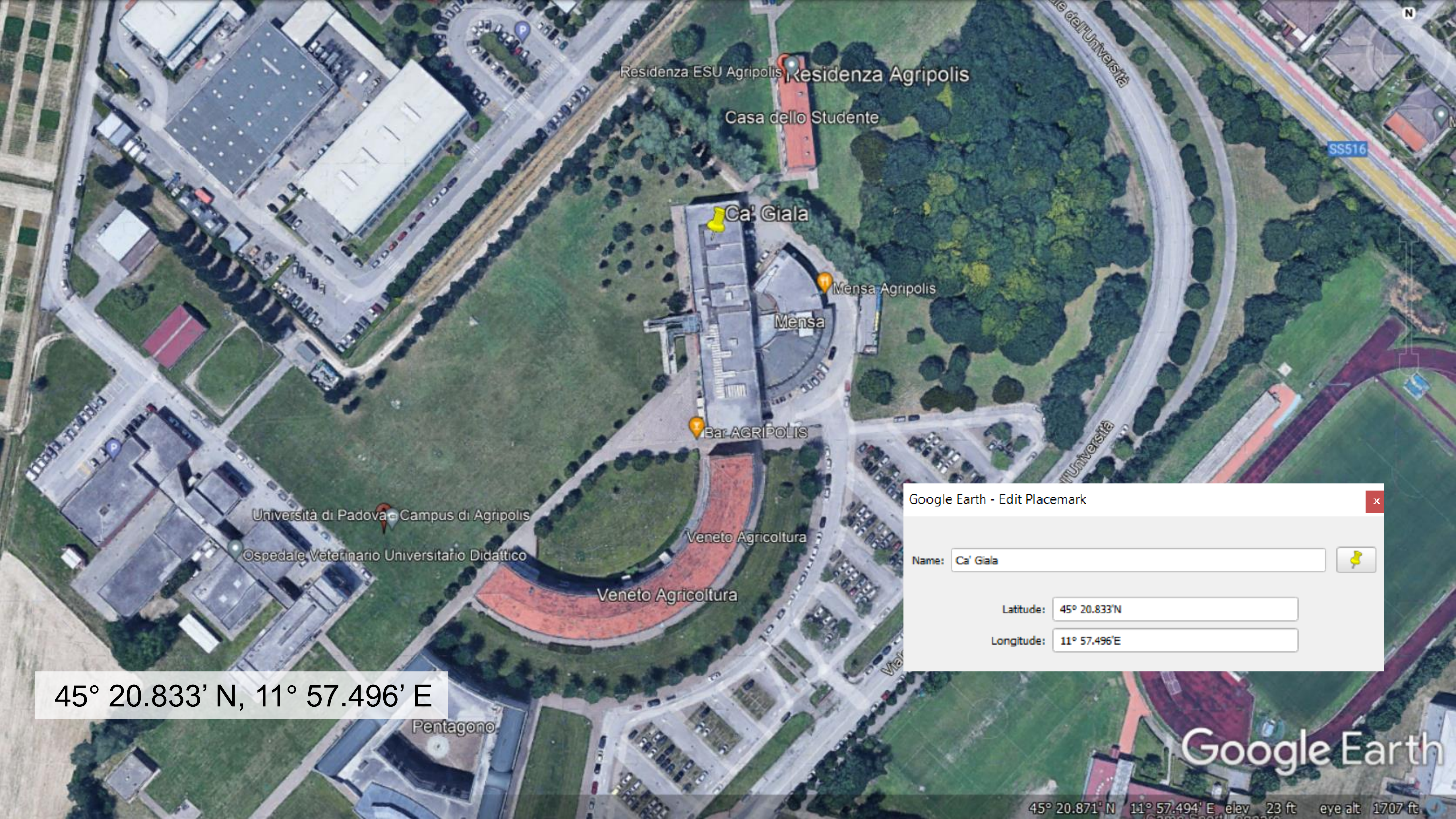
http://gpsworld.com

- The GPS System and Galileo use WGS84
- GLONASS uses SGS85

Garmin GPSmap76



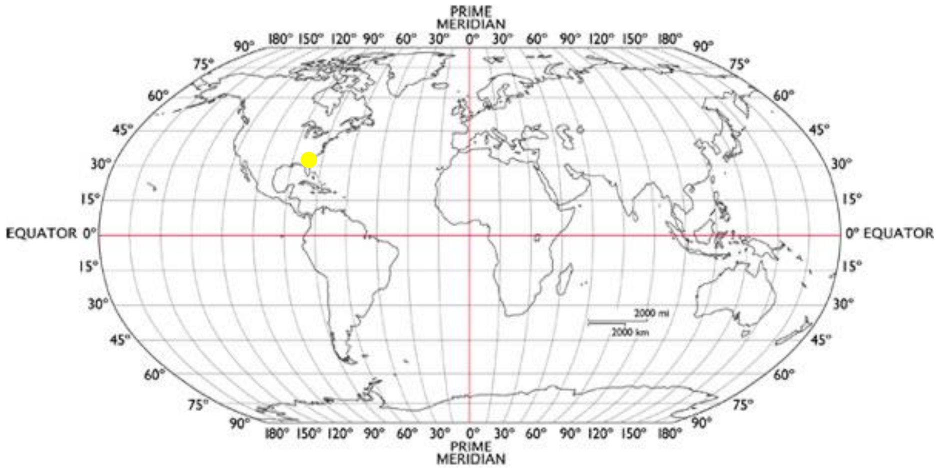



Residenza ESU Agripolis
Residenza Agripolis
Casa dello Studente
Ca' Giala
Mensa Agripolis
Mensa
Bar AGRIPOLIS
SS516
Università di Padova - Campus di Agripolis
Ospedale Veterinario Universitario Didattico
Veneto Agricoltura
Veneto Agricoltura
Pentagono
Google Earth - Edit Placemark
Name: Ca' Giala
Latitude: 45° 20.833'N
Longitude: 11° 57.496'E
45° 20.833’ N, 11° 57.496’ E
Google Earth
45° 20.871' N 11° 57.494' E elev 23 ft eye alt 1707 ft

How to Report Coordinates

- Degrees, Minutes, Seconds – 31°28'32.92"N, 83°31'49.16"W
- Degrees, Decimal Minutes – 31° 28.549'N, 83° 31.819'W
- Decimal Degrees – 31.475810°, -83.530321°

- 1 Minute = 60 Seconds
- 1 Degree = 60 Minutes



Converting Coordinates

- 31°27'44.85"N, 83°30'47.41"W
  1. 44.85 / 60 = 0.7475
  2. (27 + 0.7475) / 60 = 0.462458
  3. 31 + 0.462458 = 31.462458°

- 31.462457°, -83.513170°

- 31.462457°, -83.513170°
  1. 31.462457 – 31° = 0.462457
  2. 0.462457 * 60 = 27.74742
  3. 27.74742 – 27' = 0.74742
  4. 0.74742 * 60 = 44.845"

- 31°27'44.85"N, 83°30'47.41"W