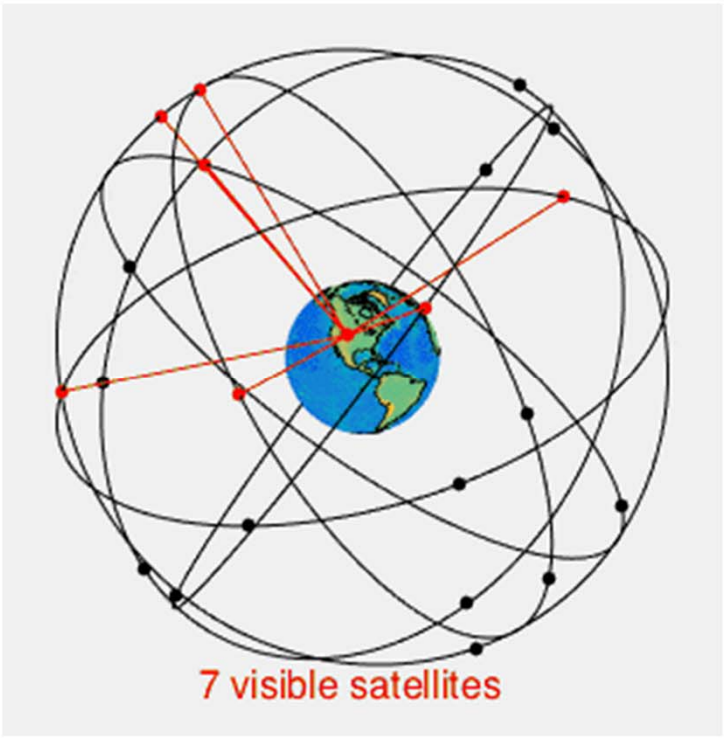
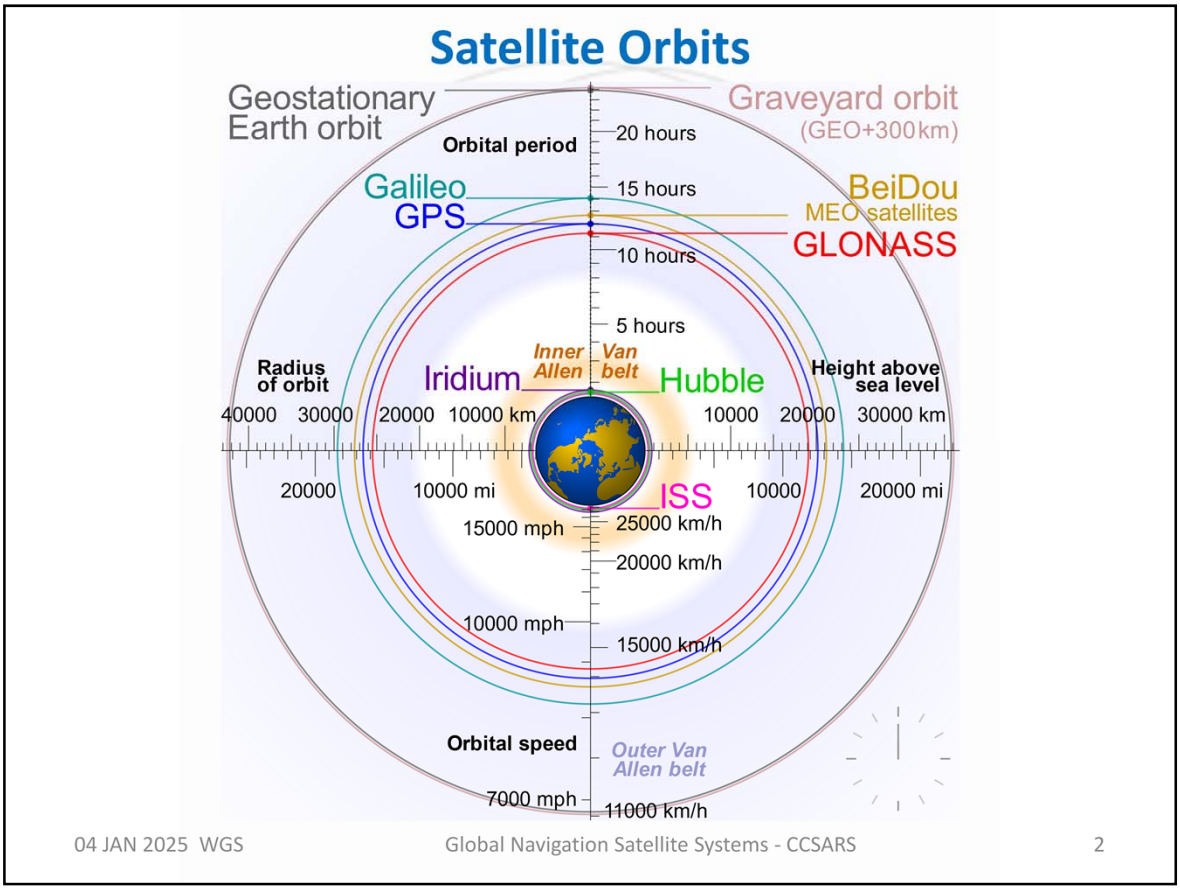


Global Navigation Satellite Systems - CCSARS

This presentation provides an overview of the various GNSS systems. A brief history of the US based GPS system. A brief description of how GNSS works and the coordinate systems that it uses. And some practical tips on how to use GPS to your advantage in the backcountry.

Six orbits with four or five satellites in each orbit – 12 hour obit period



Four global satellite navigation systems from four political entities
Two regional satellite navigation systems from two countries
The higher the orbit the longer the orbit time and slower orbital speed

GNSS Providers

Why so many providers if some cover the whole globe?

- Some global providers are run by the military and can be turned off by region at any time
  - US turned off GPS over India during a 1999 war there
- Some give improved coverage to certain regions
  - Russian satellites cover far north and far south better
- New and evolving technology
  - Newcomers like Europe and China are not tied to the older technology of the older systems of the US and Russia and can offer better performance i.e. three times the accuracy

Global orbit versus geo-stationary orbit

- Takes 24 satellites, plus spares, to cover the world - 10s of billions $
  - Needed to fight a war anywhere – US, Russia, China
  - Nonmilitary with user fee for 5X accuracy - EU
- Can cover a country with just four satellites if stationary
  - Just for use at home or focused on civilian use – Japan, India, FAA WAAS

EU's Galileo has encrypted for fee centimeter accuracy. The US said they reserved the right to shoot down the Galileo satellites if an enemy was deemed to be using the signal to their advantage. A compromise was reached to use a frequency different than the US satellites so that the US could jam the Galileo signals on the field of battle without jamming their own.

Augmentation

Augmentation is using extra information from other satellites or ground based stations

- Augmentation can occur in real time or be applied later (post processing) after the initial measurements have been made

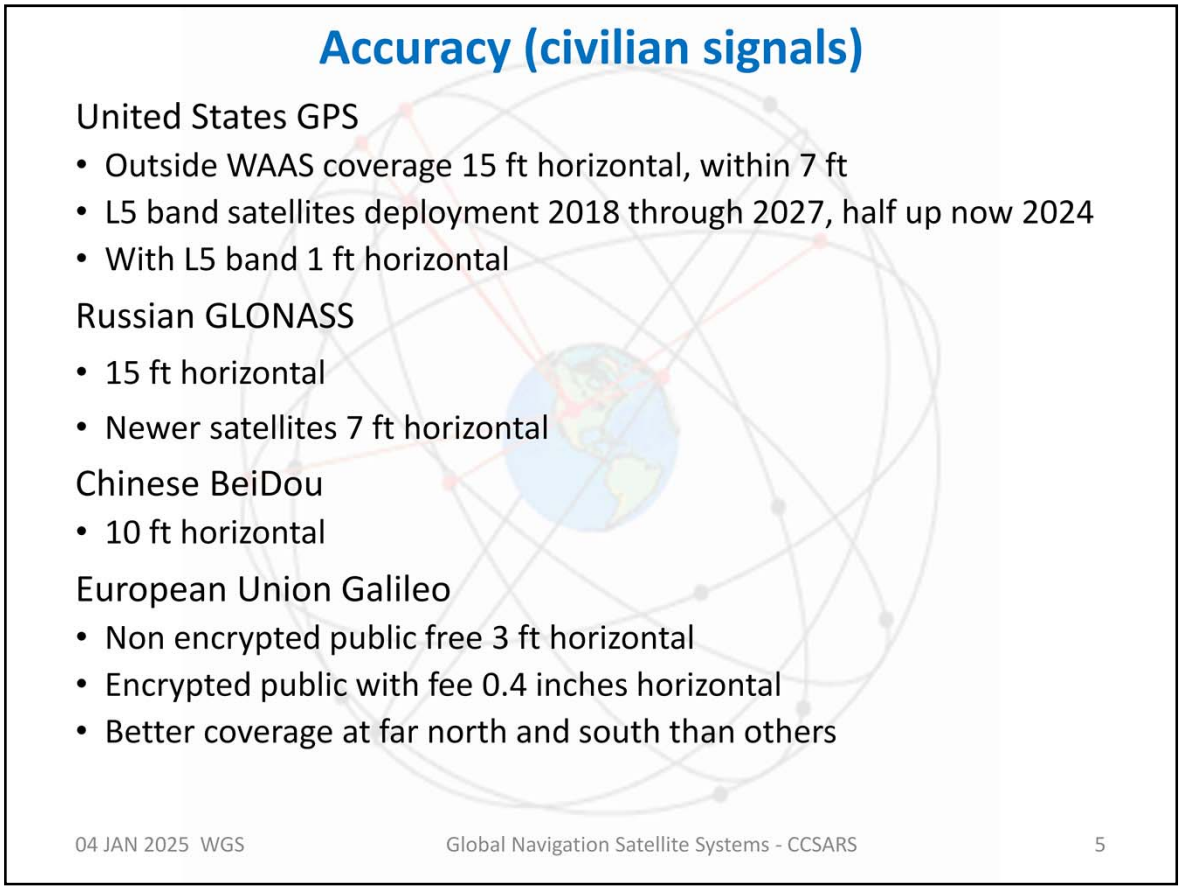
SBAS – Space Based Augmentation System

- The FAA placed transmitters on three geostationary satellites over the US calling the system WAAS (Wide Area Augmentation System)
- Ground based receivers, that know exactly where they are, provide error offsets for their region (a few states)
- Ground based receivers look for satellites with errors that make them unusable
- This information is then transmitted by the WAAS satellites that are also providing the usual GPS navigation signals

GBAS – Ground Based Augmentation System

- Offsets and integrity are sent directly from the ground station
- A separate VHF radio is used to receive the LAAS (Local Area) signal

SBAS, by providing health conditions for the satellites, made it safe to use GPS on instrument approaches to airports in the clouds and in low visibilty
GBAS results in centimeter accuracies allowing aircraft to land in zero cloud height and zero visibility conditions and even auto land the aircraft



Military grade signals are encrypted providing very high accuracies – classified as to just how good they are

Biggest source of error are changes to the speed of light as it travels through the atmosphere – it slows down

- If you can receive signals from the satellites on two different frequencies you can precisely calculate the speed change and adjust for it
- This is what makes the new L5 signal up the accuracy so much

Vertical accuracy is roughly double the error of horizontal

Beginning in 2011 most GPS receivers began using GLONASS

- Russia imposed 25% import tariffs on ones that did not
- Faster signal lock with more satellites

Most cell phones built after mid 2018 should have L5 band receivers – check the phone specifications

Most cell phones built in 2019 and later should have Galileo receivers – check the phone specifications

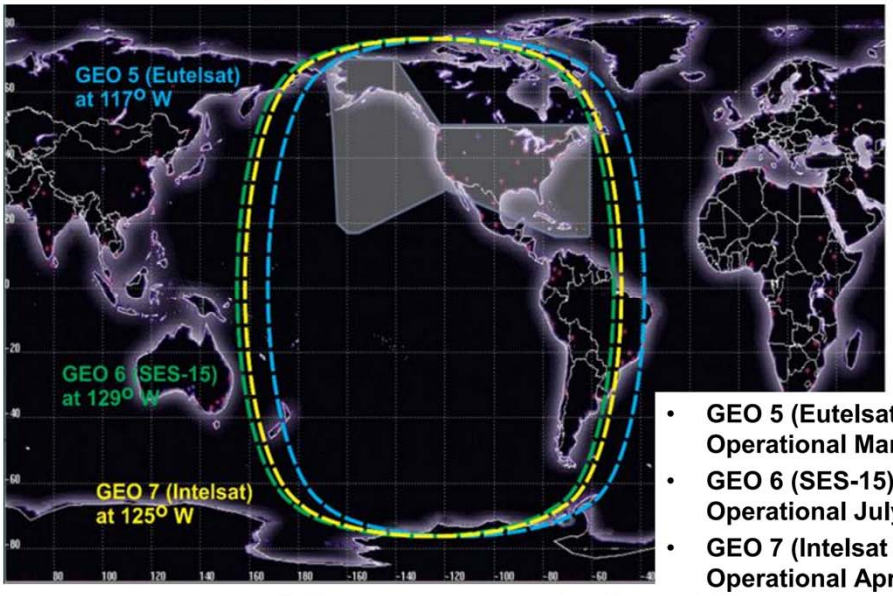
Many smart phones marketed in China have BeiDou receivers

Galileo and BeiDou monitor SAR beacon broadcast and have ability to send a help is on its way signal to the SAR beacon

GPS receivers can determine time from the satellites to 100 nanoseconds

- One tenth of a millionth of a second – light travels about a hundred feet in this time – Light can circle the earth five times in a second
- Cell phone networks depend on GPS time to synchronize phone hand offs between towers

WAAS Coverage



- **GEO 5 (Eutelsat 117WB) Operational March 2018**
- **GEO 6 (SES-15) - Operational July 2019**
- **GEO 7 (Intelsat G-30) – Operational April 2022**

WAAS satellites began L5 deployment in 2022 and plan to be fully operational in 2028

Jamming is broadcasting a signal on the GPS frequency that denies users the signal

- Current non military jammers do not jam L5
- Jamming is common in Israel and the Poland Ukraine border
- Can purchase a jammer online
- Some jammers have been used to defeat highway toll systems with colateral denial to vehicles and aircraft in the vicinity
- Military receivers use multiple encrypted frequencies and are harder to jam

Spoofing is brodcasting signals that trick the receivers into thinking that they are somewhere that they are not

- The FAA is investigating ways to detect spoofing and warn pilots, WAAS broadcast could be a way to warn pilots
- Military receivers use multiple encrypted frequencies and may not be subject to spoofing

United States GPS History

In 1957 Russia launched the first satellite - Sputnik

- US scientist were able to determine the satellite's position by observing the Doppler shift of its transmitted frequency
- They were asked if they knew the location of satellites could they use this to determine the location of a receiver on the ground - Yes
- Precise location of submarines were needed for missile launches
- By 1960 the Transit satellites were operational – one hour updates

Work on today's GPS began in 1973

- Prototype satellites launched from 1978 to 1985
- In 1983 B747 KAL Flight 007 flew off course and shot down by Russia
  - Regan announces GPS will be freely available to civil users
- Early 1990s enough satellites to navigate around the clock
- In 2000 Clinton turns off selective availability increasing accuracy from 300 ft to 30 ft
- In 2010 WAAS became operational
- In 2018 L5 signal began deployment

Newest satellites have more powerful transmitters which will make GPS more likely to work indoors through non metal roofs
Newest also have SAR 406 MHz Emergecy Locator Transmitter receivers onboard, most aircraft carry ELTs that activate on impact

How Does It Work

Trilateration – location determined by distance from satellites

- Need to receive four satellites (three if you know your elevation)
- Solving for four variables – longitude (x), latitude (y), elevation (z), and time (because the satellites are in motion)
- Satellites have precise atomic clocks allowing the signals to be sent with great time precision – look for how much the signal was delayed while travelling to the receiver to determine distance

GPS is so accurate new survey models of the earth were needed

- WGS 84 (World Geodetic System 1984) created to supersede all the local models around the world
- Since the world spins it is a little wider than tall
  - The WGS 84 ellipsoid models this – GPS altitude is above or below this ellipsoid (an ellipsoid is a sphere stretched (scaled) in specific directions)
- To convert to mean sea level changes in gravity due to changes in the density of the materials in the earth must be accurately measured
  - The resulting geoid varies from the ellipsoid by +75 to -100 meters

Having a good view of the sky is important for accuracy

See more satellites

90 degree angle between satellites gives best geometry for calculations

Knowing the angles between the satellites allows calculation of GDOP (Geometric Dilution Of Position)

This can further be resolved to HDOP (Horizontal DOP) and VDOP (Vertical DOP)

HDOP is what is displayed on the GPS as its current accuracy

Relativity and clock speed

One of the rules of relativity in physics states that clocks that are moving through space faster than you appear to you to run slower

Another rule states that clocks experiencing more gravity run slower

These errors would result in a six mile per day accumulating error

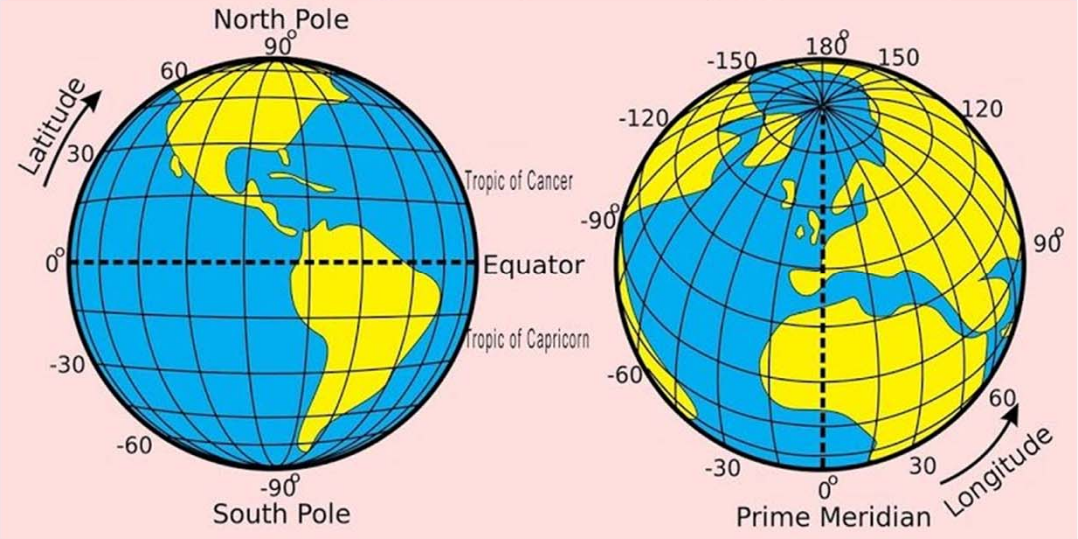
Both are accounted for in the satellites onboard clocks

Map Datums

Before GPS, regions of the world all had different datums (a reference point to measure from) – hundreds of them

- In the US this was normally NAD 27 (North American Datum of 1927)
  - All old USGS topographic maps created before 1984
- NAD 27 latitude and longitude can vary from WGS 84 by as much as 300 feet in some parts of the country
  - Enough to get you lost in some situations if you do not account for it
- Most GPS units will let you change it's coordinate system to one of the old local ones when you are using an old map
  - Once you do this the numbers you see in the GPS, and might give to someone else, will navigate to a different place if their GPS is set to the standard WGS 84 datum

Latitude and Longitude Coordinates



A good GPS that has a good moving map and perhaps a good database allows a user to navigate without understanding coordinates

Latitude and Longitude Coordinates

There are a lot of ways to describe the x and y location of a point on the planet

- Latitude and longitude use degrees as the unit of measure
- UTM uses meters
- It is common for people to get confused with coordinates

Degrees on the globe

- There are 360 degrees in a circle
  - A full circle is drawn along the equator to measure longitude
  - Zero degrees is along the prime meridian which runs north and south through the Royal Observatory in Greenwich England
  - Positive longitude is to the east and negative to the west resulting in a range of +/- 180 degrees
  - A half circle is needed for latitude
  - Zero degrees is at the equator
  - Positive latitude is to the north and negative to the south resulting in a range of +/- 90 degrees

Latitude and Longitude Coordinates

A degree has 60 minutes and a minute has 60 seconds

Three ways to split degrees

- Decimal degrees i.e. DD.dddd°, 39.1234°
- Degrees with decimal minutes i.e. DD° MM.mmm', 39° 45.321'
- Degrees, minutes, decimal seconds i.e. DD° MM' SS.sss", 39° 45' 32"
- Say the format before the numbers, indicate if Latitude or Longitude (in this part of the country is usually obvious if omitted) and say the punctuation between the numbers
- North and East are positive and South and West are negative

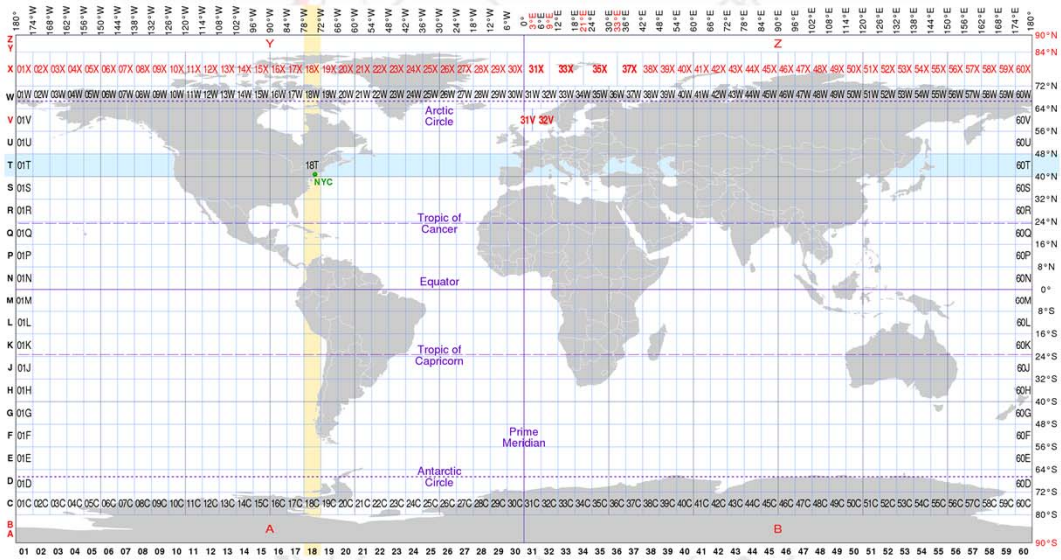
Opportunity for error

- Decimal degrees are the simplest and least likely to be confused with the others
  - Confusing with the others will result in up to a 40 mile error
- Very easy to confuse decimal minutes, and minutes with seconds
  - Confusing between these two will result in up to a 0.4 mile error

Coordinate confusion

I have personally observed multiple times in a year on county SAR missions
It took the helicopter less than a minute to move to the correct spot once the error was detected but a whole team searched the wrong area on Mt Princeton one night
Teams each have their standard and work well together but when other teams, aerial assets, cell phone service providers, or a search subject or reporting party exchange coordinates the chance of an error increases

UTM / MGRS / USNG Coordinates



UTM – Universe Transvers Mecator, MGRS – Military Grid Reference System, USNG – US National Grid

These coordinate systems measure east – west and north – south in meters

UTM divides the world into 60 numbered zones of 6 degrees of longitude each

- On the southwest coast of Norway, zone 32 is extended 3° further west, and zone 31 is correspondingly shrunk to cover only open water
- Also, in the region around Svalbard, the zones 32, 34 and 36 are not used, while zones 31 (9° wide), 33 (12° wide), 35 (12° wide), and 37 (9° wide) are extended to cover the gaps

MGRS and USNG further divides the zones into 20 letter designated bands of 8° of latitude

- Letters I and O are skipped to not be confused with 1 and 0
- Near the north pole band X is 12° of latitude
- Four letters of A, B, Y, and Z cover the polar zones and are 180° of longitude

UTM Coordinates

Several ways to describe UTM (Universal Transverse Mercator) if you include its military and US national grid extensions

- Easier to locate on paper maps, easier to measure distance, no –
- Last five digits of meters in the easting and northing are the same in all three coordinate systems, MGRS and USNG may truncate digits

UTM – the underlying basis for all three UTM based systems

- Easting is measured east and west from the center of the zone
  - To eliminate negative numbers the center coordinate is 500,000 meters
- Northing is measured north and south from the equator
  - To eliminate negative numbers in the southern hemisphere the equator coordinate is 10,000,000 meters with distance south subtracted from it, the equator is zero for northern hemisphere measurements
- For pure UTM: in order, zone number, N or S, easting, northing
  - 13N 412693 4265009
- Some devices when displaying UTM will use the MGRS band number instead of N or S for north and south creating ambiguity
  - Parts of Colorado are in zone S, one of the two bands of ambiguity

MGRS Coordinates

MGRS - Military Grid Reference System

- Used by NATO ground forces, although ships and aircraft use Lat/Lon
- Adds band letter after UTM zone number (in place of UTM N/S)
- Adds a couple of letters to create 100km (60 mile) square regions within each zone/band polygon with corners on UTM 100,000 meter multiples (regions in non polar bands described here)
  - Column letter (easting) is first – A to Z omitting I and O
  - Row letter (northing) is next – A to V omitting I and O
- Easting and northing are then from the lower left corner of the regional square
- For MGRS: in order, zone number, band letter, region letters, easting, northing
  - 13S DC 12573 65010
  - Numbers are shortened (truncating not rounding) if less than 1 meter resolution is needed – 10 meter resolution (4 + 4 digits) is NATO standard
  - If operating in a small area - zone, band, and even region may be omitted, for small area operation and 10m resolution only two four digit numbers

The absence of a zone number and use of band letters A, B, Y, or Z indicate Universal Polar Stereographic projection not UTM

Region column letters are A-H in zone 1, J-R (omitting O) in zone 2, and S-Z in zone 3, then repeat in following zones

Region rows use two different standards one for WGS 84 datum (and some other modern datums) and one for older datums

Region row AA scheme a.k.a. MGRS-New for WGS 84 and some other modern datums

In odd numbered zones begin with letter A

In even numbered zones begin with letter F

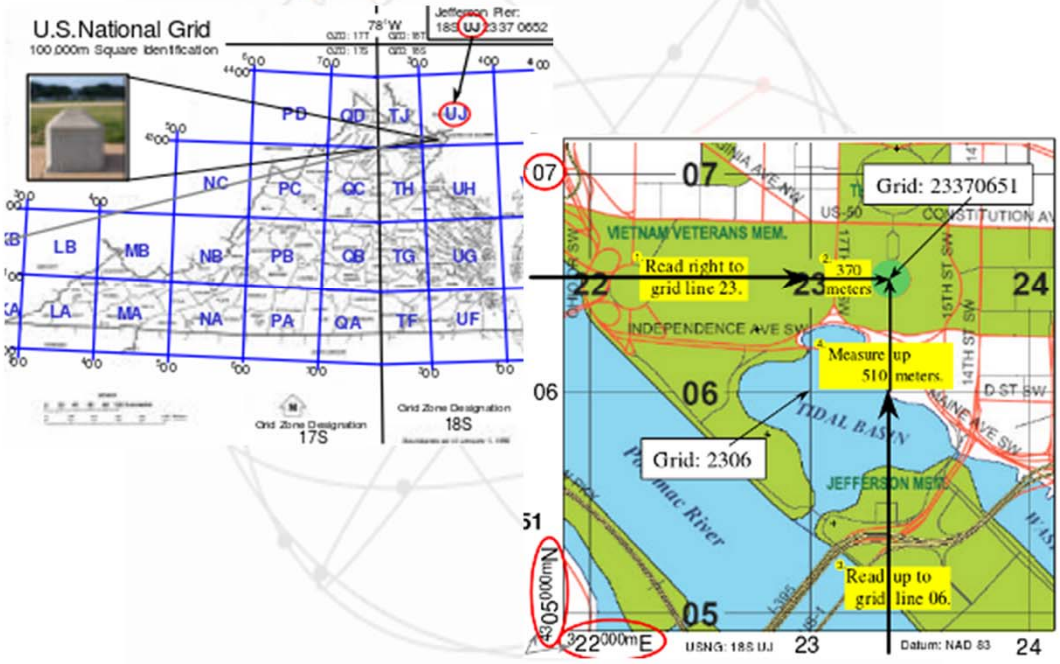
Region row AL scheme a.k.a. MGRS-Old for older datums

In odd numbered zones begin with letter L

In even numbered zones begin with letter R

USNG Coordinates

USNG (United States National Grid) is MGRS in the US



Meant to be of special help to first responders operating in the local area to locations without street addresses

- Public statements at the national level to foster usage but has not caught on in our area
- FEMA mandated usage for land-based operations in 2015
- BLM is an adopter placing it on signs along trails

Even other grid systems

- Amateur Radio operators use the Maiden Head Locator System to apply letters and numbers to latitude and longitude squares
- The Civil Air Patrol has a search grid system that applies numbers to one-quarter degree cells for all the cells on an FAA Sectional Chart

Open Location Code (OLC) a.k.a. Plus Codes

Created by Google based on latitude and longitude

- Pairs of characters latitude (from -90) first then longitude (from -180)
- Character set is 20 numbers and letters, skipping look alikes, not case sensitive
- First five pairs are 20 x 20 blocks then single characters for 5 x 4 grid
- Plus sign after four pairs to aid human readability
- Example 85CPG2J4+M7 or G2J4+M7 Salida, CO

Block sizes of Open Location Codes

Code length	2	4	6	8	+	10	11
Block size	20°	1°	0.05° (3′)	0.0025° (9″)		0.000125° (0.45″)	
Approximately	2,200 km	110 km	5.5 km	275 m		14 m	3.5 m

Mapping of Open Location Codes

Base 10 digit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Base 20 digit	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	G	H	I	J
Code digit	2	3	4	5	6	7	8	9	C	F	G	H	J	M	P	Q	R	V	W	X

Division of subblocks in Open Location Codes

	longitude →			
latitude ↑	R	V	W	X
	J	M	P	Q
	C	F	G	H
	6	7	8	9
	2	3	4	5

Uses

- Google Maps
- A few international locations
- Navajo Nation

Minimum length of eight characters (unless removing the first four) and the plus sign requires padding zeros before the plus sign with nothing after the plus sign

The first four characters can be removed if a place name within 40 km (24 miles) is added

What3Words Coordinates

Combinations of three words to identify any three meter square on the earth – 40,000 word vocabulary – Over 40 languages

- Patented algorithm to convert to and from latitude and longitude
- Charges businesses for high volume use; others are free of charge
- Not yet widely used nor available in many GPS devices or apps

canny. steer. guilty	stone. firmly. cones	grant. shade. newest	gums. clubs. terms	label. drill. shave	flight. result. ships	bunk. show. retail	locker flip shack
bets. hooked. firms	deals. nuns. colleague	amuse. tuck. lows	loud. rising. bravo	spike. stir. singer	rushed. woven. exchange	when. agent. grab	apple flats noted
cooks. total. putty	tubes. page. forced	bond. motel. excuse	gravel. chart. burn	deed. cross. times	hills. moods. dunes	sorters. stem. both	causes scared shiny

Big Ben clock tower

Inspired by bands and equipment that could not find the correct dock at large venues
Adopted by many emergency service organizations in Europe and spurned by others as too easy to confuse words, especially with forgein accents

Navigation Without Coordinates

With a good database and a good map the user does not need to use or even understand coordinates

- Automotive GPS systems convert street addresses, business addresses and other points of interest to coordinates for the user
- Aviation databases do the same with navigation waypoints, airports and the like
- Moving maps will show the location of the automobile or aircraft on a moving map providing situational awareness of the immediate surroundings and a look ahead to what's coming up and the destination
- A handheld GPS with moving topographic maps showing place names, trails, streams, trailheads, contours and more can guide a user in the backcountry without the need to deal with coordinates

Learning to Use a GPS App

I tried several times to teach GPS to SAR members with Power Point slides and did not succeed

- Hands on exercises with a small group walking to waypoints lead to success

All GPS units and apps basically do the same things but hide it behind different buttons and in different menus

- I worked on the design of the user interface for aviation GPS units
  - Most users only ever used 30% of the features and cursed the other 70% that got in their way
  - A design that makes the most common features easy to find and use is an elegant design

Dedicated GPS or Smartphone with App

A smartphone with a GPS app

- Offers the best user interface and choice of maps (most are free)
- But its battery may not last a full day if used continuously
- Put it in airplane mode to save battery
- Keep it warm in an inner pocket if the air is cold
- Carry another battery and cable to recharge
- For multiday trips turn it off when not being used

A dedicated GPS

- Cost a few hundred dollars
- Requires the use of a computer to add maps
- Maps usually cost money
- Usually has a smaller screen
- Its battery may last for days of continuous use
- It is probably waterproof and won't break if you drop it
- If not used for 4 months or moved more than 120 mi - search the sky

Full message from a satellite takes 12.5 minutes

Includes detailed orbit for this satellite called an ephemeris and course orbit data for all satellites (up to 32) called an almanac

If the unit has not been on for more than 4 months or has moved more than 120 miles since last used a new almanac is needed

Acquiring the new almanac is called "search the sky" and may require up to 30 minutes

My Favorite GPS App

Gaia GPS – Greek for mother nature

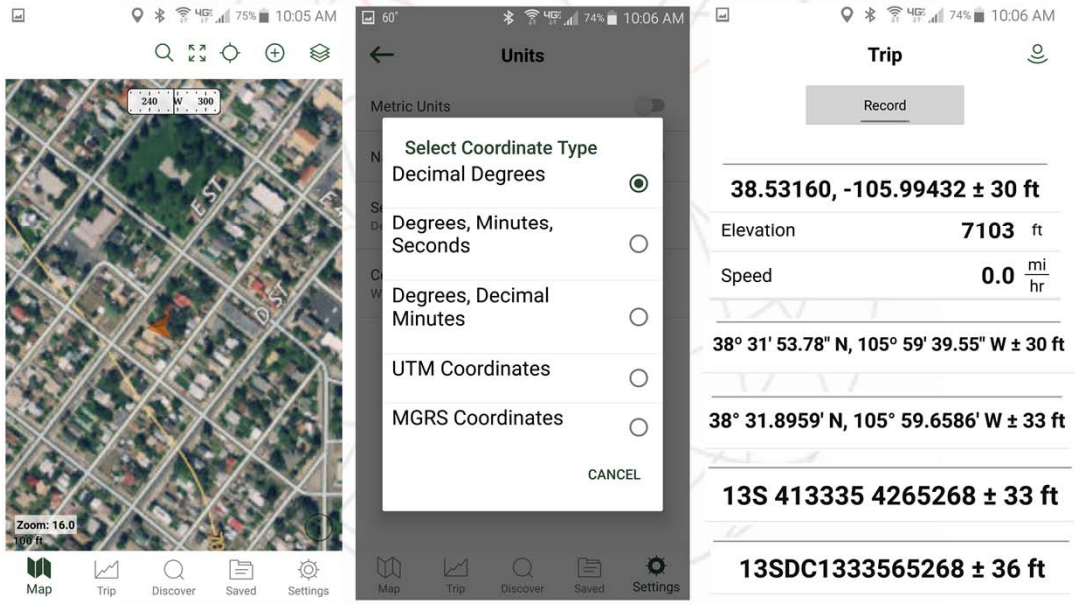
- Android and Apple versions
- Once the maps are loaded no cell service is needed
- $5 per month for premium map access
  - I bought mine back when it was $20 for life
- Large and still growing selection of maps, and allows you to add your own lines and points such as trails and waypoints
  - Maps are everywhere from topographical like National Geographic Trails Illustrated maps to cell phone coverage maps and everything in between
- With the premium subscription you can make and load your own maps
  - I load my own maps as a tile map service without paying for premium – but this requires the use of GIS tools and knowledge of how to use them
- Can manage your maps, tracks and points on a computer and sync with your phone and other devices and other Gaia users

Where am I ?

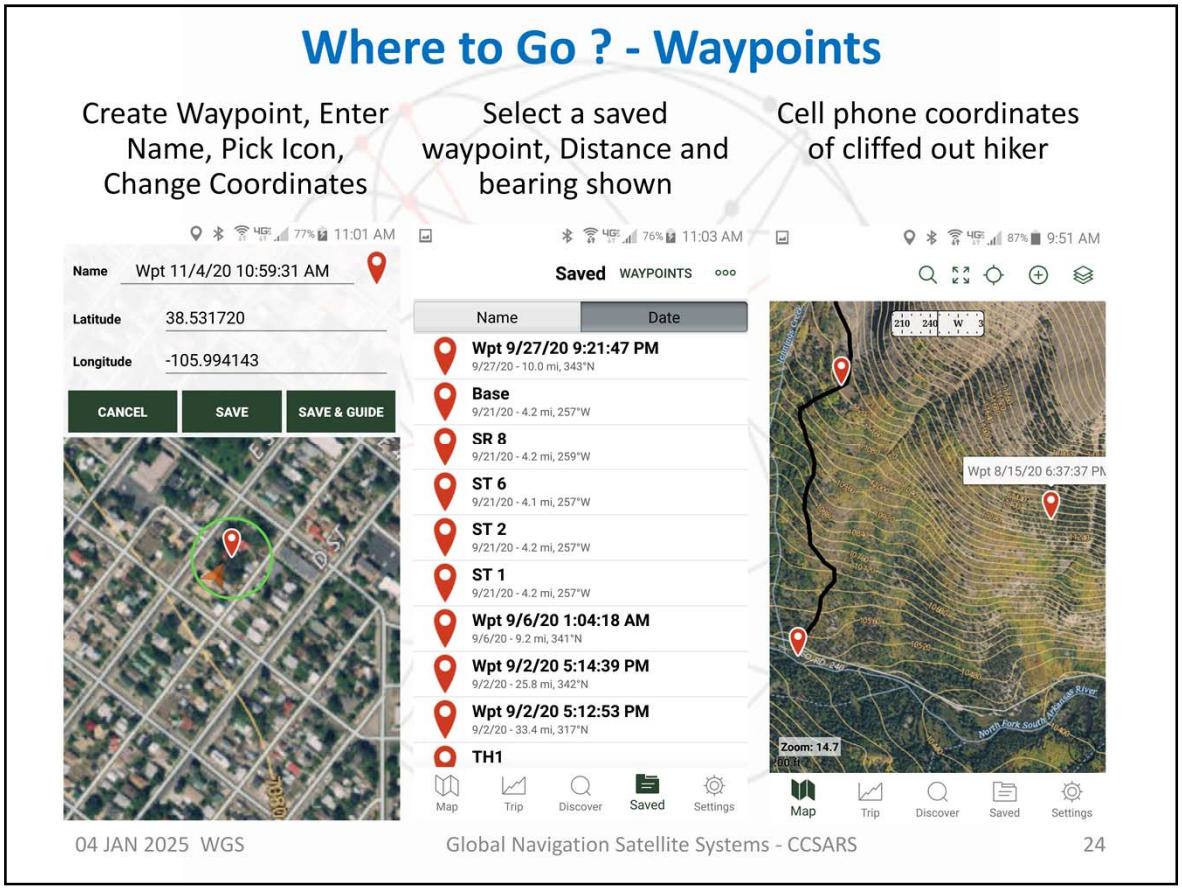
Orange triangle in center of the map

Settings – Coordinate Type

Trip – Coordinates Displayed



UTM choice incorrectly displays MGRS band letter instead of just N and S for north and south



When creating waypoint present position is auto filled

Waypoints may be loaded from a computer file – example Colorado Trail route segments and waypoints

- Creating a waypoint for your campsite or where you parked you car will help you return if it gets dark or the visibility becomes restricted

Rescue Aug 15, 2020

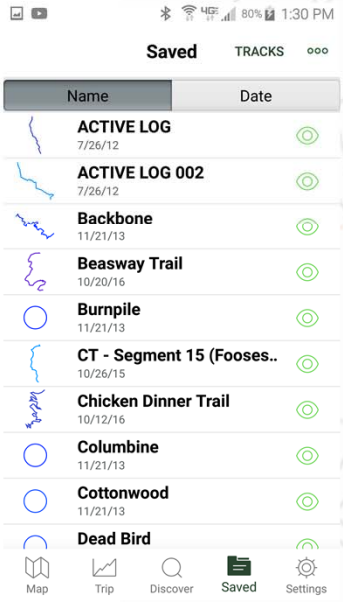
- Climber at right center pin stopped on descent by cliffs, needs help getting back to vehicle at lower left pin location
- Rescue team hiked up Jennings Creek trail show by black line to upper pin and then followed contour to subject

Where Have I Been ? – Save Your Tracks

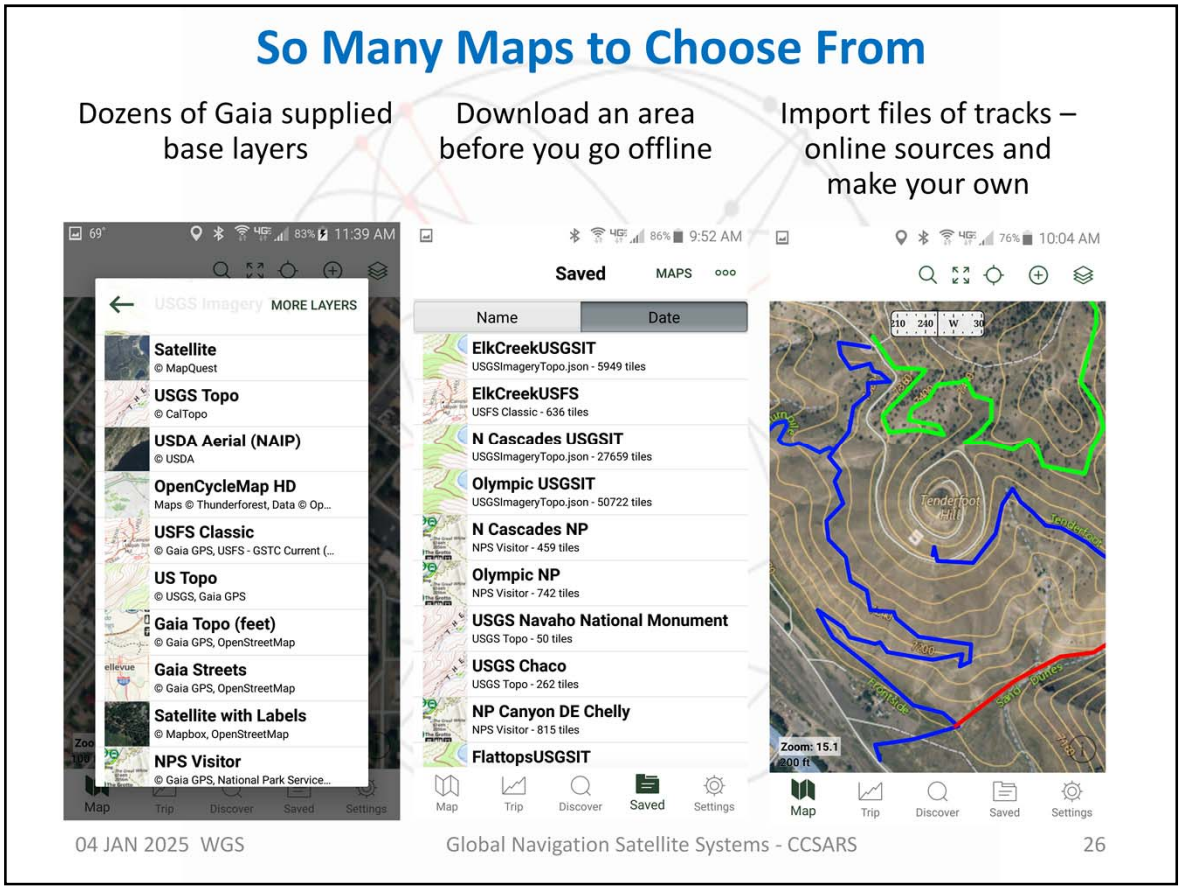
Saved and Downloaded Tracks

Track Statistics Top Of Page

Track Statistics Bottom Of Page



Can choose displayed track line color on map for each track



Some layers require the $60 per year pro subscription.
While online draw a box around the area of interest, select the level of detail, name it and download it
Downloaded tracks from International Mountain Bike Association, 14ers.com, and Colorado Trail Foundation

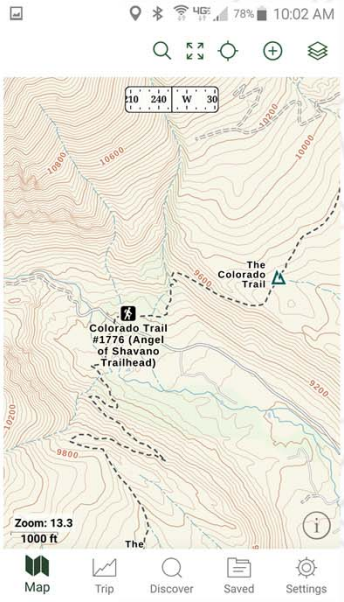
Made my own track file for the Mesa Trail

My track colors for mountain bike trails

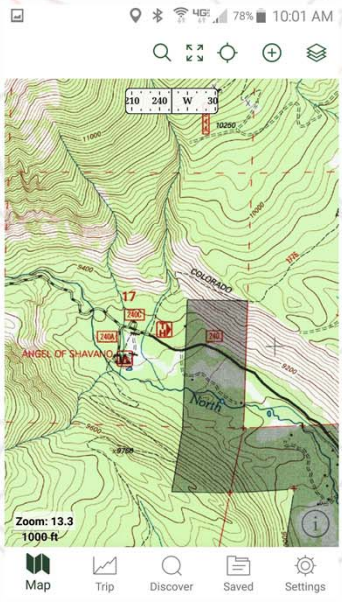
Green – Easiest
Blue – More Difficult
Red – Most Difficult

So Many Maps to Choose From

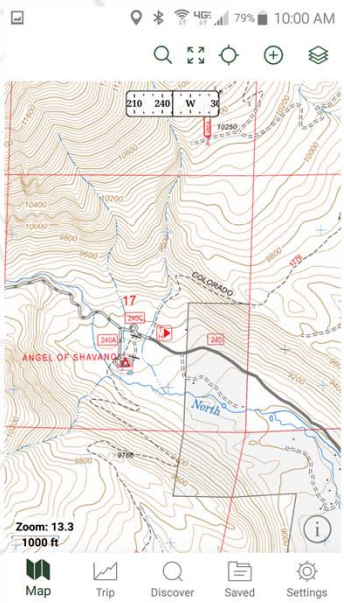
Gaia Topo – Vector Map Is Very Small Download Size



Scanned Old USGS 7.5 Minute Topo Maps – Green shading is forest



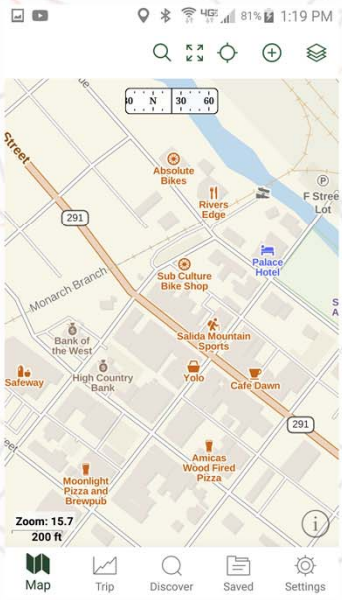
USFS Topo Maps Are Updated Regularly – No forest shading



So Many Maps to Choose From

National Park Service Visitor Maps

Gaia Street Map



USGS Imagery Topo – Made a Custom Link to USGS Map Server