

Global Navigation Satellite Systems



Geopositioning



Determining or estimating the geographic position of an object or person.

GNSS uses satellite signals to support positioning and timing.

Applications include navigation, mapping and surveying.

Four global constellations

System	Country or region
GPS	United States



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Galileo	European Union



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Galileo	European Union
GLONASS	Russia



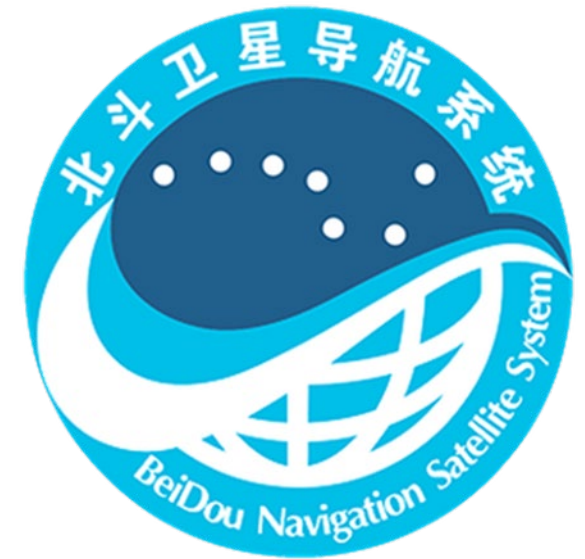
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GPS	United States
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GLONASS	Russia
BeiDou	China



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MULTI-CONSTELLATION RECEIVER

More visible satellites can improve redundancy, reliability and performance, particularly in difficult observing conditions.

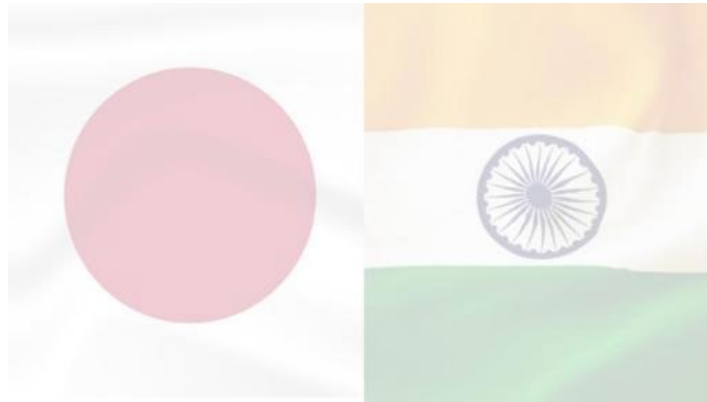
Regional satellite systems

QZSS

Japan's Quasi-Zenith Satellite System supports satellite navigation and augmentation in its region.

IRNSS / NavIC

India's regional navigation system serves India and the surrounding area.



Where GNSS fits in a construction project

Positioning supports the project from early survey through delivery and monitoring.

CONTROL Establish the project coordinate framework

CAPTURE Topographic and detail surveying

DELIVER Setting out and machine/sensor positioning

MONITOR Deformation and repeat observations



Accuracy must match the task

GNSS has no single accuracy: specification comes first.

CONTROL SURVEY

sub-centimetre

Primary project control

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typically 1–10 cm

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topography

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one to a few metres

Approximate GIS /
navigation

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Approximate GIS /
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Do not use centimetre equipment to justify a metre-level brief, or metre-level positioning for engineering set-out.

What Satellites Transmit

Each GNSS satellite continuously transmits radio signals that contain three main types of information:

Ephemeris Data

Information about the
satellite

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Timing

Precise Timing Information

The receiver's role



Receive

Capture signals from usable satellites.

Decode

Read navigation and timing information.

Estimate

Use observations to solve position and clock offset.

Receivers range from phones and handhelds to specialist surveying equipment.

Distance from signal travel time

Distance = speed × time

Range $\approx c \times \Delta t$

c is the speed of light.

Δt is the signal travel time.

Worked example: signal travel time

Illustrative travel time: 0.070 seconds

$$\begin{aligned} &299,792,458 \text{ m/s} \\ &\times 0.070 \text{ s} \end{aligned}$$

$$\approx 20,985 \text{ km}$$

Range $\approx$ 20,985,472 metres

Satellite 3



Satellite 1

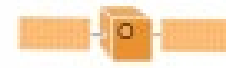


Satellite 2

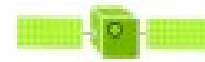




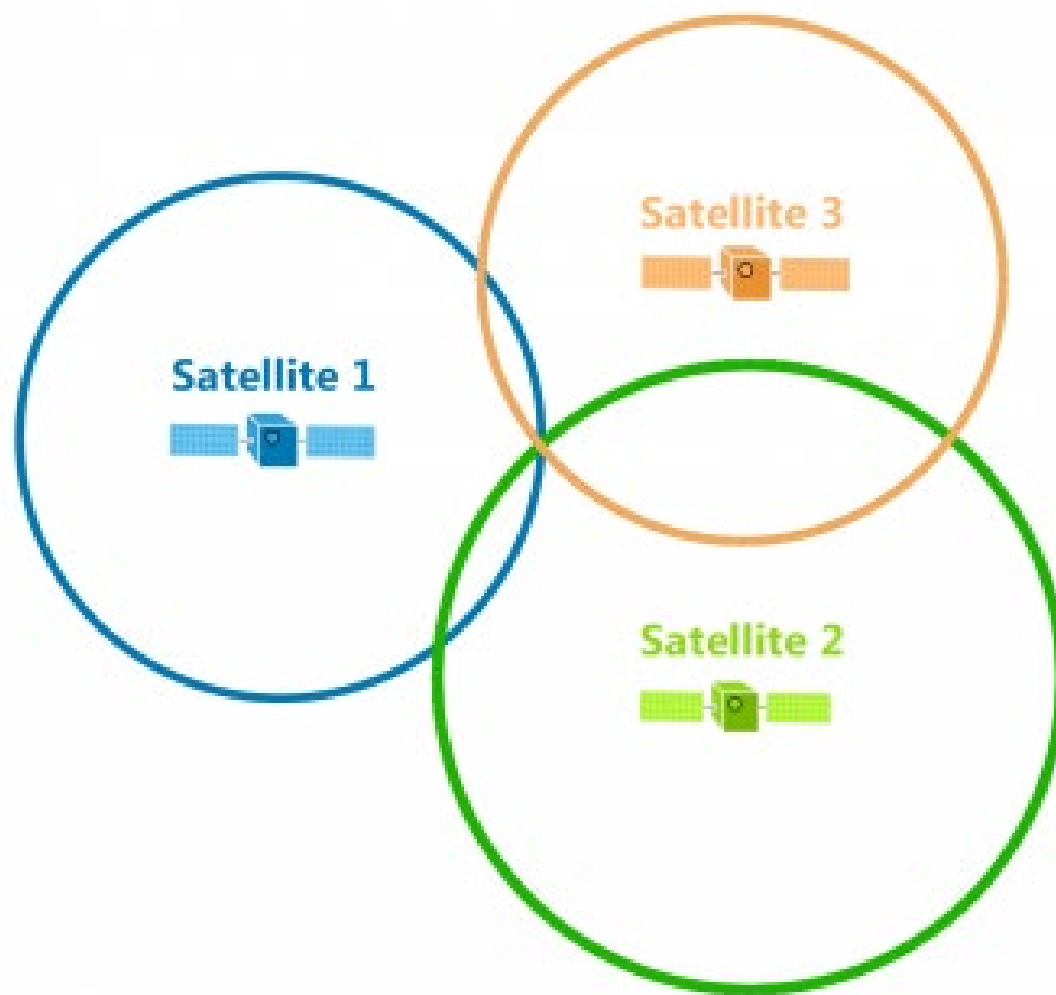
Satellite 3

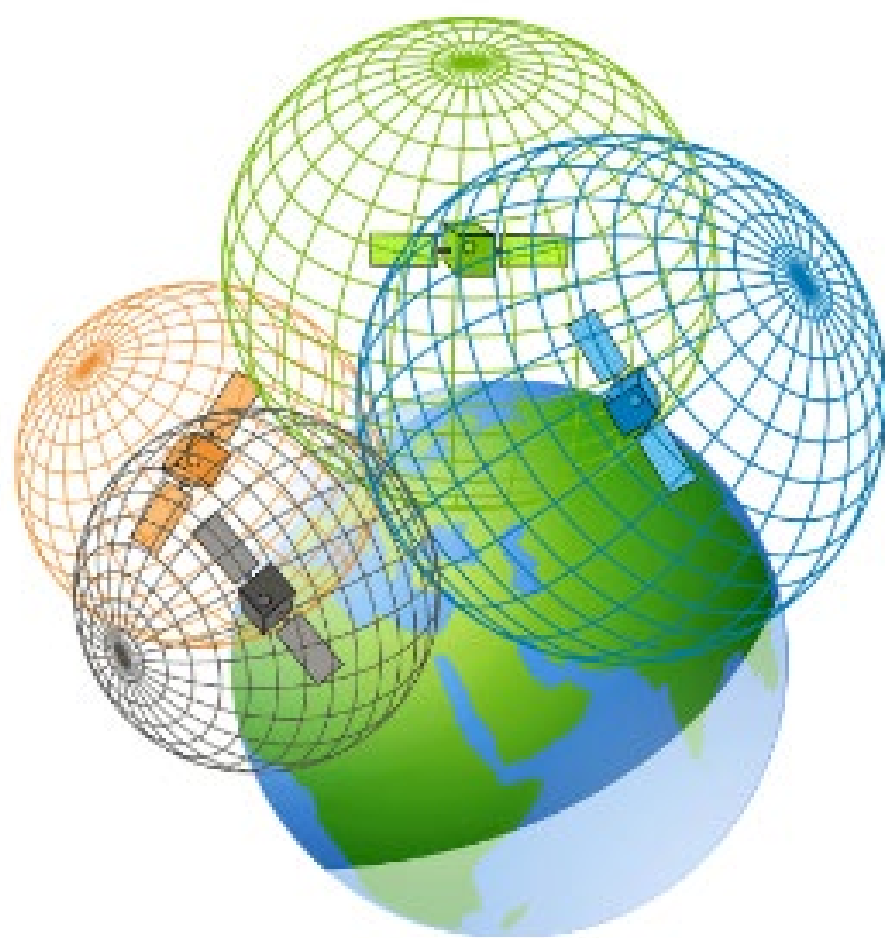


Satellite 2









Four unknowns in a basic GNSS solution

x

Position

y

Position

z

Position

Δt

Receiver clock
offset

At least four independent satellite observations support the basic 3D position-and-clock solution.

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.

Clock Errors



Satellite Clock Errors:

GPS satellites carry very precise atomic clocks, but slight timing inaccuracies can occur.

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Receiver Clock Errors:

GPS receivers, especially low-cost or non-professional ones, typically use less accurate clocks.

Small timing errors mean large range errors

Illustrative calculation

299,792,458 m/s
× 0.000001 s

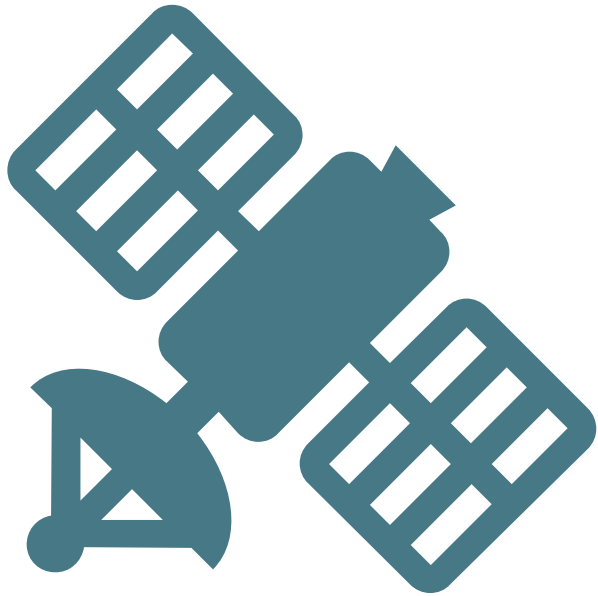
~300 m

A timing error of one microsecond corresponds to about 300 metres of range error.

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.
Ephemeris errors	Misrepresent the satellite's position.

Ephemeris Errors



Orbital Information Errors:

The ephemeris refers to the data that describes the satellites' orbits and is broadcast to GPS receivers

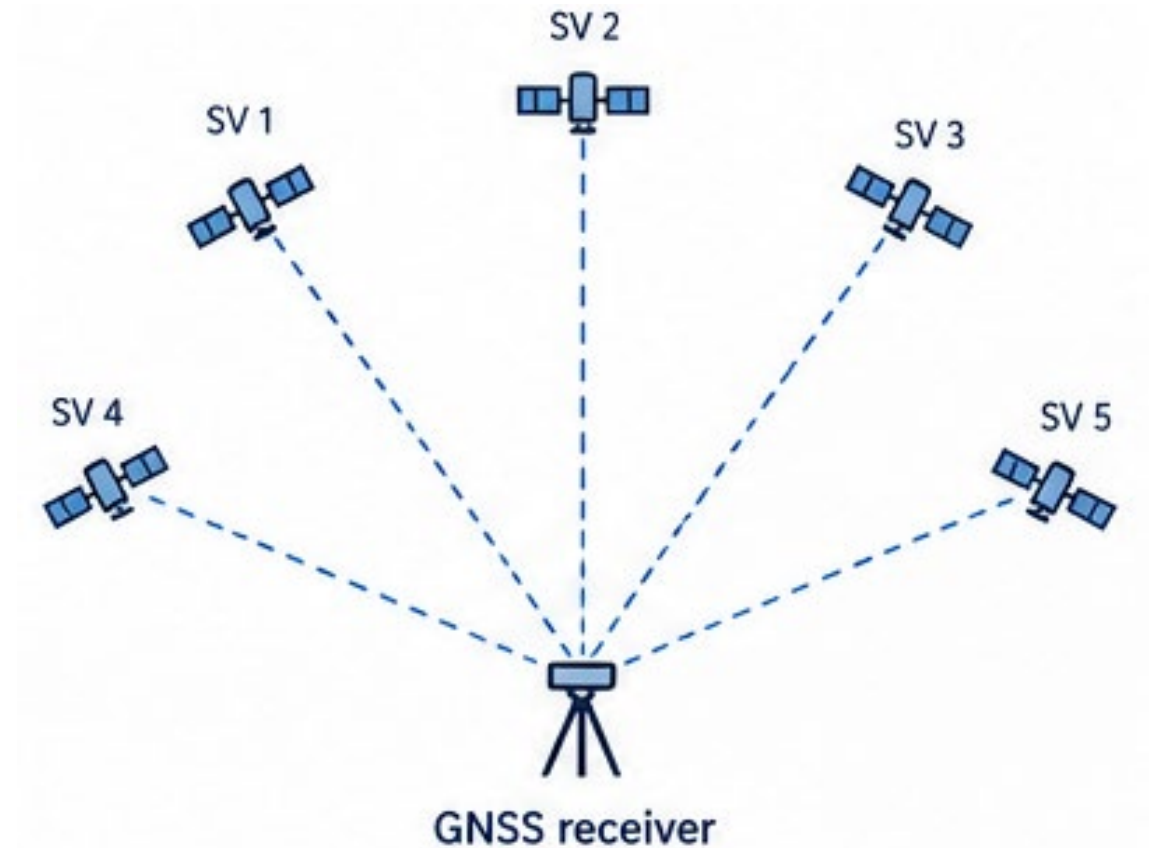
Any small inaccuracies in the satellites' reported positions can introduce errors in the calculation of the user's position

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.
Ephemeris errors	Misrepresent the satellite's position.
Satellite geometry	Amplifies measurement uncertainty.

GDOP and PDOP

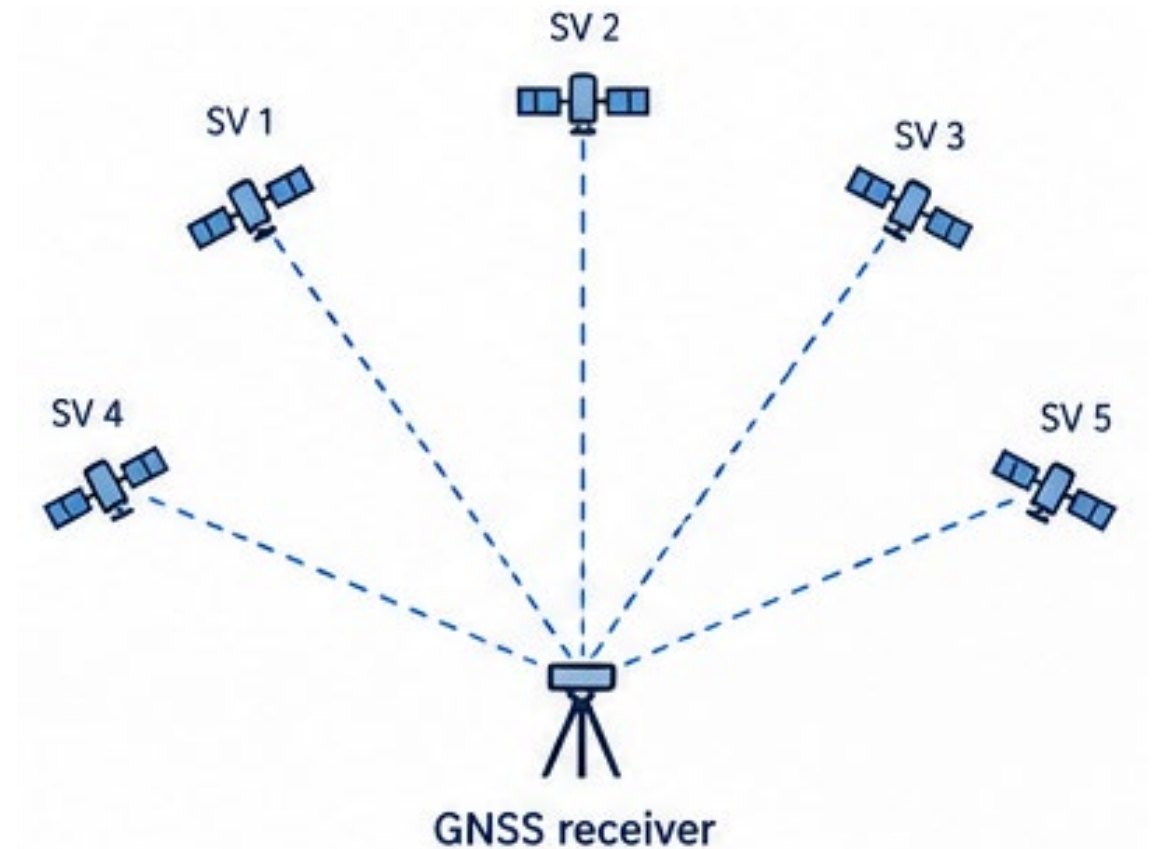
GDOP and PDOP measure the overall effect of satellite geometry on the precision of the GNSS positioning solution.



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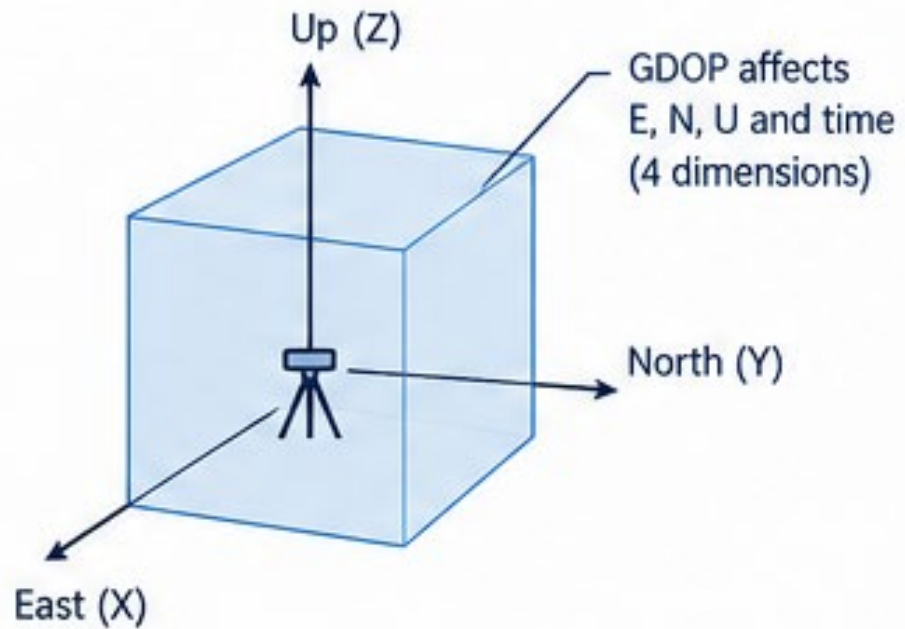
They are dimensionless factors that scale the effect of range measurement errors on the position.



GDOP and PDOP

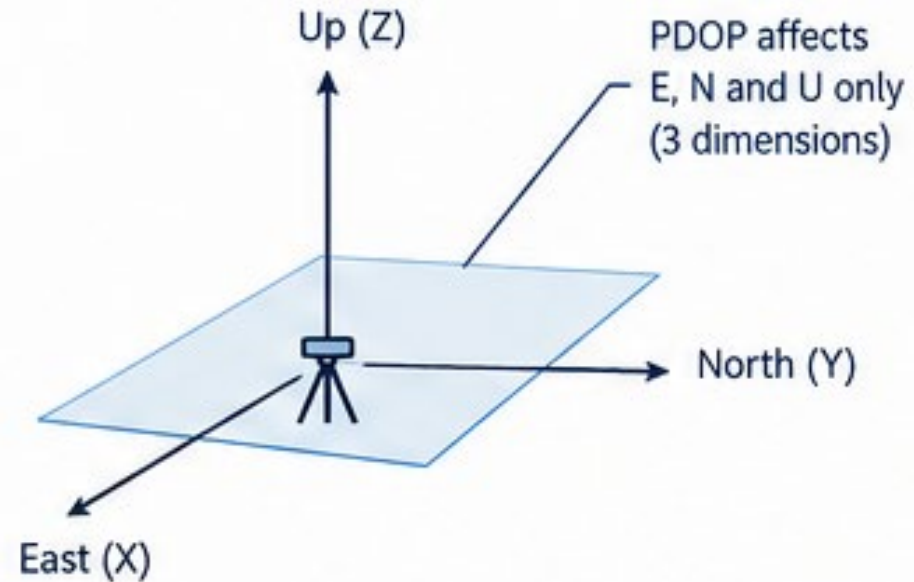
GDOP (includes time/clock error)

Represents the total effect of satellite geometry on position and time/clock estimation.



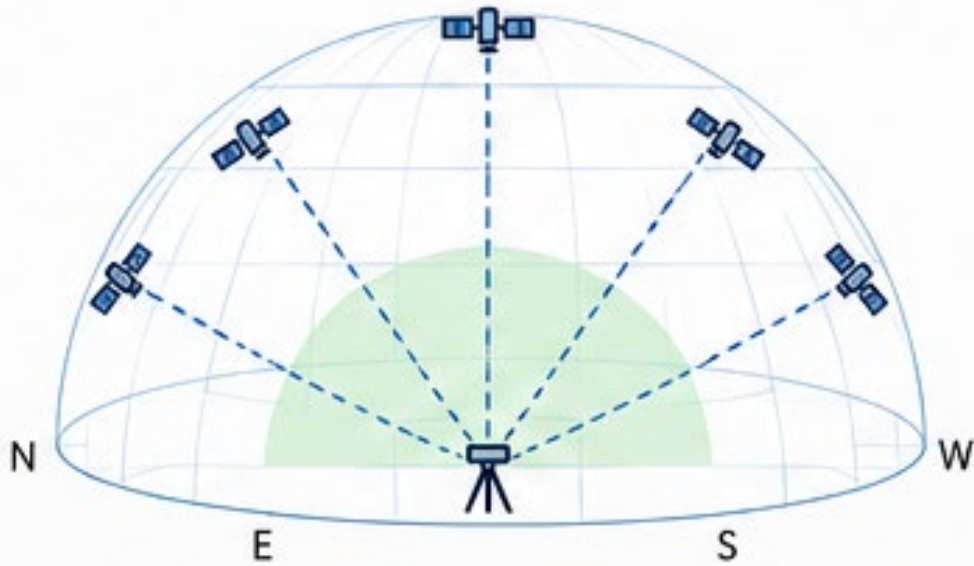
PDOP (position only)

Represents the effect of satellite geometry on the 3D position (no time/clock component).



GDOP and PDOP

Satellites are well distributed across the sky, providing strong geometry and higher precision.



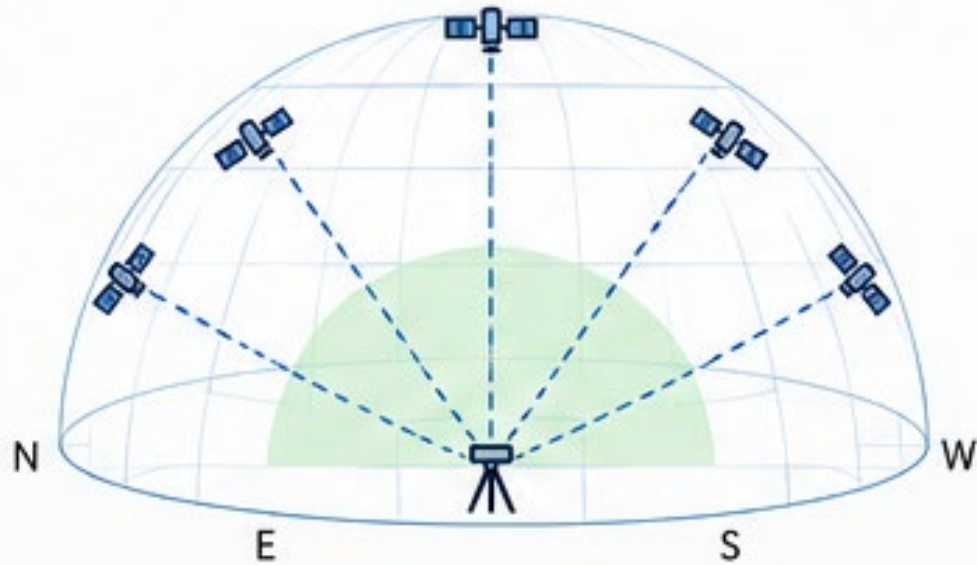
Typical values:

PDOP $\approx 1 - 2$

GDOP $\approx 1.5 - 3$

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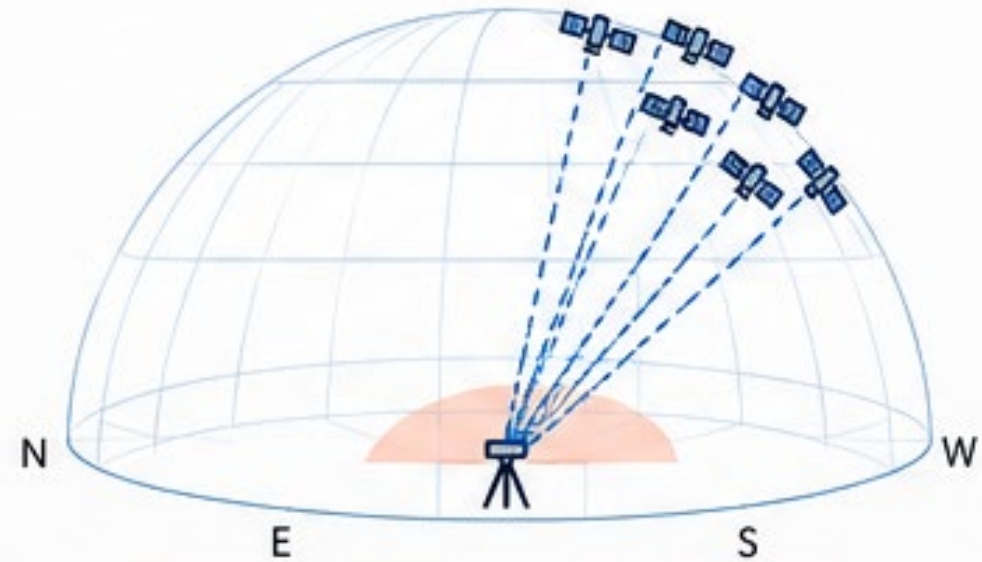


Typical values:

PDOP $\approx 1 - 2$

GDOP $\approx 1.5 - 3$

Satellites are clustered in one part of the sky, providing weaker geometry and lower precision.



Typical values:

PDOP $\approx 5 - 10$

GDOP $\approx 6 - 15$

GDOP and PDOP

Lower values for both GDOP and PDOP indicate a better satellite configuration, leading to higher positioning accuracy.

< 3: Excellent satellite geometry. Highly accurate positioning.

3-6: Good satellite geometry. Decent accuracy.

6-10: Moderate satellite geometry. Positioning accuracy decreases.

>10: Poor satellite geometry. High uncertainty in position estimation.

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.
Ephemeris errors	Misrepresent the satellite's position.
Satellite geometry	Amplifies measurement uncertainty.
Atmospheric delays	Change signal travel time.

Atmospheric Delays



Ionospheric Delays:

The ionosphere is a layer of Earth's atmosphere that contains charged particles. As GPS signals pass through the ionosphere, they are slowed down, which can introduce errors in distance calculations

Atmospheric Delays



Tropospheric Delays:

The troposphere is the lowest part of the Earth's atmosphere, containing weather systems. Variations in temperature, pressure, and humidity can also delay GPS signals.

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.
Ephemeris errors	Misrepresent the satellite's position.
Satellite geometry	Amplifies measurement uncertainty.
Atmospheric delays	Change signal travel time.
Path errors	Adds reflected signal paths.

Path Errors



Obstruction:

Obstructions occur when objects such as buildings, trees, or terrain block or weaken GNSS signals, reducing satellite visibility and potentially decreasing positioning accuracy or preventing a reliable position fix

Path Errors



Signal Reflection:

Multipath errors occur when GPS signals reflect off nearby surfaces, such as buildings, water, or the ground, before reaching the receiver.

Sources of positioning error

Source	Effect on the observation or solution
Clock errors	Bias the timing of the signal.
Ephemeris errors	Misrepresent the satellite's position.
Satellite geometry	Amplifies measurement uncertainty.
Atmospheric delays	Change signal travel time.
Multipath	Adds reflected signal paths.

Several error sources can act at the same time.

Static or kinematic?

The main trade-off is between control quality, occupation time and productivity.



STATIC

Receiver remains over a point. Favoured for high-quality control and post-processing.



RTK / KINEMATIC

Rover moves around the site. Favoured for rapid detail capture and practical set-out.

Introduction to DGNSS and RTK

Both methods use reference data to improve a rover's GNSS position.

DGNSS

Differential GNSS

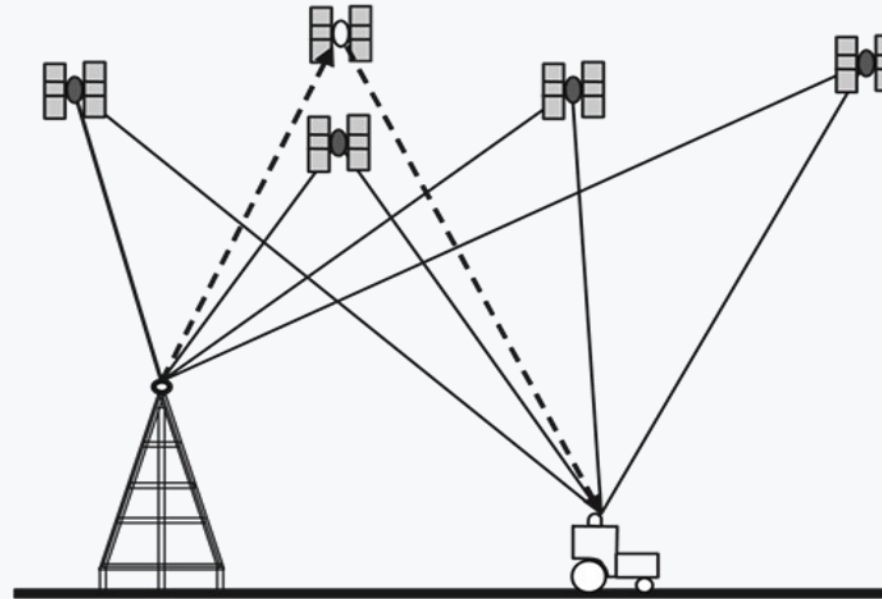
Uses corrections to code-based ranges.

Supports mapping and navigation where lower accuracy is acceptable.

How differential corrections work

Nearby receivers observe similar satellite and atmospheric errors.

- 1 Known reference: a base at a surveyed coordinate observes the same satellites as the rover.



How differential corrections work

Nearby receivers observe similar satellite and atmospheric errors.

- 1 Known reference: a base at a surveyed coordinate observes the same satellites as the rover.
- 2 Estimate errors: compare measured satellite ranges with ranges expected at the known reference.
- 3 Send corrections: a radio or internet link carries time-tagged correction data to the rover.
- 4 Apply and check: the rover corrects its observations, calculates its position and checks quality.

Introduction to DGNSS and RTK

Both methods use reference data to improve a rover's GNSS position.

DGNSS

Differential GNSS

Uses corrections to code-based ranges.
Supports mapping and navigation where lower accuracy is acceptable.

RTK

Real-time kinematic

Uses carrier phase and resolves whole-cycle ambiguities.
Can deliver centimetre-level positions under suitable conditions.

How RTK uses carrier-phase measurements

The carrier gives a fine measurement, but the receiver must resolve whole cycles.

CARRIER-PHASE IDEA

$$\text{Range} \approx (N + \phi) \times \lambda$$

N whole cycles, initially unknown

ϕ measured fraction of a cycle

λ carrier wavelength

Conceptual model, before error terms

How RTK uses carrier-phase measurements

The carrier gives a fine measurement, but the receiver must resolve whole cycles.

1 Compare base and rover phase

Combined observations reduce shared errors and estimate the relative position.

2 Resolve integer ambiguities

FIXED

- The carrier-phase ambiguities have been resolved to integer values. This is generally the preferred state for precise surveying.

FLOAT

- The ambiguities have not been fully resolved, so the position is generally less reliable.

DGNSS versus RTK

The required tolerance determines whether the extra precision is useful.

Comparison	Code-based DGNSS	RTK
Main observation	Code (pseudorange)	Carrier phase, supported by code
Indicative accuracy	Sub-metre to metre level	Centimetre level when fixed
Initialisation	No integer ambiguity fixing	Must resolve integer ambiguities
Coverage and setup	Often longer usable baselines and lower equipment cost	Local base or network service with reliable communications
Construction use	Approximate asset mapping and site reconnaissance	Detail survey and suitable set-out, subject to tolerance and checks

Indicative performance only. Receiver, baseline, site conditions and survey procedure affect achieved accuracy.

Factors affecting correction quality

Correction quality and the final coordinate depend on different parts of the workflow.

Reference and baseline

Wrong base coordinates shift the rover result. Longer baselines reduce similarity of atmospheric errors.

Atmosphere

Ionospheric and tropospheric variations leave residual errors, especially as conditions differ.

Reflections and interference

Multipath is local to the antenna. A correction service cannot remove every reflected signal.

Correction link

Interruptions or stale data weaken real-time corrections. Monitor correction age and service status.

Sky view and geometry

Obstructions and poor satellite geometry weaken positioning and make phase tracking less reliable.

Setup and reference system

Check antenna height, pole stability, project grid and height model before accepting coordinates.

Field decision: check known control and repeat observations independently. Pause or change method if checks fail.

A practical GNSS survey workflow

1 Plan

Check control, required accuracy, sky visibility and Co-ordinate Reference System.

2 Set up

Centre and level the pole or antenna.
Measure antenna height correctly.

3 Connect

Select the correction source and check communications.

4 Observe

Wait for a stable solution. Check satellites, DOP and status.

5 Record

Store coordinates, point code, time, antenna height and metadata.

6 Verify

Check known control and repeat or compare observations.