Precise Point Positioning

An introduction to the concepts that make up Precise Point Positioning (PPP)

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Precise Point Positioning

There are several distinct parts to the process that allows us to determine a position using a GNSS. These parts include:

- The GNSS signal being created within and broadcast by the satellite,
- The passage of that signal through space and the Earth's atmosphere, and
- Its reception by a receiver on the Earth's surface.

Each one of these parts is capable of introducing elements into the process which ultimately reduces the accuracy of the position that is calculated. Precise Point Positioning (PPP) aims to understand what these elements are and builds models to create corrections such that the final position is as accurate as is possible.

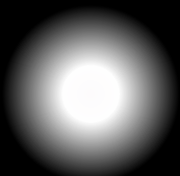
Orbit and clock variations

Because the system takes measurements based on the speed of light – big number – tiny variations in orbit position and satellite clock time has a big effect on a calculated position on Earth.

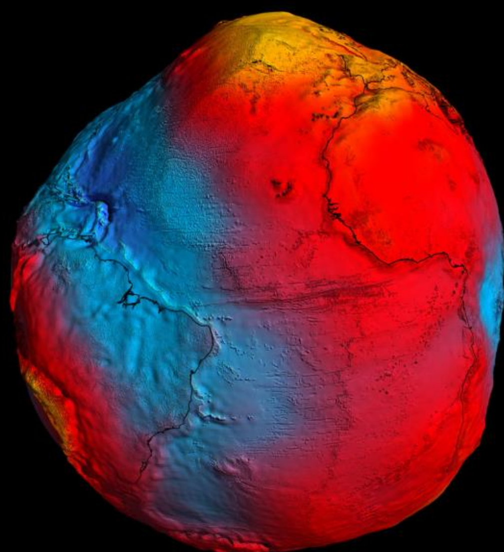
The power of the satellite's transmitter can create a pushing force.

The movement of the moon and other bodies have gravitational effects on the satellites.

The systems within the satellite itself have "biases" – delays in time on signals due to the physical creation of the signal within the electronics.



Satellites carry very accurate clocks, but even they will drift a little over time and need to be corrected.



The "pressure" of sunlight on the satellite can push it away from the Sun

The Earth changes shape – Solid Earth Tides – in response to the gravitational pull of the Sun and Moon.

The Earth is not a perfect sphere – it's fatter round the middle and has "lumpy" gravity.

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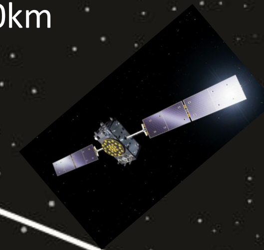
Atmospheric effects

The Troposphere
and Ionosphere

End of the Ionosphere at ~2,000km



The Ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth. It exists primarily due to ultraviolet radiation from the Sun.

The irregular electron density in the Ionosphere can cause phase and amplitude fluctuations in the GNSS signal so degrading its accuracy. The Ionosphere is dispersive – it delays radio of different frequencies by different amounts.

The start of the Ionosphere at ~85km

The Mesosphere and Stratosphere

The Troposphere up to 18km

The surface of the Earth

The Troposphere gives the Earth its weather. It's a layer up to 18km thick that contains 75% of the Earth's atmosphere and 99% of the water vapour. It both delays and refracts GNSS signals.

The Troposphere is not ionised – it does not contain free electrons. The Troposphere is not dispersive – it delays radio of all frequencies by an equal amount.

The Troposphere hydrostatic (dry) delay is caused by dry gases and particles in the troposphere, and it is about 80–90% of the total tropospheric delay. Hydrostatic delay can be precisely determined from surface pressure measurements using empirical models. The tropospheric wet delay is due to water vapor content in the troposphere, and is difficult to precisely model.

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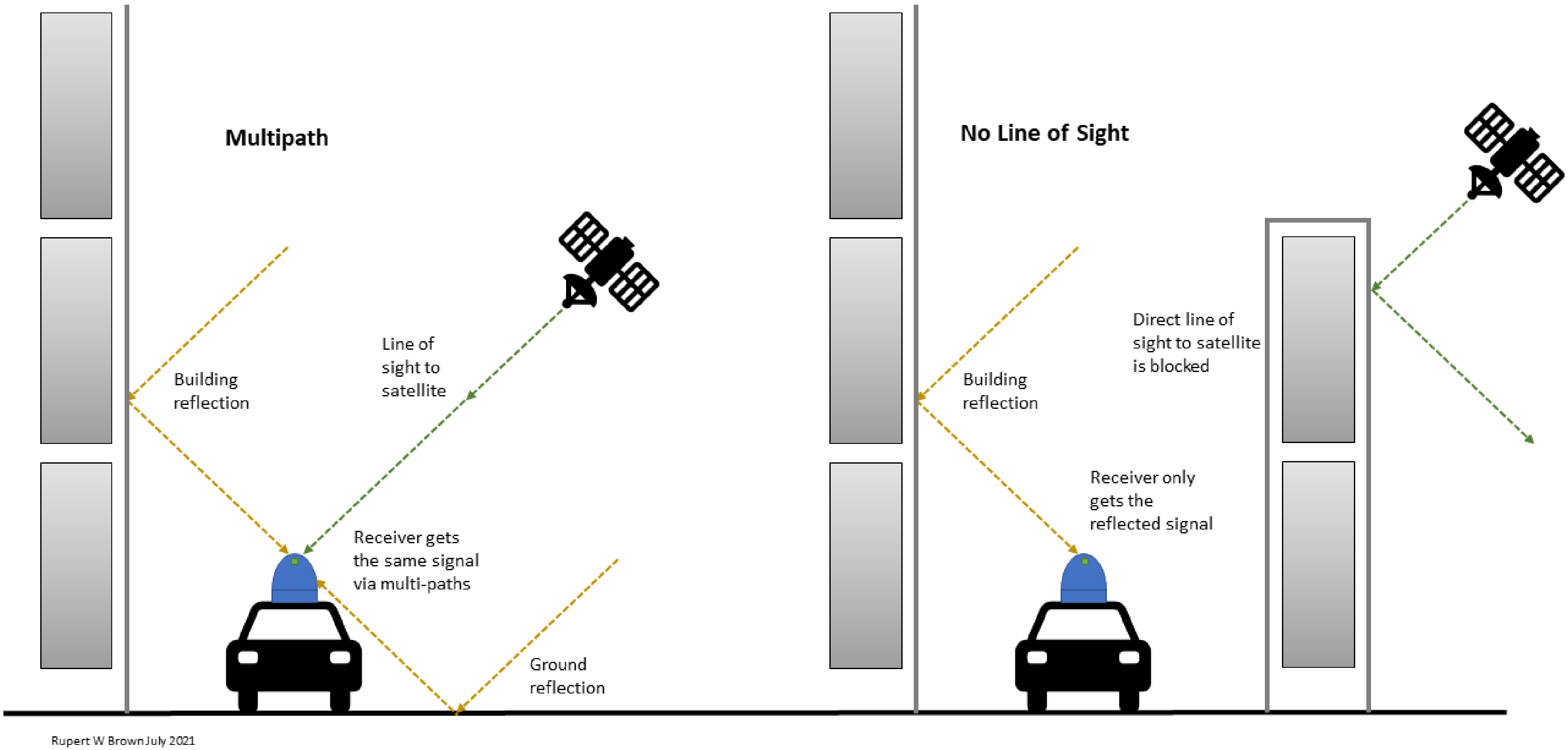
At the receiver



Much like the satellites that broadcast the GNSS signal, receivers also have biases. This time the delay is between the receipt of the signal at the antenna and the processing of that signal by the receiver's electronics. It is also important for the receiver to know where its antenna is. Any calculated position will be that of the antenna.

Another phenomenon that can occur is the idea of multipath and no line of sight signals. GNSS signals can be reflected off the ground and the side of large buildings. The reflected signal has travelled further than the line of sight signal and so arrives at a slightly later time. This kind of interference can cause the measured position to drift or jump around as the multipath signals reach the receiver.

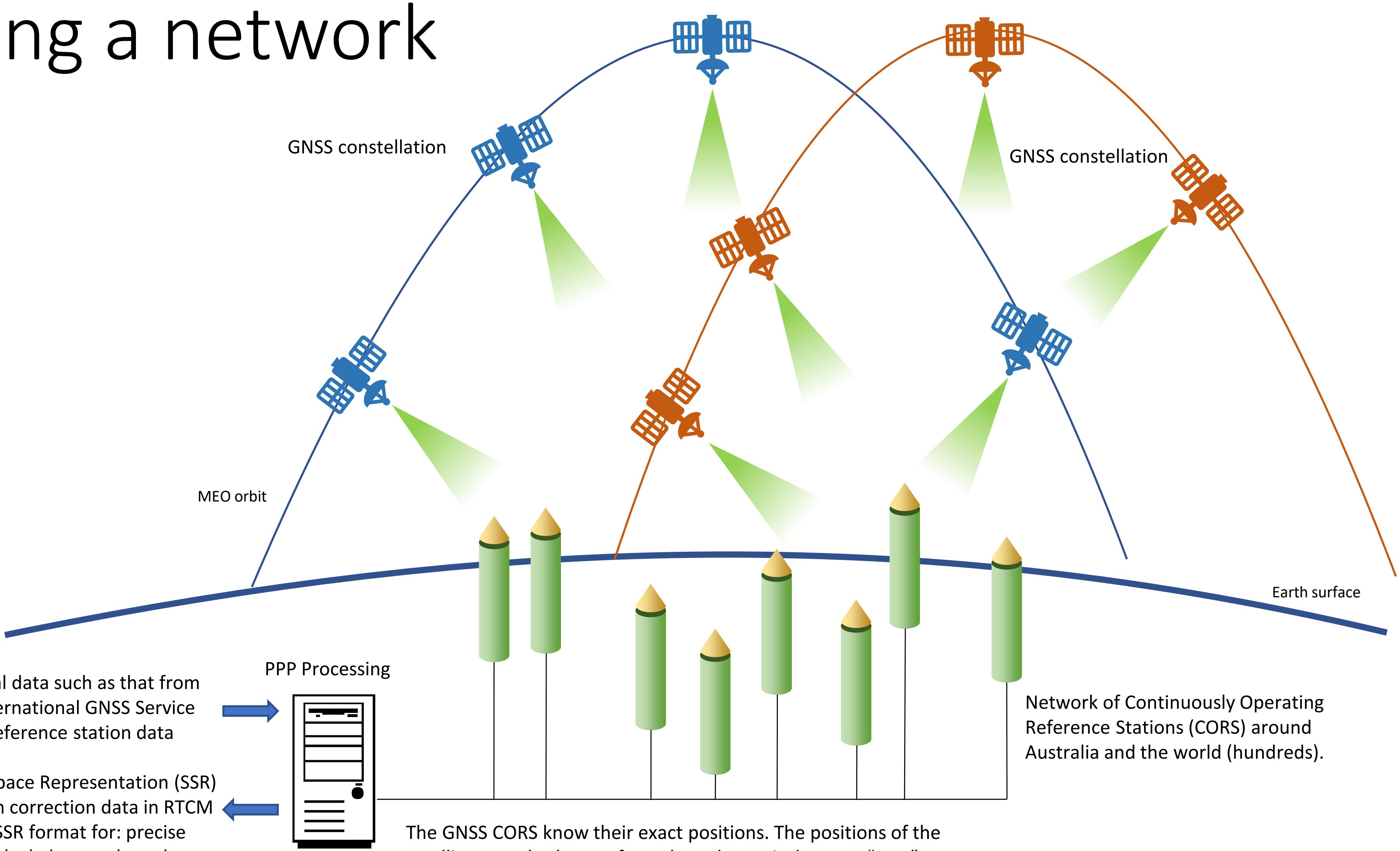
Creating PPP

The trick to being able to create high quality corrections is having access to reliable, sometimes independently sourced data that supports the use of algorithms which can deliver answers to our questions.

For example, we have a GNSS receiver fixed to a point on the Earth. We know very accurately the position of that receiver because we have verified its position using GNSS-independent means. We know the receiver's physical dimensions, we have good data on its biases (electronics). Co-located with the receiver is a barometer that gives us an indication of the air pressure at the site. The site is free from obstructions that could cause multi-path interference. When that receiver records signals from a GNSS satellite we can look up a lot of data on that satellite. Also we are not constrained to the C/A code signals. Our receiver lets us observe the actual carrier wave signal. Suddenly we have a lot of data to answer questions like:

- Is the satellite where it says it is?
- Does it look like its clock is drifting?
- What effect does the Troposphere seem to be having?

Using a network



External data such as that from the International GNSS Service (IGS) Reference station data

State Space Representation (SSR) position correction data in RTCM or IGS-SSR format for: precise orbits, clock data, code and phase biases.

File based products including:
Precise orbit and clocks (SP3),
Station coordinates (SINEX),
Ionosphere models,
Zenith Troposphere Delay (COST format).

Network of Continuously Operating Reference Stations (CORS) around Australia and the world (hundreds).

The GNSS CORS know their exact positions. The positions of the satellites are also known from the ephemeris, hence a “true” range to the satellites can be calculated. By comparing the “true” to the measured range, various biases affecting GNSS signals are computed and serve as the basis of corrections.

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A network of data

One reference station can only tell us so much. A whole network of reference stations providing many observations from many satellites gives us a rich source of data with which to work to produce correction messages. A complete PPP solution would use the results of the analysis of signal observations with other reference data to:

- Derive corrections for satellite orbital eccentricities and clock drifts,
- Remove the effects of ionospheric refraction,
- Remove signal delays caused by the troposphere,
- Use precise locations for satellite and receiver antenna phase centres,
- Allow for the satellite signal carrier phase wind up effect,
- Make corrections for satellite transmission power changes,
- Compensate for Earth solid tides,
- Use undifferenced and uncombined raw observations.

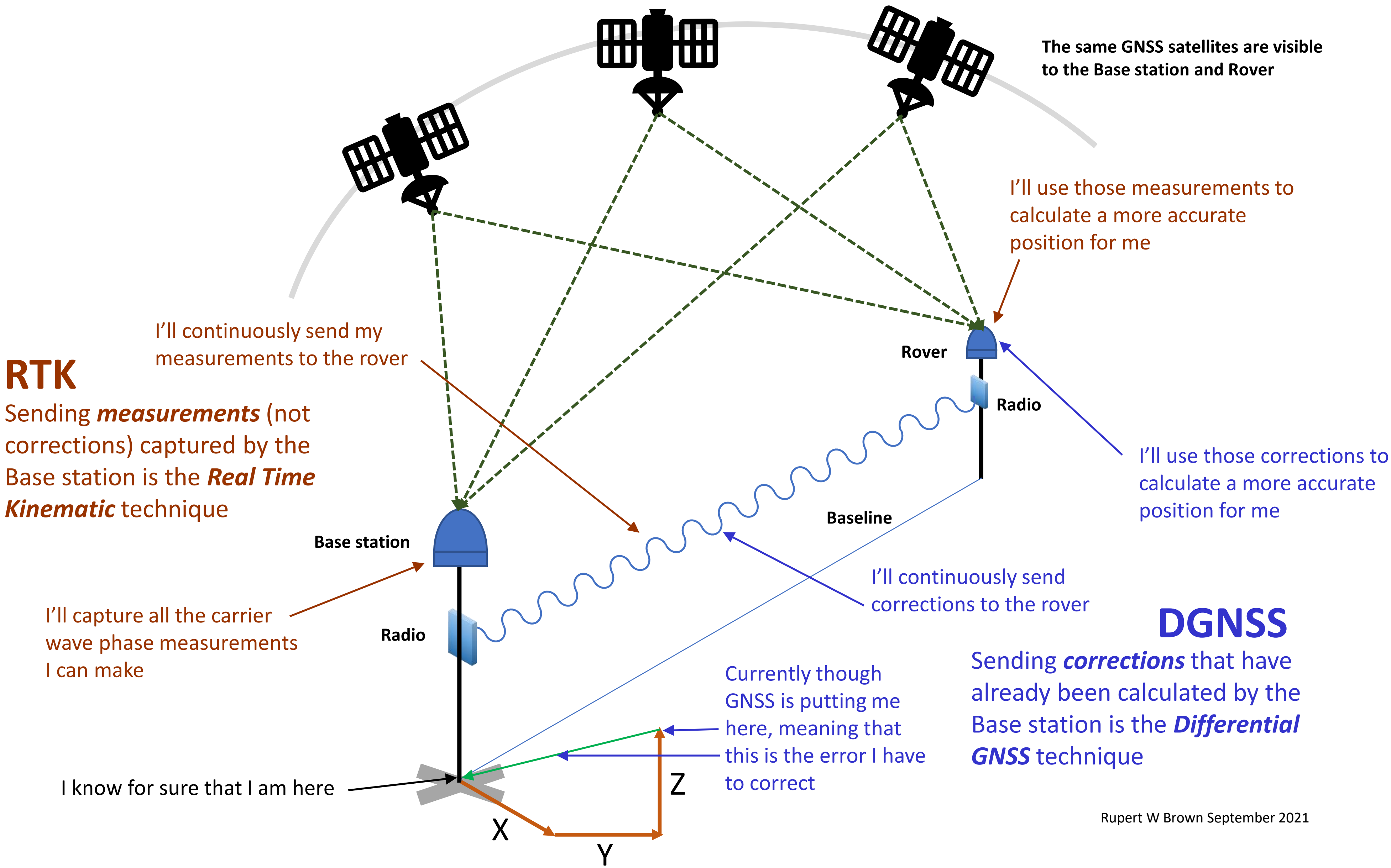
Benefits of PPP

PPP brings with it some valuable advantages compared to a technique like RTK:

- PPP doesn't require all of the corrections to improve accuracy. For example, just using precise satellite orbit and clock corrections will improve accuracy on their own.
- PPP can provide an absolute precise position with respect to a global reference frame using a single receiver i.e. it does not measure position relative to another point, which itself could be moving,
- The fact that PPP does not rely on another receiver (like RTK) potentially makes it easier and cheaper to use,
- Taking an undifferenced, uncombined approach reduces the amount of signal noise potentially improving accuracy,
- PPP using carrier wave ambiguity resolution is able to achieve position accuracy on the level of few centimetres,
- PPP produces other products of value such as Zenith Troposphere Delay (ZTD) data water vapour in the atmosphere.

One of the challenges and opportunities faced by PPP is to minimise the time taken to converge on a position, something that can be problematic with PPP given the complexity of the processing.

Real Time Kinematic (RTK) and Differential GNSS (DGNSS)



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RTK and DGNSS

RTK and DGNSS are similar in that both rely on a base station GNSS receiver that knows its exact position, usually verified using techniques in addition to GNSS. The base station receives GNSS signals and transmits data to another GNSS receiver, the rover, which also knows the position of the base station. The rover is able to use the data sent by the base station, and its own GNSS observations, to calculate its position very precisely.

The key difference is that with RTK, the base station is sending to the rover the GNSS carrier wave phase measurements it is observing – ***measurements***. With DGNSS, the base station is sending position correction date which it has calculated – ***corrections***, typically corrected pseudoranges.

The distance between the base station and the rover is called the baseline. RTK and DGNSS work on the basis that, so long as the baseline is not too great (i.e. hundreds of kilometres), the errors at the rover will be very similar to those at the base station and so can be accounted for.

RTK, and to an extent DGNSS, are very successful and widely used techniques. They have good accuracy and converge on a position quickly, but have some downsides:

- Both rely on having at least two GNSS receivers (base station and rover) which increases cost. You can buy what is in effect a "base station service" so you don't have to have the physical equipment, but that service still costs money.
- You need radio or some other form of communications to transmit the correction signal.
- If you lose the correction signal, you can lose accuracy.
- The rover has to stay within a few tens of kilometres of the base station. The further away, the less reliable the correction signal becomes.


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