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# Satellite Navigation

# Precise point positioning (PPP)

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Precise Point Positoning (PPP) allows a single GNSS receiver user to determine his position with dm/cm uncertainty in kinematic / static mode using precise satellite orbits and clocks.

In doing so PPP uses state space representation (SSR) correction products such as precise satellite orbits, clocks and signal biases from either commercial or/and public (e.g., IGS) that are delivered to the user via satellite and/or internet.

**SPP**

Broadcast orbit and clock information

+

User satellite tracking information (code phase)

=

m-level user position accuracy

**PPP**

Precise orbit and clock information

+

User satellite tracking information (code & carrier phase)

+

Precise error modelling

=

cm to dm-level user position accuracy

# Precise point positioning (PPP)

**The mathematical Model for PPP** (compare to module 10!)

$$\begin{aligned} L_k^p &= \rho_k^p + c(dt_k - dT^p) - I_k^p + T_k^p + \lambda B_k^p + d_k^p + \varepsilon_L \\ P_k^p &= \rho_k^p + c(dt_k - dT^p) + I_k^p + T_k^p + \varepsilon_P \end{aligned} \tag{11.1}$$

where

$L_k^p, P_k^p$ : undifferenced carrier phase and code observations (meters)

$\rho_k^p$ : geometric distance (satellite-receiver)

$dt_k, dT^p$ : receiver and satellite clock offsets

$I_k^p$ : ionospheric delay

$T_k^p$ : tropospheric delay

$B_k^p$ : carrier phase bias (incl. ambiguities)

$d_k^p$ : model corrections

$\varepsilon$ : random error or residual

# Precise point positioning (PPP)

## PPP error budget

| Effect | magnitude | mitigation method | Residual error |
|---|---|---|---|
| Ionosphere | 10-100 m | dual-freq. lin. comb. | mm |
| Troposphere | 1-10 m | modelling; estimation | mm-cm |
| Relativity | 10 m | modelling. | mm |
| sat. phase center | 1 m | modelling; | mm-cm |
| code multipath | 1 m | filtering | mm-dm |
| Solid Earth tides | 20 cm | modelling | mm |
| phase windup | 10 cm | modelling | mm |
| Ocean loading | 5 cm | modelling | mm |
| sat. orb & clocks | a few cm | filtering | mm-cm |
| phase multipath | 1 cm | filtering | mm-cm |
| rcv. phase center | a few cm | modelling; | mm |

# Precise point positioning (PPP)

## IGS orbit and clock products

| Type | | Accuracy | Latency | Updates | Sample Interval |
|---|---|---|---|---|---|
| Broadcast | orbits | ~100 cm | real time | -- | daily |
| | Sat. clocks | ~5 ns RMS<br>~2.5 ns SDev | | | |
| Ultra-Rapid (predicted half) | orbits | ~5 cm | real time | at 03, 09, 15, 21 UTC | 15 min |
| | Sat. clocks | ~3 ns RMS<br>~1.5 ns SDev | | | |
| Ultra-Rapid (observed half) | orbits | ~3 cm | 3 – 9 hours | at 03, 09, 15, 21 UTC | 15 min |
| | Sat. clocks | ~150 ps RMS<br>~50 ps SDev | | | |
| Rapid | orbits | ~2.5 cm | 17 – 41 hours | at 17 UTC daily | 15 min |
| | Sat. & Stn. clocks | ~75 ps RMS<br>~25 ps SDev | | | 5 min |
| Final | orbits | ~2.5 cm | 12 – 18 days | every Thursday | 15 min |
| | Sat. & Stn. clocks | ~75 ps RMS<br>~20 ps SDev | | | Sat.: 30s<br>Stn.: 5 min |

(source: `http://www.igs.org/products`)

# Precise point positioning (PPP)

## PPP accuracy

| Processing Mode | RMS (cm) | | |
|---|---|---|---|
| | East | North | Up |
| Daily static | <0.5 | <0.5 | <1 |
| Hourly static | ~4 | ~2 | ~3 |
| Post-processed kinematic | ~5 | ~4 | ~10 |
| Real-time kinematic | <10 | <10 | <20 |

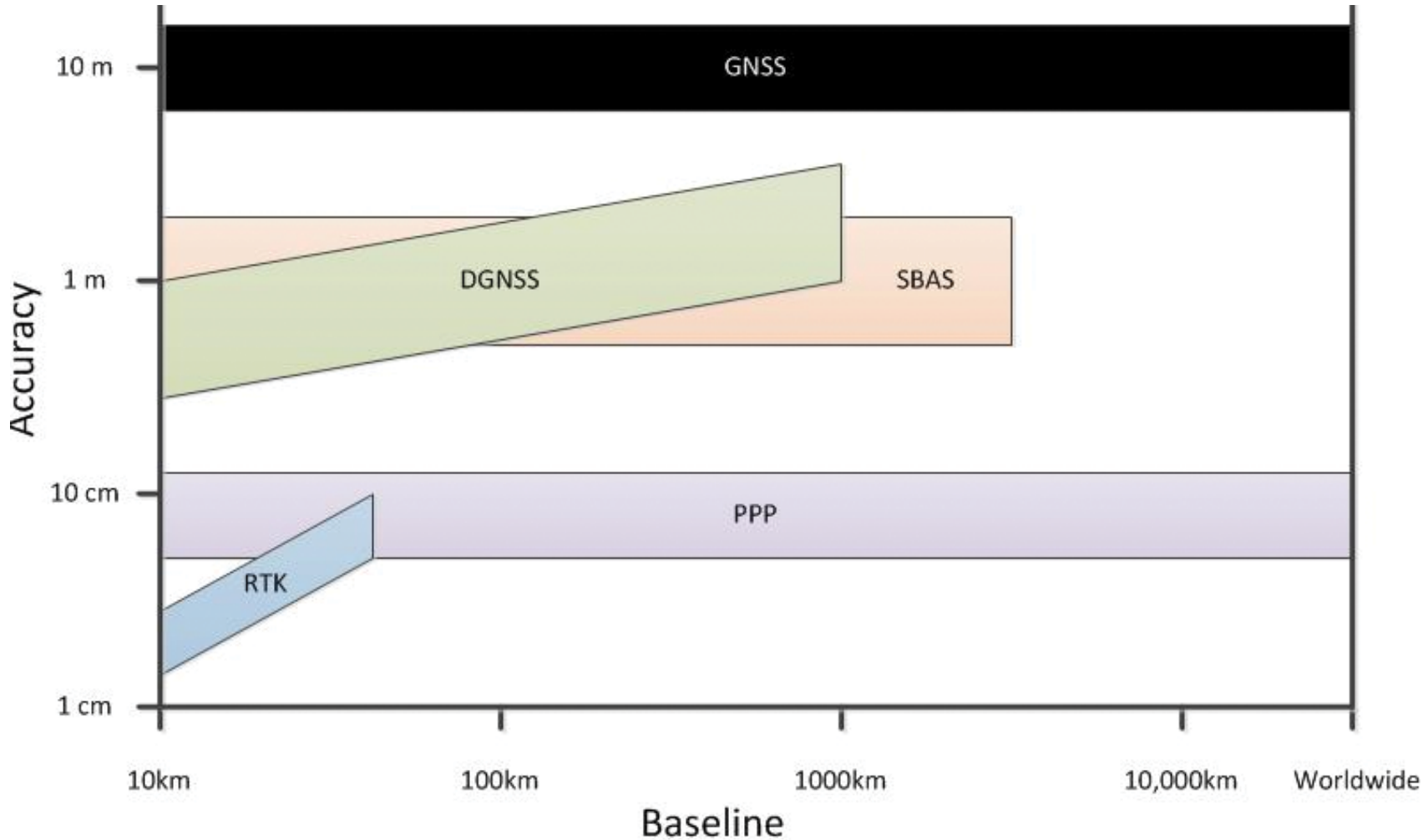
Note: Based on dual-frequency measurements

Work in progress:

- PPP ambiguity resolution (PPP-AR), requires additional (external) information, e.g. satellite phase biases
- reduction of filter convergence; currently between 30 min and 1 h;
- PPP-RTK; obtain ionosphere and troposphere correction from RTK-like service

# Precise point positioning (PPP)

## Overview of GNSS positioning modes




(source: https://www.novatel.com/)