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Volunteering for the future – Geospatial excellence for a better living

LEO aiding GNSS positioning in challenging environments

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Outline

- Why LEO? Opportunities and Challenges
- Positioning Using LEO SOP
- Precise orbit determination (POD) of LEO satellites
- LEO satellite clocks
- Concluding remarks

LEO VS. GNSS

- 20 times closer to Earth compared to the GNSS
- 90-120 minutes orbital periods
- 300-1500km altitudes
- Thousands of LEO satellites

Two types:

1- Carry navigation payloads,

2- Communications/internet satellites, e.g. Starlink (Space X), OneWeb, Iridium etc.,

GPS

A mix of LEO mega-constellations

Why LEO? Opportunities and Challenges

- Much stronger signal power
  - more resilient to interference and available in limited GNSS visibility, e.g. urban canyons
- Faster satellite geometry change
  - shortens the convergence time for precise point positioning (PPP)
- Can be developed and operated by the private sector.

Challenges

- Smaller footprint and satellites do not have significant overlap
- Low quality clocks onboard
- Shorter tracking period (6- 20 min)
- Different frequency bands (Ka, Ku)
- Needs modified antenna/receivers
- SOP requires a modified positioning algorithm

Positioning Using LEO SOP

- LEO have higher orbital speed resulting in a greater Doppler effect

Observables	The *pseudorange rate* formed from *carrier-Doppler shifts* estimated as the negative of the time derivative of the accumulated delta range divided by the carrier wavelength
State model (unknowns)	- the user position and velocity, - satellite clock offset and drift, - receiver clock offset (per constellations), and their rates, - Combined system biases
Method	Extended Kalman filter

Measurements

Carrier Doppler shift

$$D^j = -\frac{1}{\lambda}\frac{d\Delta\rho^j_{ADR}}{dt_R}$$

Accumulated delta range

$$\Delta\rho^j_{ADR}(\vec{r},\delta_R;t_R) = \sqrt{\begin{array}{c}\left[\vec{r} - A\left(\omega_E\delta t^j_p\right)\vec{r}^j\left(t_R-\delta_R-\delta t^j_p\right)\right]^{\mathrm{T}} \\ \times\left[\vec{r} - A\left(\omega_E\delta t^j_p\right)\vec{r}^j\left(t_R-\delta_R-\delta t^j_p\right)\right]\end{array}}$$

$$+ c(\delta_R - \delta^j) + c\left[\delta t^j_{trop} - \delta t^j_{ion}\right] + \lambda\beta$$

Precise Orbit Determination (POD) of LEO Satellites

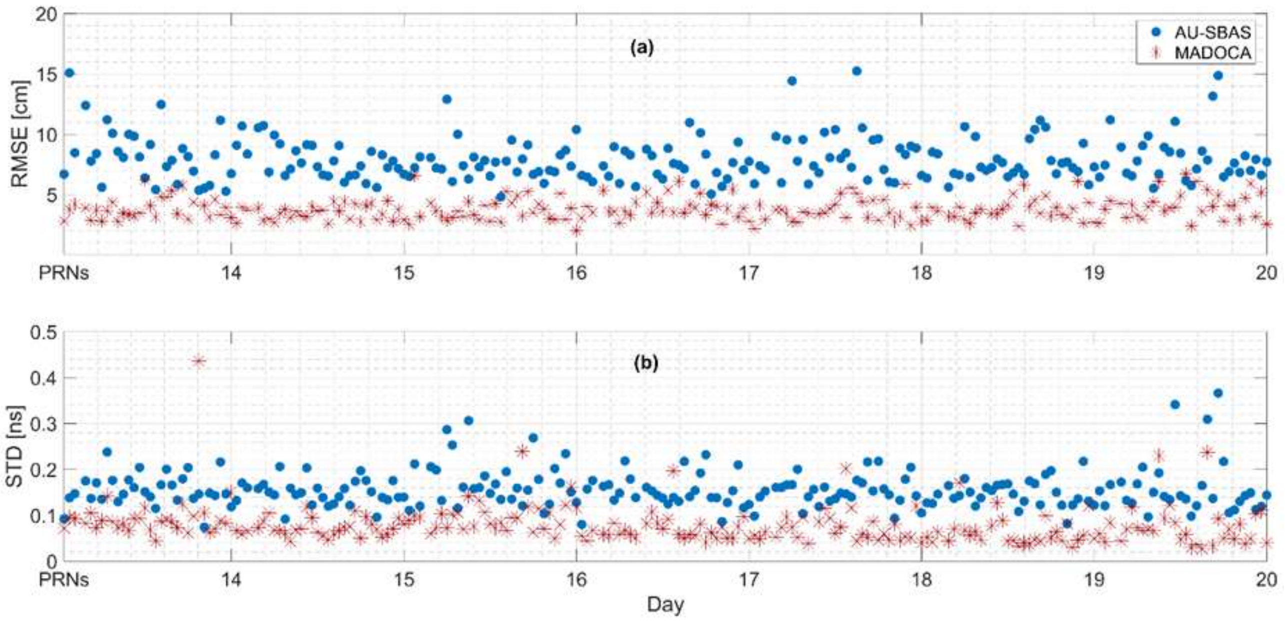
- Kinematic POD (GNSS observations)
- Reduced Dynamic (GNSS obs + dynamic models)

  - ❑ Post-mission (classical)
  - ❑ Real-time (New)

POD in Real-time in Space

- Real-time POD in Space using GNSS orbit + clock corrections from
  - MADOCA
  - Testbed of Australia/NZ SBAS (SouthPAN)

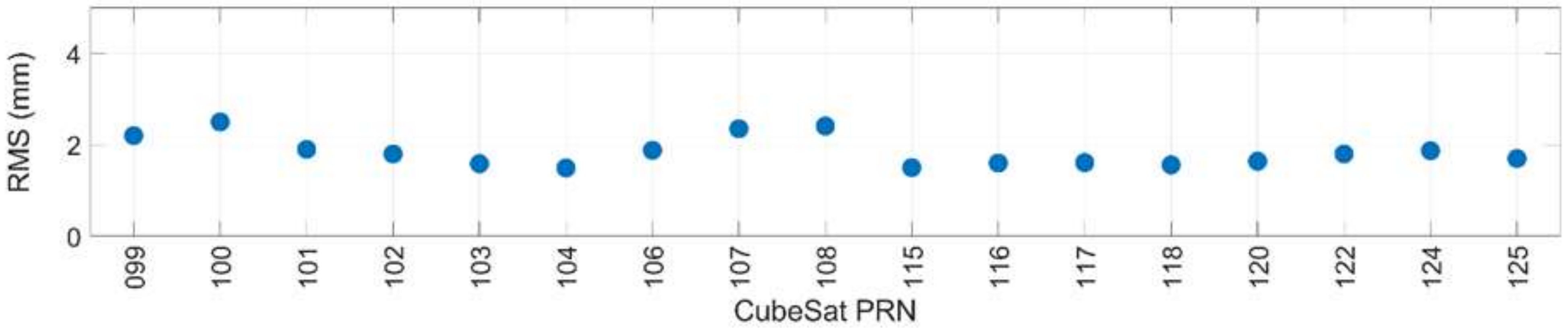
They provide GPS orbits better than 15 cm and clocks < 0.2ns



Results of POD in Real-time in Space

- RMS of POD 0f 17 CubeSats in Space using real-time orbit + clock corrections

  Test period (16 Dec 2020 – 15 Jan 2021)

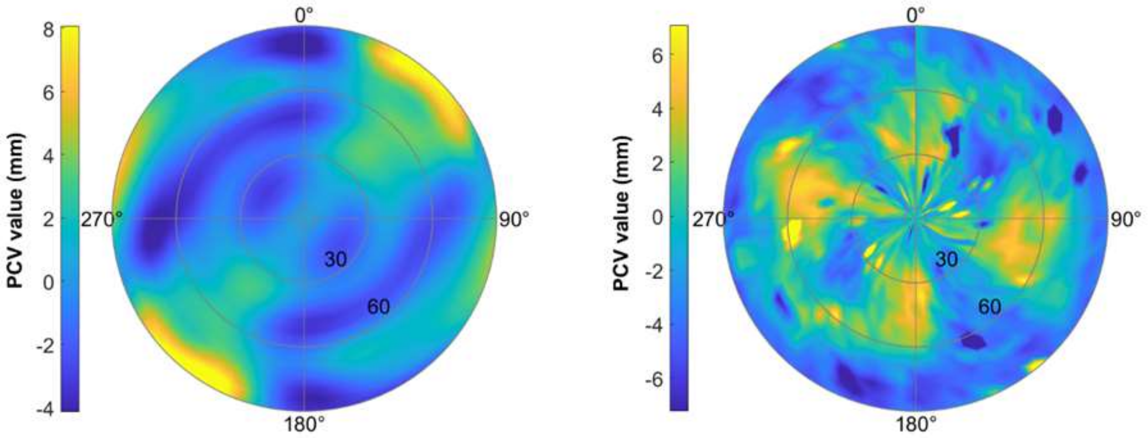


The overlapping differences < 5 cm and RMS < 4 mm.

Phase Centre Offsets and Variations (PCO and PCV)

An empirical PCV pattern is developed based on the actual observations using the iterative residual method.

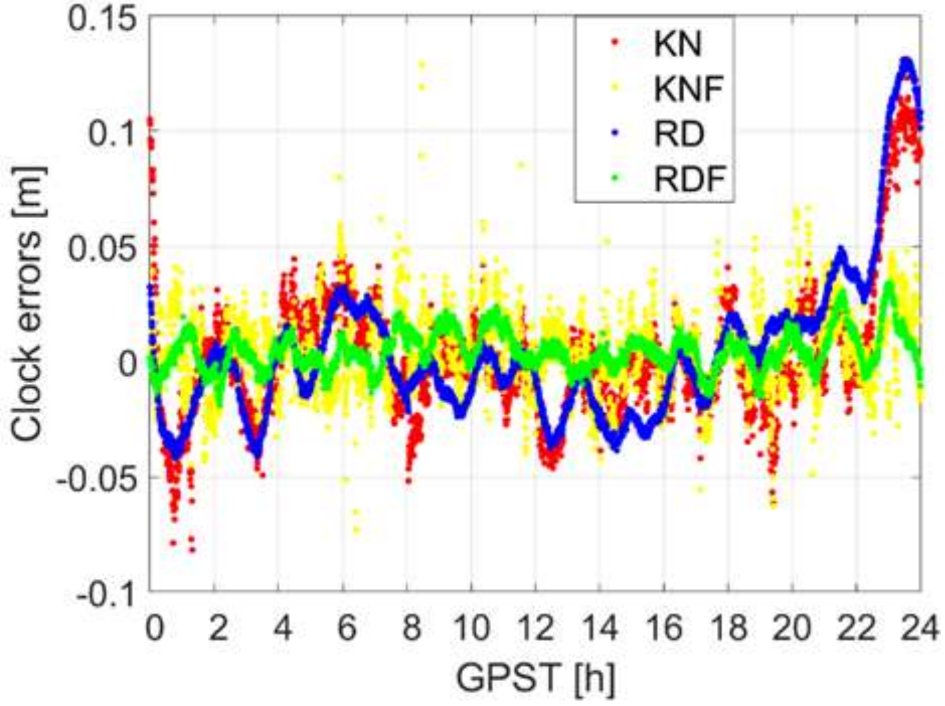
Applying this pattern in kinematic POD can reduce the observation residuals to 6-7 mm



Initial PCV pattern provided by the manufacturer (left), the empirical PCV pattern from real observations (right)

LEO Satellite Clocks

- Similar to the LEO satellite orbits, precise LEO satellite clocks are essential
- The main weakness of the LEO system is its timing accuracy.
- Most LEO satellites do not have atomic clocks, but use OCXO or USO that have poorer stability
- The accuracy of the LEO clock estimates is related to the accuracy of the used GNSS measurements and satellite orbits and clocks

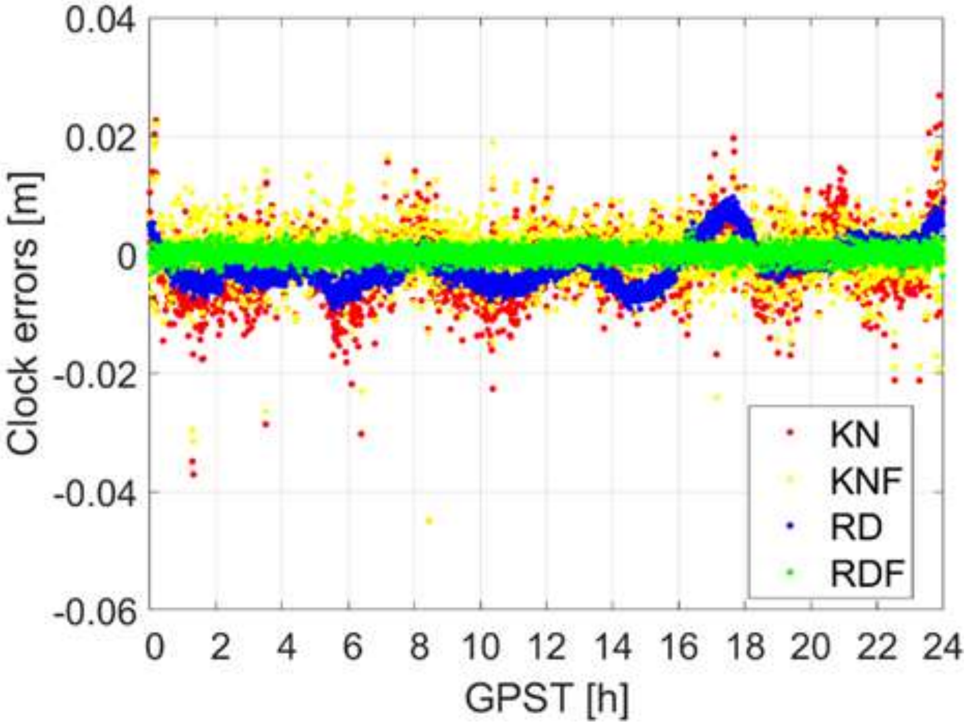


“KN” and “KNF” kinematic without and with integer ambiguities fixed.

“RD” and “RDF” without and with the integer ambiguities fixed.

- Considering only the noise, the ambiguity-fixed clocks (green and yellow dots) become white noise.

- However, without fixing the ambiguities (blue and red dots), long-term systematic effects over hours can be observed.



LEO satellite clock errors

considering only the equal-weighted noise.

Possible remedies

- Equipping the LEO satellites with small chip-scale atomic clocks.
- Increasing the strength of dynamic models in POD,
- Applying a better thermal control model to decrease the hardware biases;
- Applying empirical PCV patterns based on actual space situations
- Considering a higher order of gravity in the relativity model

Several microseconds improvements in the estimated CubeSat clocks are observed

CONCLUDING REMARKS

- LEO-based positioning is a promising technique that can cover a known gap in GNSS
- It is, however, is in its early phases and has many challenges that need to be tackled before being commercially available.
- More research is needed in many areas. Among these are,
  - ❖ studying signal acquisition and tracking, direction, angle of arrival, and strength
  - ❖ type of receivers and antenna that can be used for positioning,
  - ❖ satellite number, geometry and footprint and their impact on positioning,