



1-5
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One-Hz real-time multi-GNSS satellite phase clocks for global rapid geohazard response

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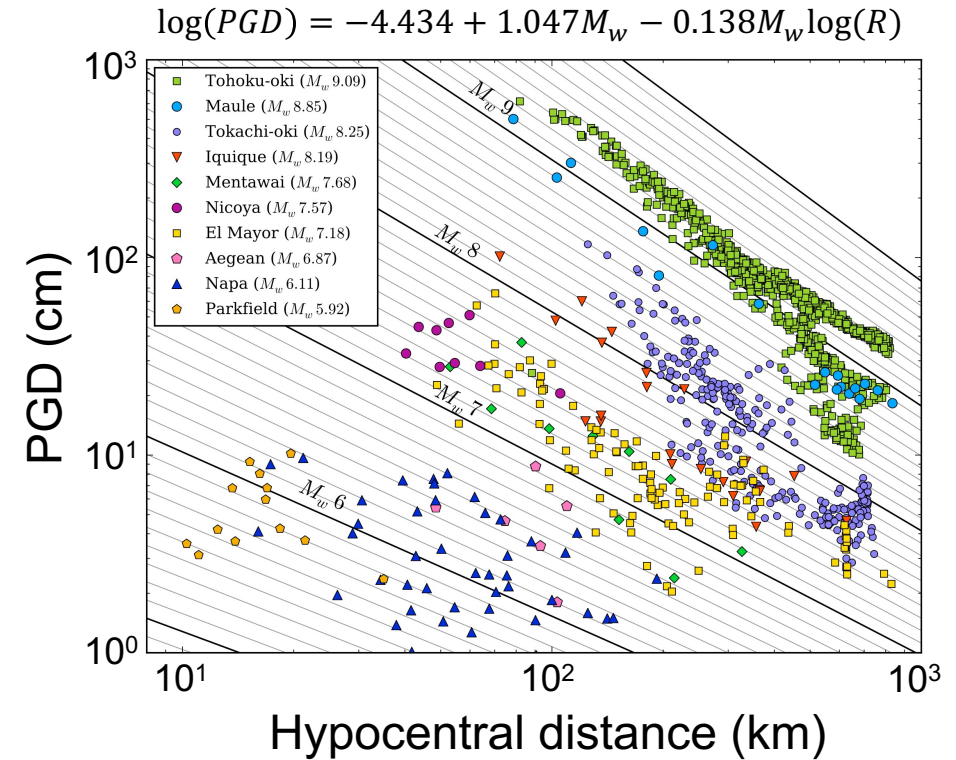
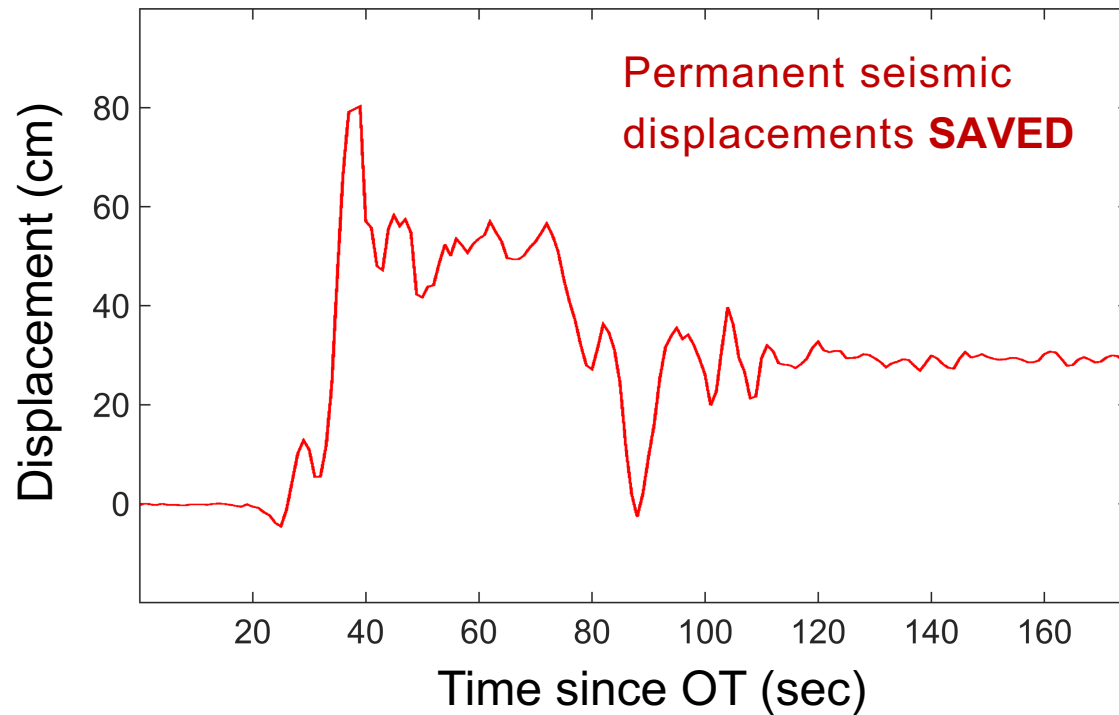


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Real-time GNSS plays important roles in seismic monitoring

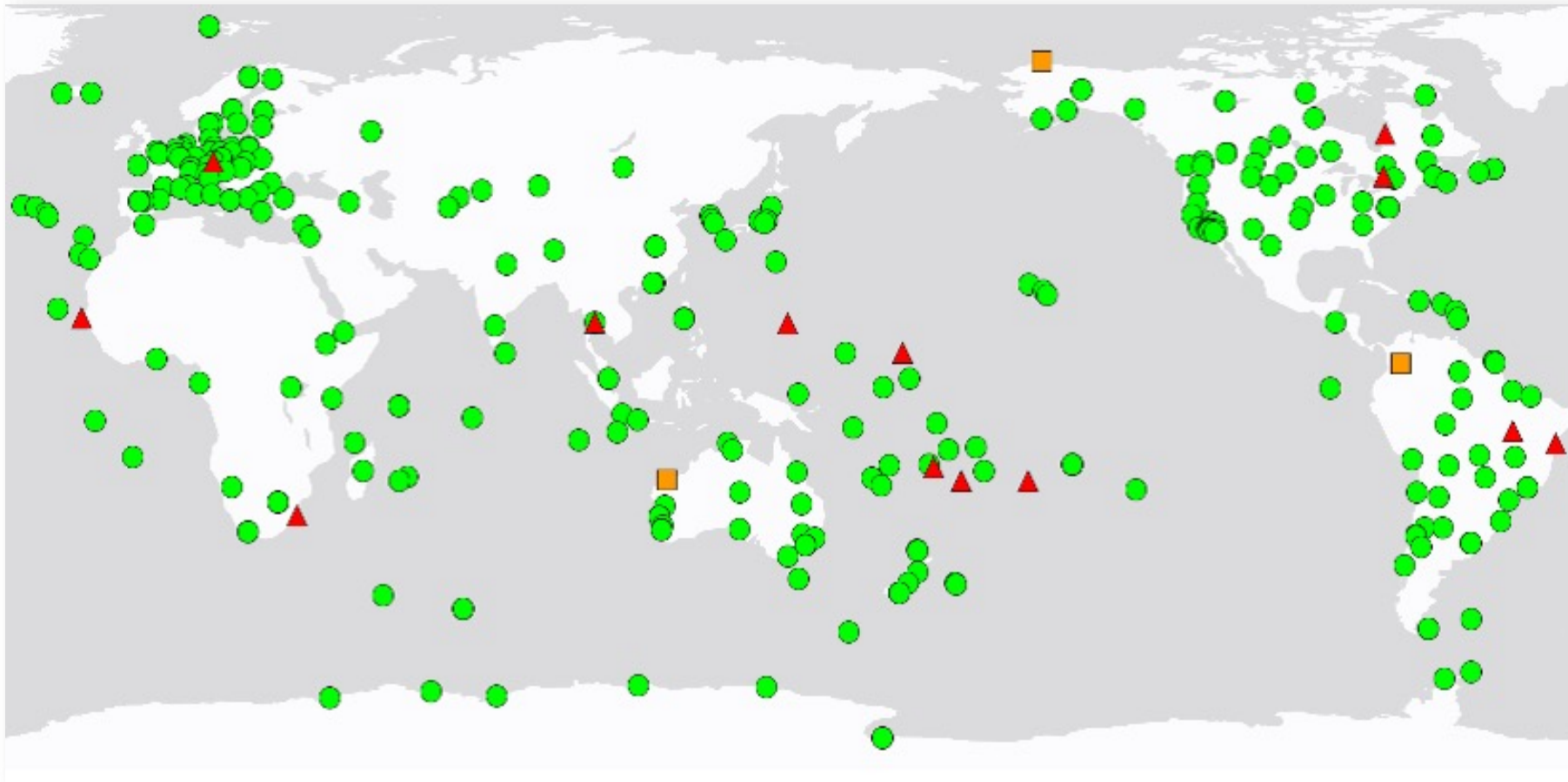
- GNSS to obtain peak ground displacements (PGD) for earthquake magnitude scaling



Melgar et al. 2015

Real-time GNSS network processing in the IGS

- **Hundreds of stations** for real-time satellite orbit/clock determination

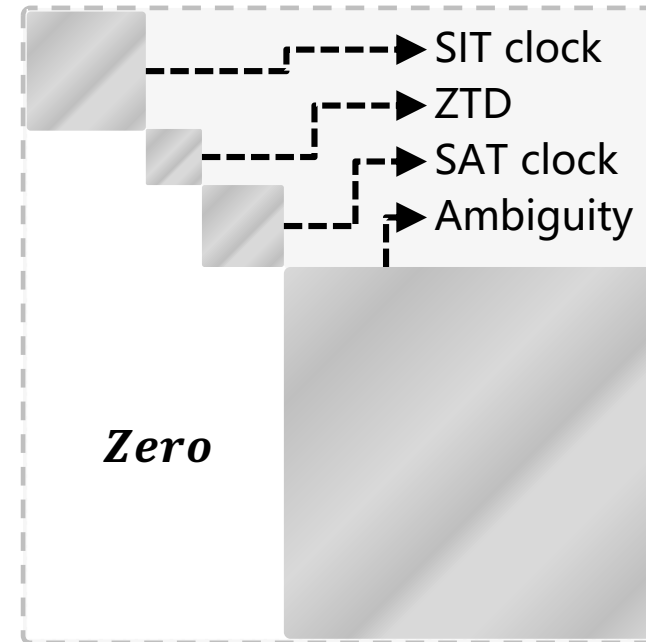


Challenge I: Real-time high-rate satellite clock estimation

- A massive number of high-rate (e.g., 1-Hz) clocks to be estimated at each epoch



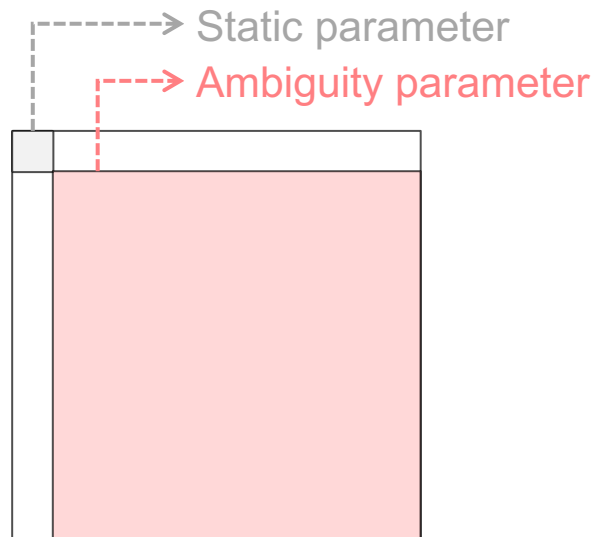
 Satellites 120+
 frequencies 10+



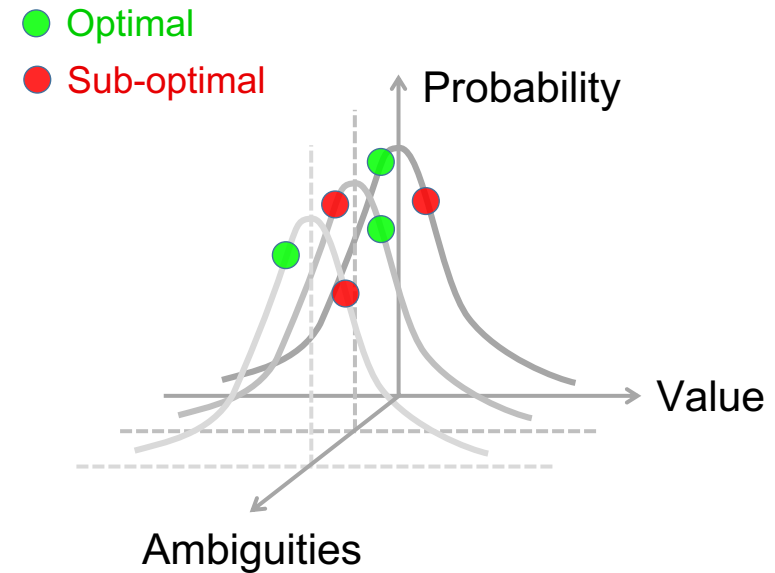
Epoch-wise clocks

Challenge 2: Real-time ambiguity resolution

- A large number of ambiguities risk being incorrectly resolved in real time



Server end has considerable ambiguity parameters



High-dimensional ambiguity vector is hard to resolve in real time

Iterative QR decomposition using single-precision parameters

- Truncate the original observation equations to single precision for **rapid processing**

$$B_{single} \cdot x_0 = l_{single}$$

The single-precision domain enables higher-throughput rapid numerical computations

- Compute the residuals of the original observations and then updated to the equation above

$$r_0 = l - B \cdot x_0$$

r_0 will be used to update l to iteratively improve numerical precision

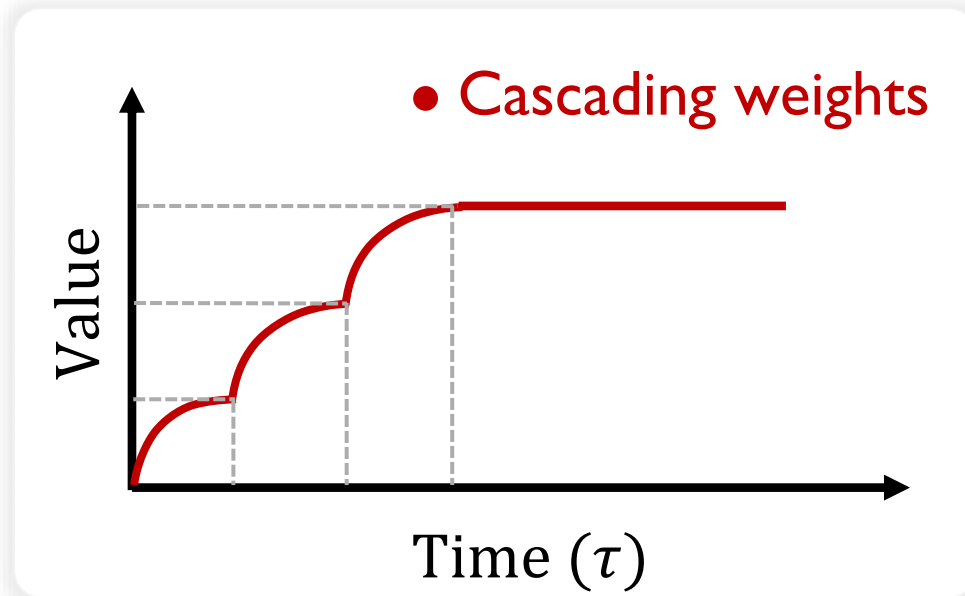
Processing speed could be accelerated by 30-40%

Loose constraints on ambiguities

- Constrain sufficiently converged single-difference ambiguities in a loose manner

$$N_{i,IF}^{js} = I_{amb} \cdot \tilde{N}_{i,IF}^{js} + v_{amb}, \quad P_{amb} = w(\tau)$$

Single-difference
ambiguity



Constraint weights are determined empirically by **continuous fixing duration** of ambiguities

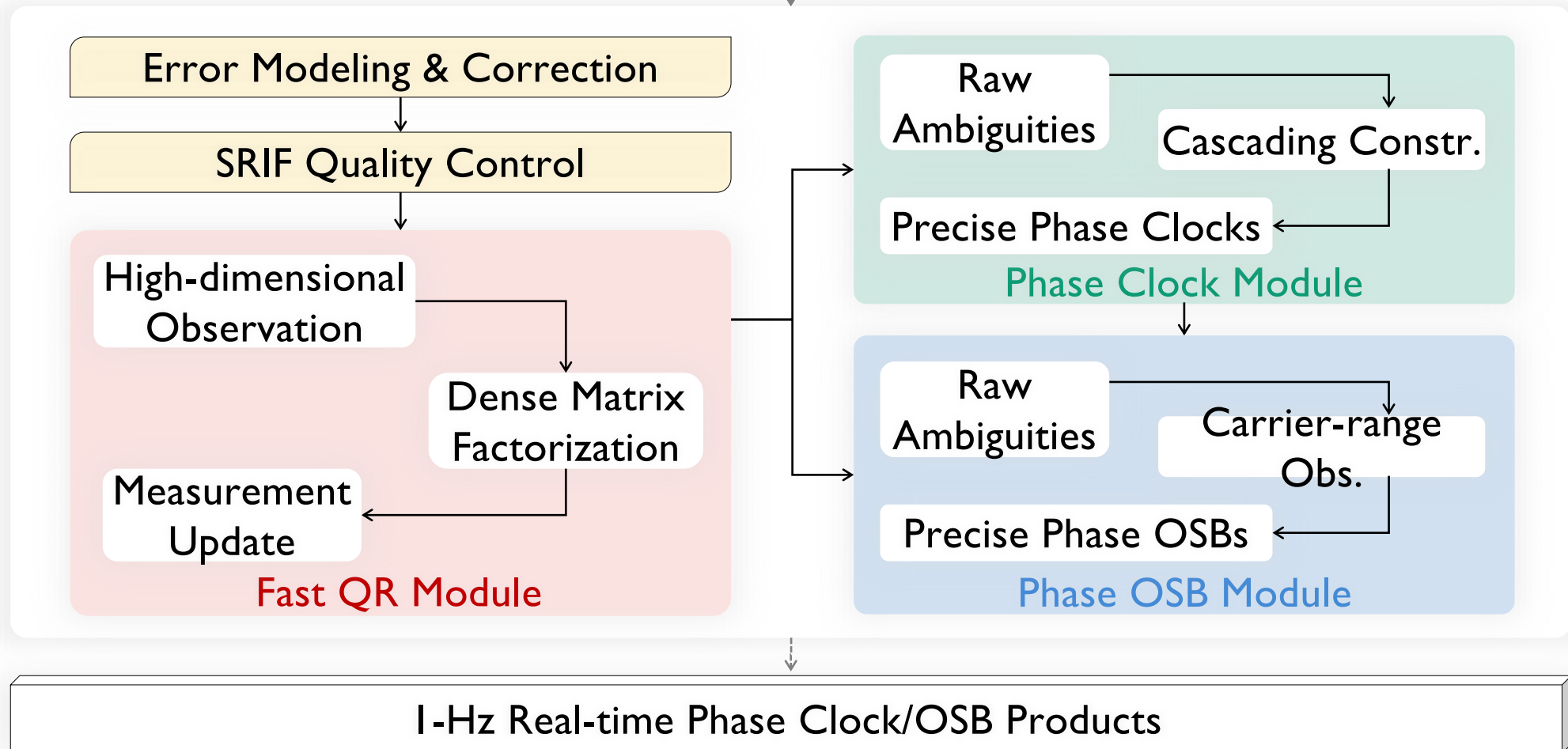
Ambiguities are not fixed integers, but constrained to real-valued quantities

Software: **GSeisRT**

Global Data Streams

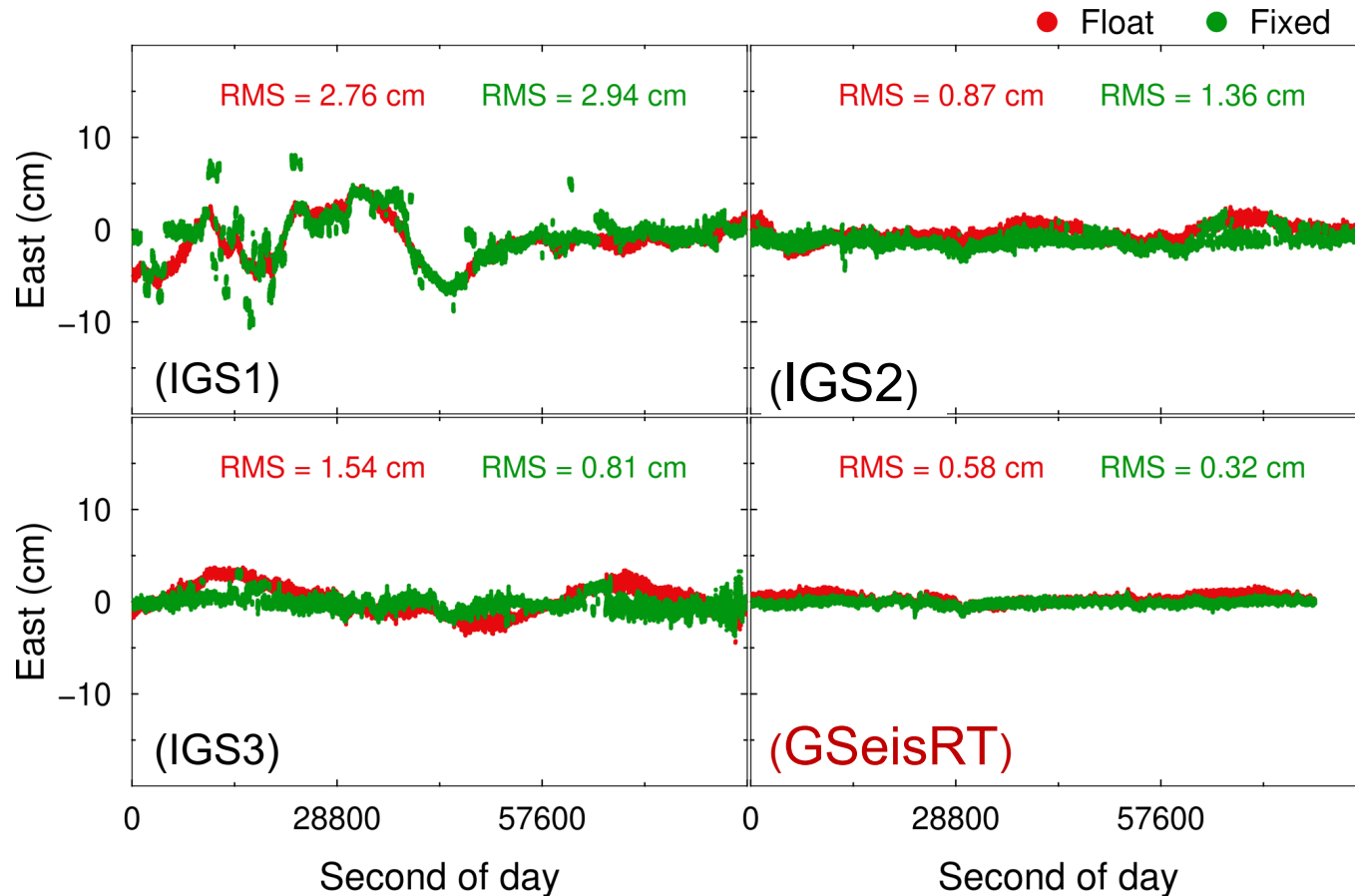
IGS Ultra-rapid Orbits

Broadcast Ephemeris



I-Hz real-time satellite phase clock

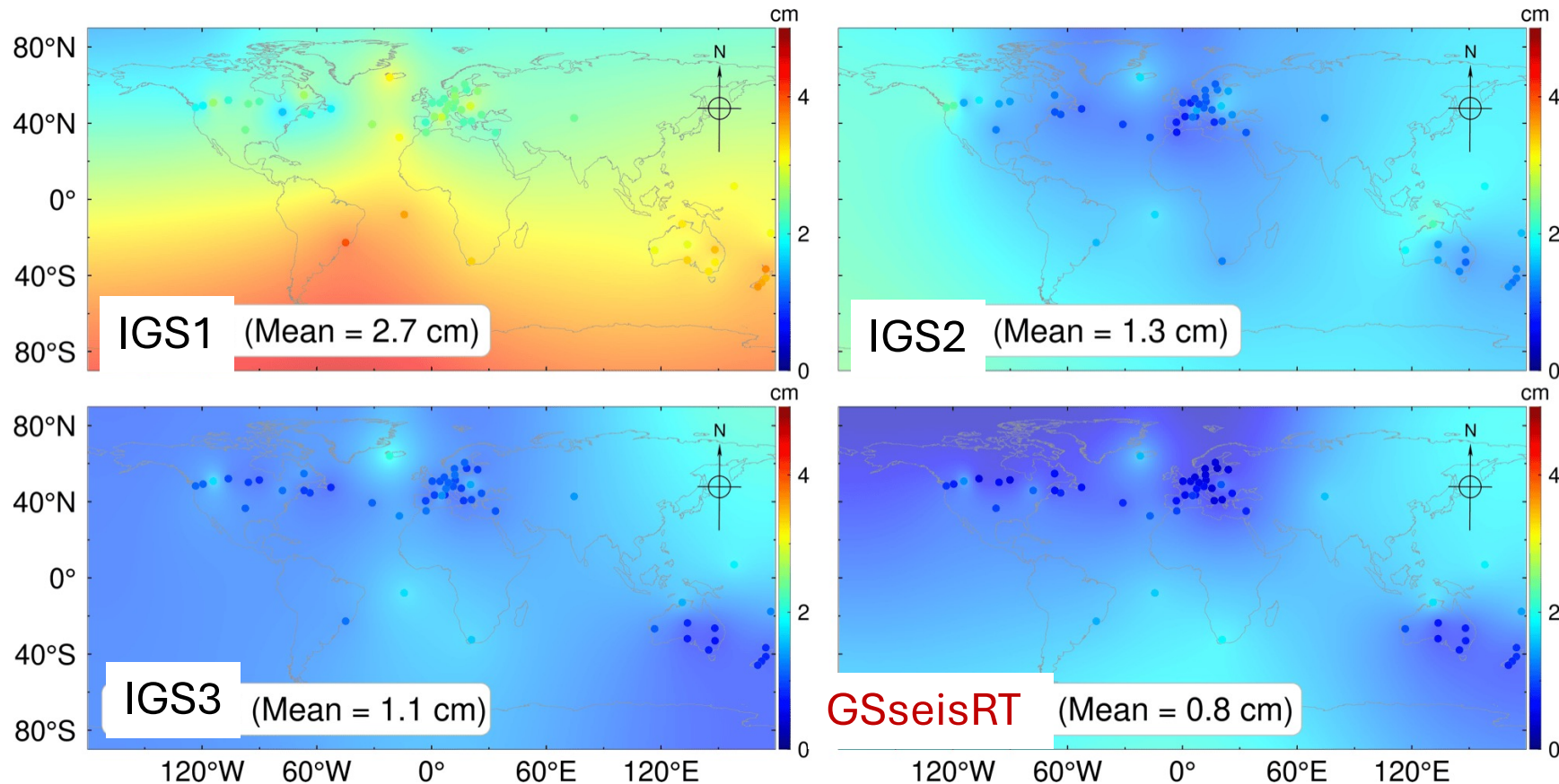
- Real-time PPP-AR validation (24-h positioning error in East)



I-Hz phase clock enables
smoother and lower-noise positioning

I-Hz real-time satellite phase clock

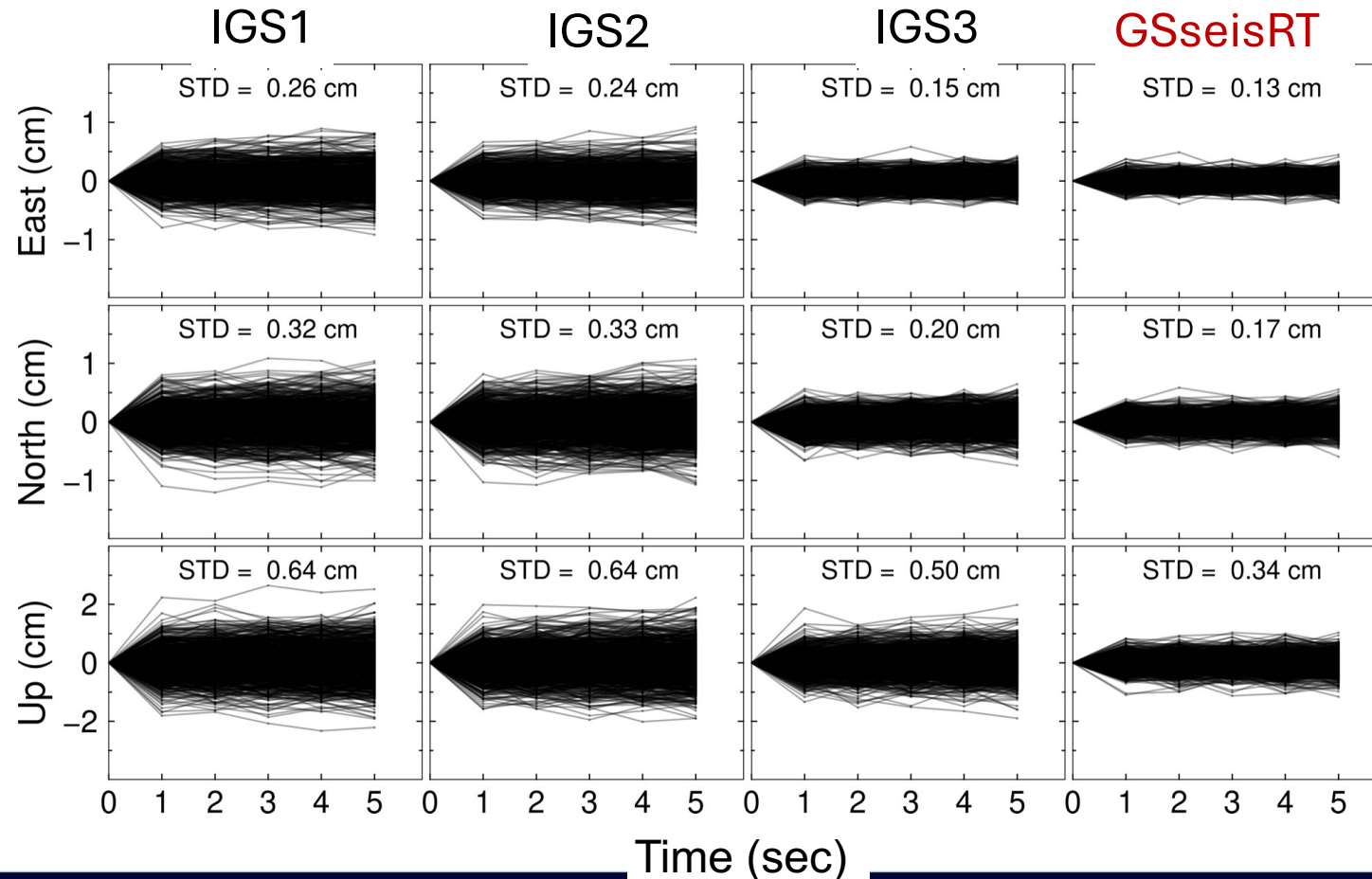
- Real-time PPP-AR validation (East RMS error distribution)



**High positioning
precision globally**

I-Hz real-time satellite phase clock

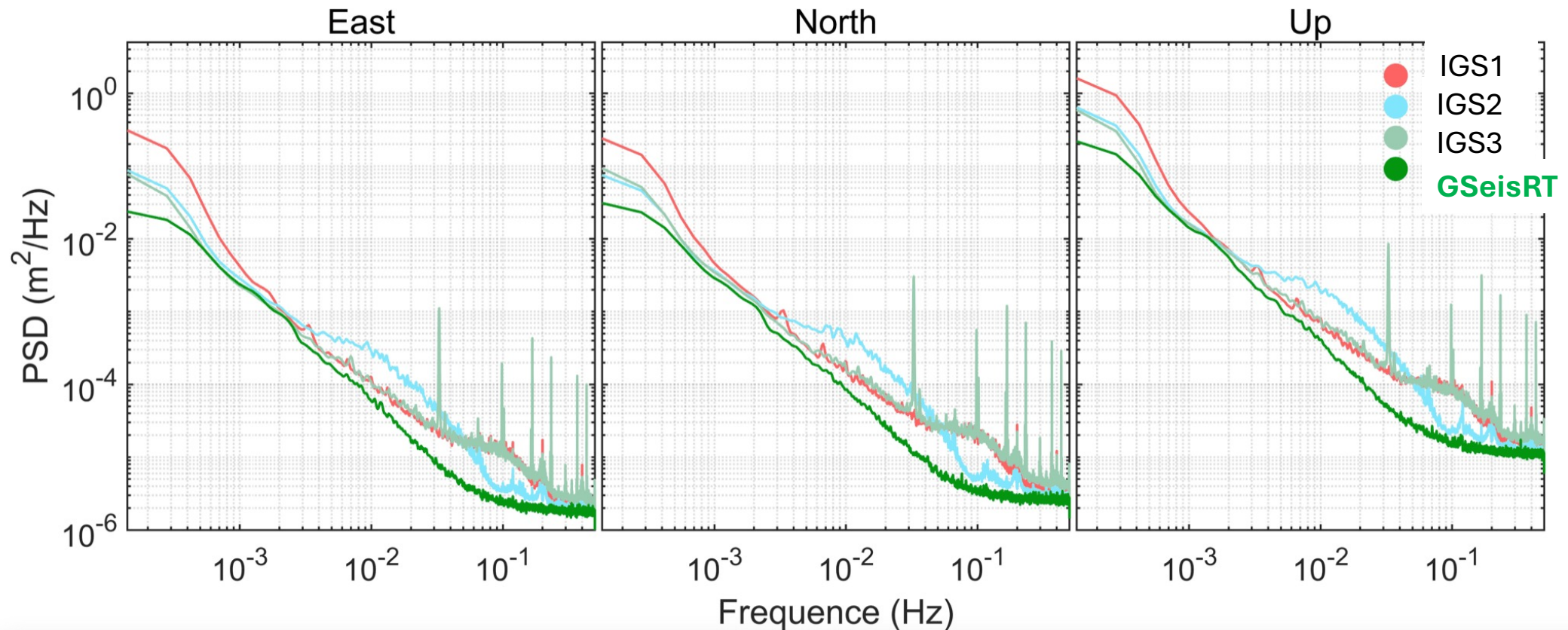
- Real-time PPP-AR validation (Positioning error within each 5-s bin)



High positioning precisions
without extrapolation

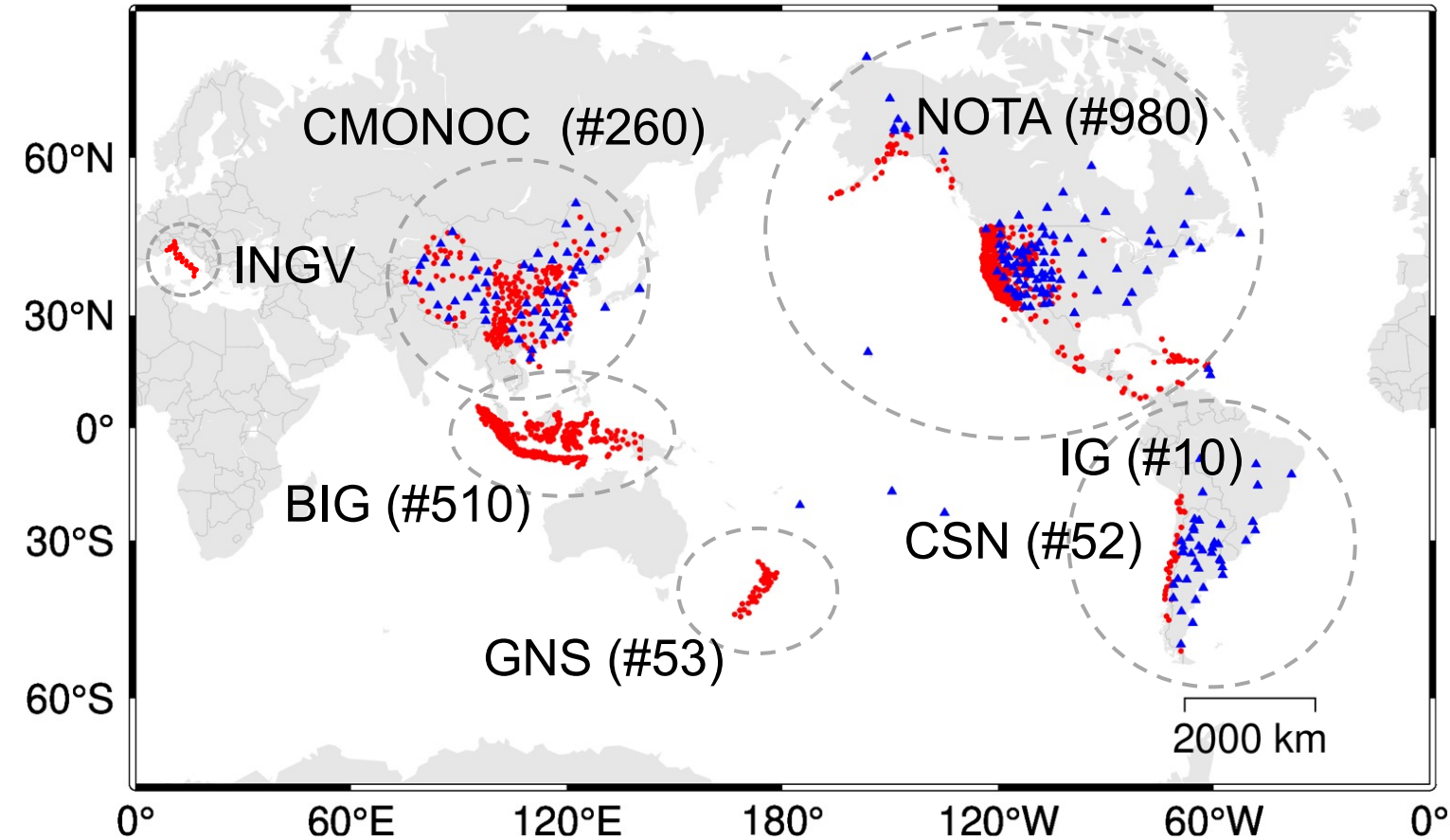
I-Hz real-time satellite phase clock

- Real-time PPP-AR validation (PSD of I-Hz positioning errors)



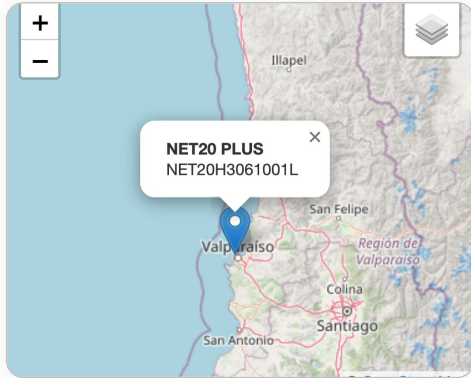
I-Hz clocks improve positioning precision over high-frequency bands

GSeisRT for the pacific rim

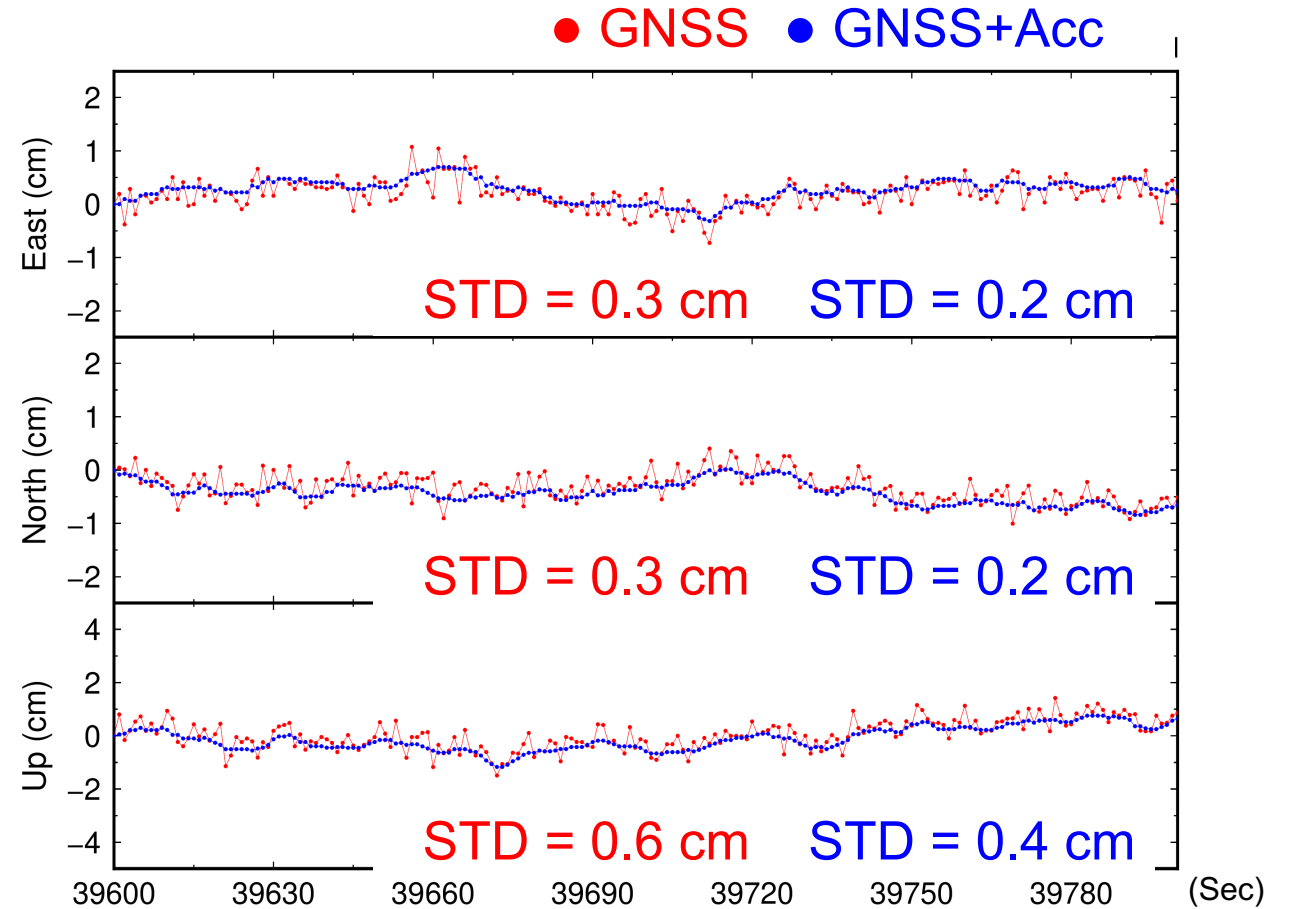


CMONOC	 (China)
NOTA	 (USA)
BIG	 (Indonesia)
GNS	 (New Zealand)
CSN	 (Chile)
INGV	 (Italy)
IG-EPN	 (Ecuador)

Deployment of GSeisRT **seismometers** in Chile with CSN



Current status of GSeisRT
seismometers



Real-time positioning series

Time: 2025-8-23

Summary

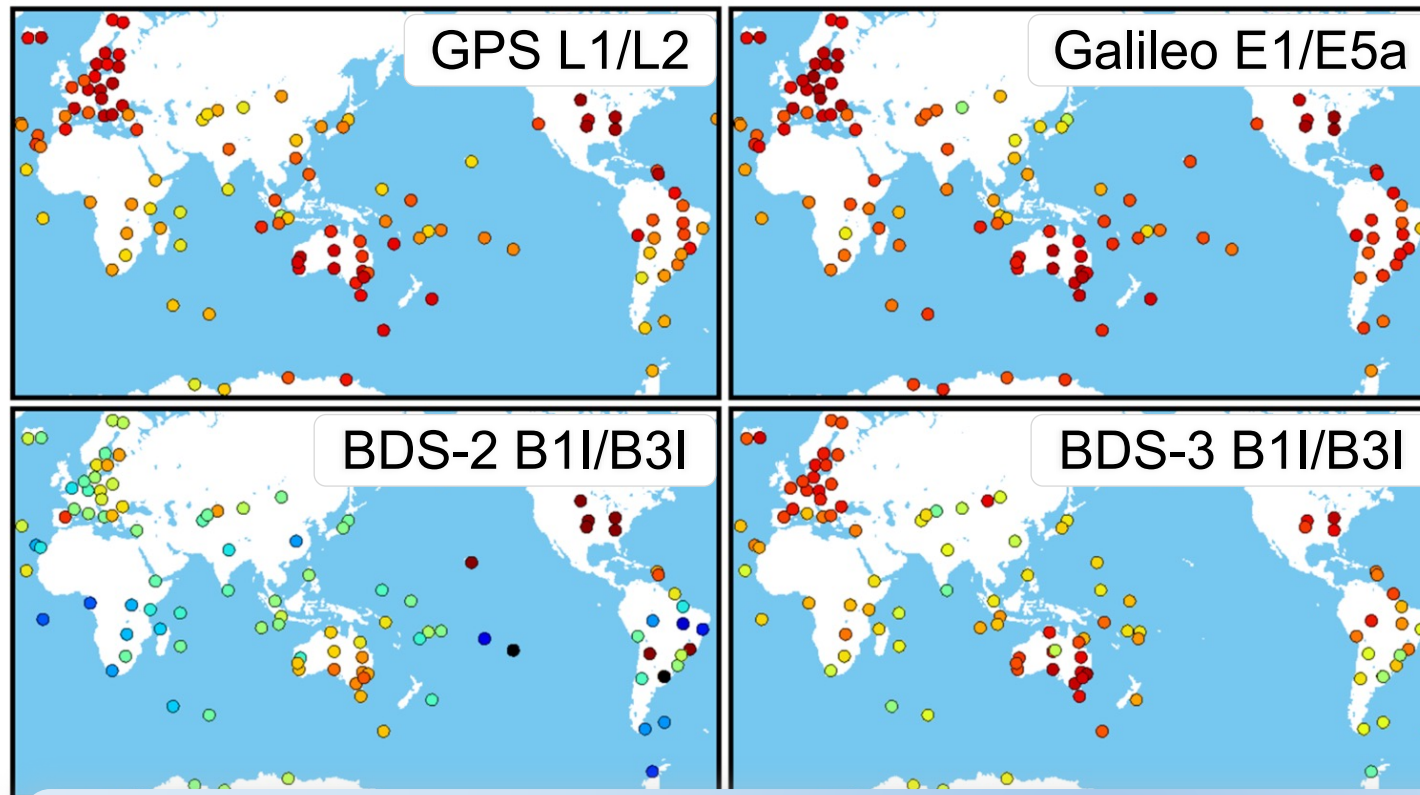
- 1-Hz real-time phase clocks improve the timeliness of real-time services and enhance the client positioning precisions.
- GSeisRT estimates phase OSB products, facilitating all-frequency PPP-AR applications.
- Real-time GNSS is integrated with accelerometers in an independent instrument, achieving better seismic monitoring capability.



Thanks for your attention!

All-frequency satellite phase OSB

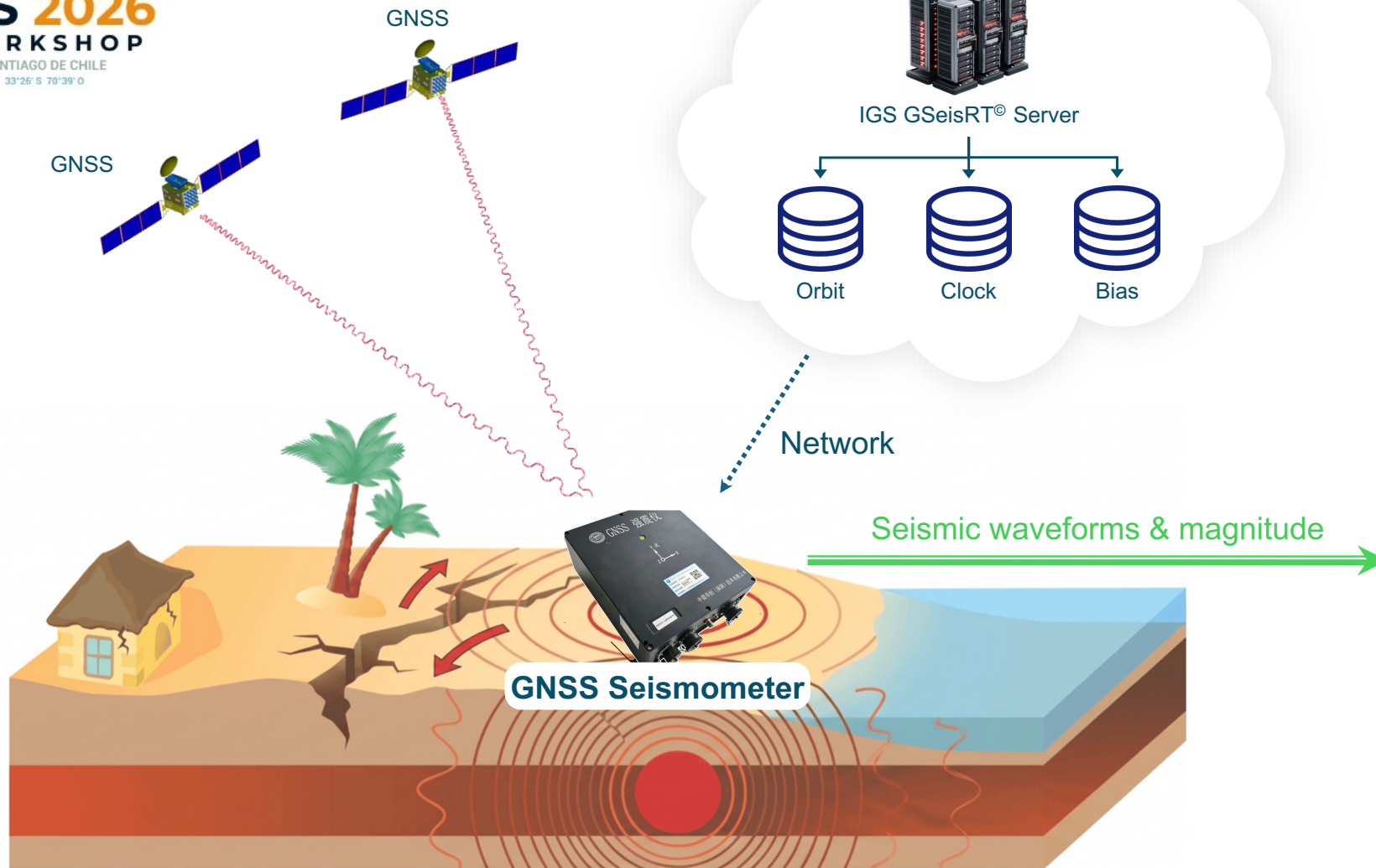
- Real-time PPP-AR validation (fixing rate)



● wide-lane ● narrow-lane

Constellation	Fixing rate (%)
GPS	88.5 / 82.4
Galileo	93.2 / 84.5
BDS-2	89.3 / 60.4
BDS-3	92.3 / 76.1

Global real-time PPP-AR services are supported



Earthquake Early Warning System



Determination



Warning!
 $M_w > 6.0$



Public Safety and Property