



BeiDou High-Accuracy Services (BD-HAS): Opportunities for Geodetic Applications



R&D and next-gen supply chain - innovation and technology development

Ningbo Wang^{1,2} (Email: wangningbo@aoe.ac.cn)

¹ Aerospace Information Research Institute (AIR), Chinese Academy of Sciences (CAS), Beijing, China

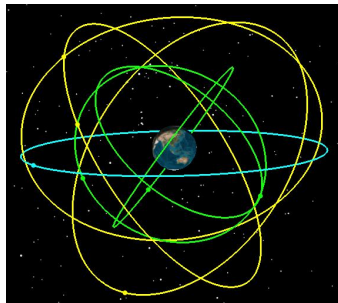
² China-South Africa Joint Laboratory on Aerospace Information Technology and Applications, Beijing, China

SAGWG | 1-2 Oct 2026



BeiDou Navigation Satellite System

- ▶ BDS has evolved through three development phases: BDS-1 -> BDS-2 -> BDS-3
 - ▶ BDS-1: Experimental regional system (2000)
 - ▶ BDS-2: Regional service over the Asia-Pacific region (2012)
 - ▶ **BDS-3: Global navigation satellite system (2020)**
- ▶ Global services were officially initiated on **31 July 2020**
- ▶ **Hybrid constellation architecture** combining GEO, IGSO and MEO satellites
- ▶ Provide global PNT services with enhanced coverage over the Asia-Pacific region



BeiDou Navigation Satellite System

- ▶ BDS PRN reassignment in April 2026
 - ▶ Most BDS-2 satellites were decommissioned in April 2026
 - ▶ BDS-3 satellites were reassigned to PRNs previously used by BDS-2 satellites
 - ▶ The PRN reassignment was completed by the end of April 2026
 - ▶ Current BDS-3 constellations: **4 GEO + 5 IGSO + 28 MEO** satellites

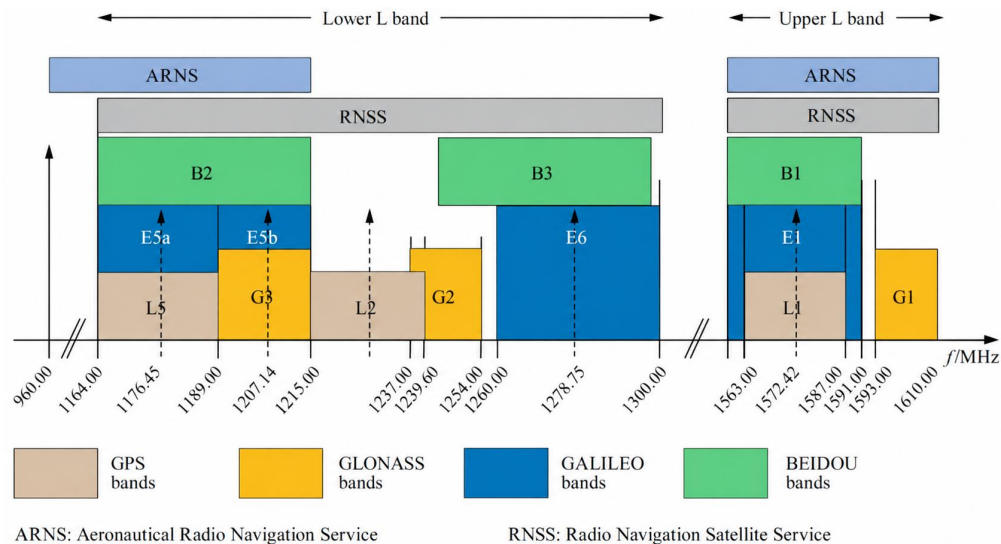
PRN	SVN	Orbit Type	NORAD ID	Clock Date	Launch Date	Status	Service Signal
01	GEO-4	GEO	56564	H	2023-05-17	Healthy	B1I/B3I
02	GEO-2	GEO	45344	H	2020-03-09	Healthy	B1I/B3I
03	GEO-3	GEO	45807	H	2020-06-23	Healthy	B1I/B3I
04	GEO-1	GEO	43683	H	2018-11-01	Healthy	B1I/B3I
06	IGSO-1	IGSO	44204	H	2019-04-20	Healthy	B1I/B3I/B1C/B2a/B2b
07	IGSO-2	IGSO	44337	H	2019-06-25	Healthy	B1I/B3I/B1C/B2a/B2b
08	IGSO-3	IGSO	44709	H	2019-11-05	Healthy	B1I/B3I/B1C/B2a/B2b
09	IGSO-6	IGSO	41434	Rb	2016-03-30	Healthy	B1I/B3I
10	IGSO-7	IGSO	43539	Rb	2018-07-10	Healthy	B1I/B3I

PRN	SVN	Orbit Type	NORAD ID	Clock Date	Launch Date	Status	Service Signal
11	MEO-25	MEO	61186	Rb	2024-09-19	Healthy	
12	MEO-26	MEO	58655	H	2023-12-26	Healthy	
13	MEO-27	MEO	61187	Rb	2024-09-19	Healthy	
14	MEO-28	MEO	58654	H	2023-12-26	Healthy	
19	MEO-1	MEO	43001	Rb	2017-11-05	Healthy	
20	MEO-2	MEO	43002	Rb	2017-11-05	Healthy	
21	MEO-3	MEO	43208	Rb	2018-02-12	Healthy	
22	MEO-4	MEO	43207	Rb	2018-02-12	Healthy	
23	MEO-5	MEO	43581	Rb	2018-07-29	Healthy	
24	MEO-6	MEO	43582	Rb	2018-07-29	Healthy	
25	MEO-11	MEO	43603	H	2018-08-25	Healthy	
26	MEO-12	MEO	43602	H	2018-08-25	Healthy	

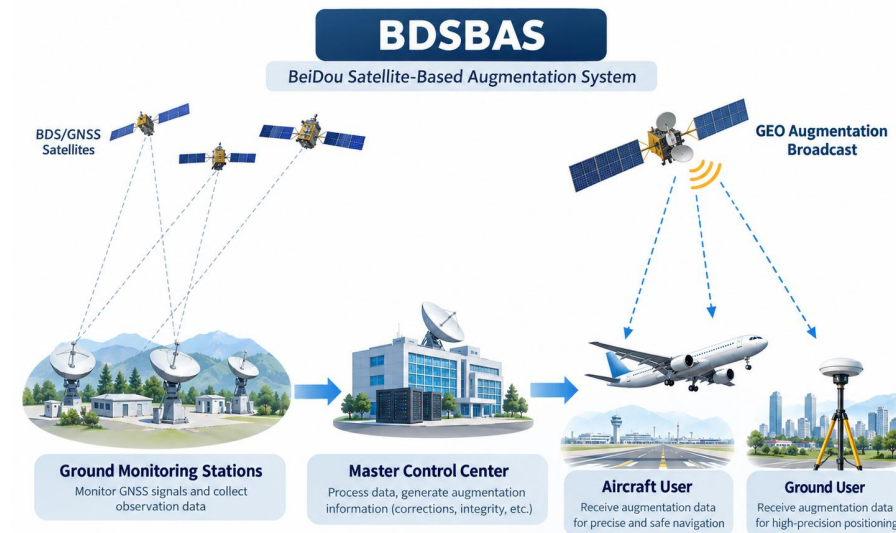
PRN	SVN	Orbit Type	NORAD	Launch Date	Status	Service Signal
27	MEO-7	MEO	Rb	2018-01-12	Healthy	B1I/B3I/B1C/B2a/B2b
28	MEO-8	MEO	Rb	2018-01-12	Healthy	B1I/B3I/B1C/B2a/B2b
29	MEO-9	MEO	Rb	2018-03-30	Healthy	B1I/B3I/B1C/B2a/B2b
30	MEO-10	MEO	Rb	2018-03-30	Healthy	B1I/B3I/B1C/B2a/B2b
31	MEO-22	MEO	H	2019-11-23	Healthy	B1I/B3I/B1C/B2a/B2b
32	MEO-13	MEO	Rb	2018-09-19	Healthy	B1I/B3I/B1C/B2a/B2b
33	MEO-14	MEO	Rb	2018-09-19	Healthy	B1I/B3I/B1C/B2a/B2b
34	MEO-15	MEO	H	2018-10-15	Healthy	B1I/B3I/B1C/B2a/B2b
35	MEO-16	MEO	H	2018-10-15	Healthy	B1I/B3I/B1C/B2a/B2b
36	MEO-17	MEO	Rb	2018-11-19	Healthy	B1I/B3I/B1C/B2a/B2b
37	MEO-18	MEO	Rb	2018-11-19	Healthy	B1I/B3I/B1C/B2a/B2b
38	MEO-21	MEO	H	2019-11-23	Healthy	B1I/B3I/B1C/B2a/B2b
39	MEO-23	MEO	Rb	2019-09-23	Healthy	B1I/B3I/B1C/B2a/B2b
40	MEO-24	MEO	Rb	2019-09-23	Healthy	B3I/B2a/B2b
41	MEO-19	MEO	Rb	2019-12-16	Healthy	B1I/B3I/B1C/B2a/B2b
42	MEO-20	MEO	Rb	2019-12-16	Healthy	B1I/B3I/B1C/B2a/B2b

BeiDou Navigation Satellite System

- ▶ Integrated services combining navigation, augmentation & high-accuracy positioning
 - ▶ Global PNT services using a hybrid MEO/IGSO/GEO constellation
 - ▶ Short Message Communication (SMC) and Search-and-Rescue (SAR) services
 - ▶ **BDSBAS**: BDS Satellite-Based Augmentation System via GEO satellites
 - ▶ **PPP-B2b**: Precise Point Positioning service with real-time corrections broadcast via GEO satellites



(adapted from Teunissen & Montenbruck, 2017)



BeiDou Navigation Satellite System

► **PPP-B2b**: BDS-3 satellite-based precise point positioning (PPP) service

System	Service	Satellite	Status	Data rate	Format	Coverage
QZSS CLAS	PPP-RTK	IGSO/GEO	Operational (2018-)	2,000 bps	Compact SSR	Regional (Japan)
QZSS MADOCA	PPP	IGSO/GEO	Experimental (2017-)	2,000 bps	RTCM SSR	Regional (Japan)
Galileo HAS	PPP	MEO	Operational (2021-)	500 bps	Based on Compact SSR	Global
BDS PPP	PPP	GEO	Operational (2020-)	500 bps	SSR (PPP-B2b ICD)	Regional (China), global plans (?)
Australian SBAS	PPP	GEO	Development (2023-)	250 bps?	TBD	Regional (Aus/NZ)
GLONASS PPP	PPP	GEO	Concept (2030-)	4,000 bps	RTCM SSR	Regional (Russia)

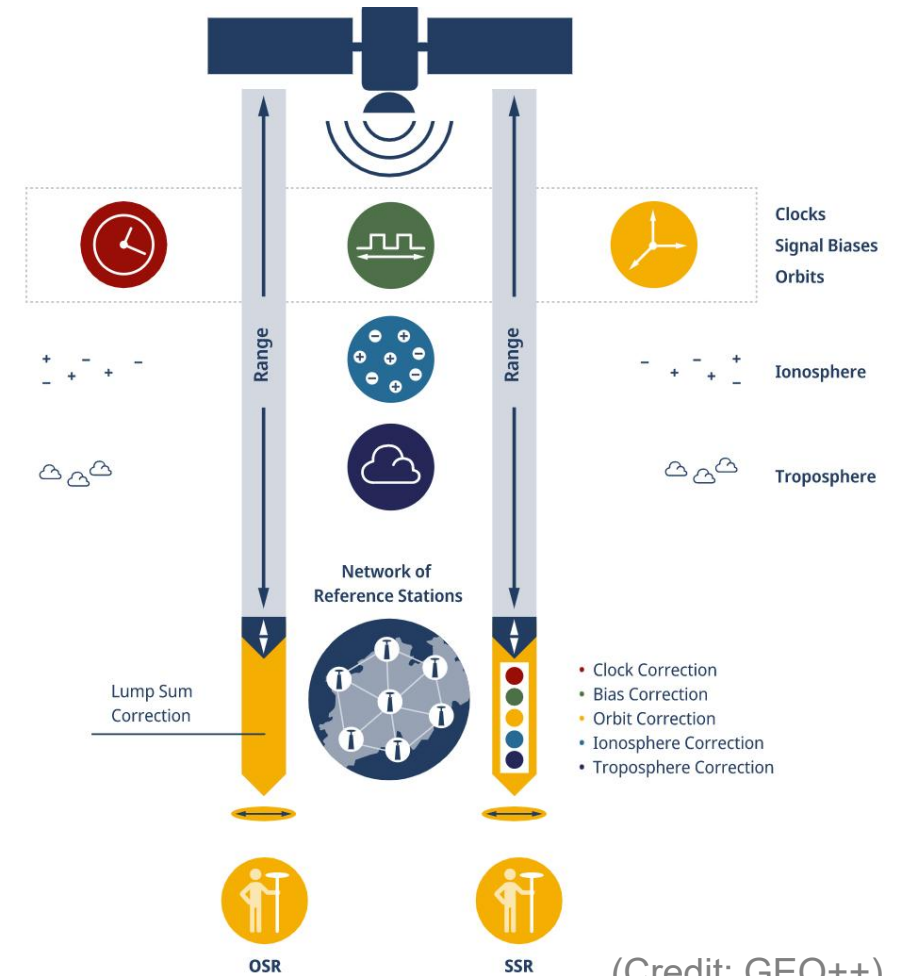
IGS Real-Time Service

- ▶ IGS Real-Time Committee started in 2001
 - ▶ Maintain and expand IGS **real-time GNSS station network** data resources
 - ▶ Monitor and improve observation data and broadcast ephemerides
 - ▶ Provide real-time corrections of **orbits, clocks, biases and atmospheric delays**
 - ▶ Combine correction data streams for **IGS Real-Time Service (IGS-RTS, 2017)**
 - ▶ Evolving toward **GPS + GLONASS + Galileo + BDS** multi-GNSS real-time services
- ▶ **Real-Time Analysis Centers**: APM, BKG, CAS, CHC, CNES, GFZ, GMV, NRCan, SHAO, WHU, JPL
- ▶ **Real-Time Analysis Center Coordinator**: BKG (Germany)
 - ▶ Real-time combined broadcast ephemerides
 - ▶ Real-time combined precise orbit, clock, and bias products
 - ▶ Real-time combined global ionospheric VTEC products



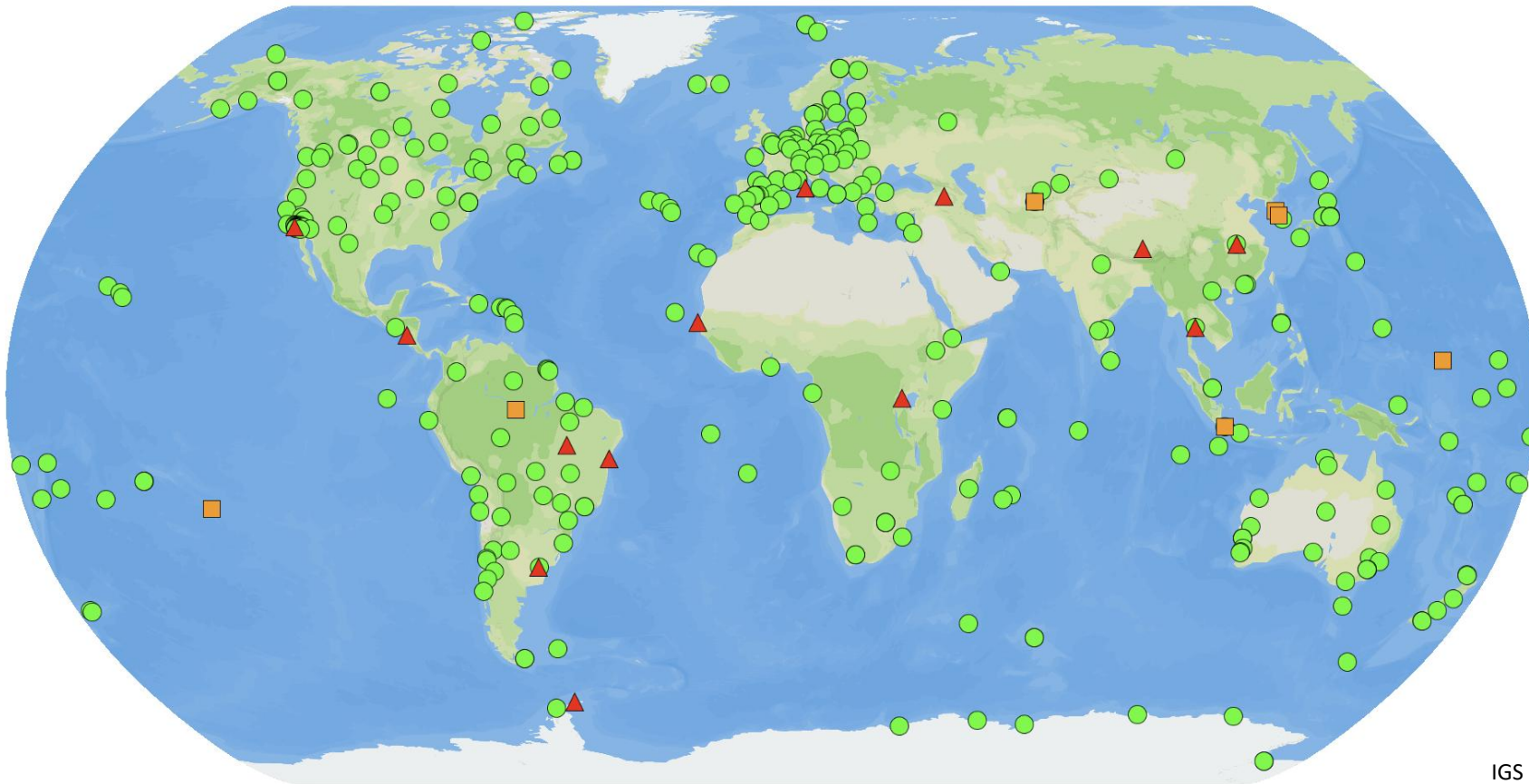
IGS RTS: Precise Point Positioning

- ▶ GNSS Error Corrections
 - ▶ **Global** (satellite orbit, clock & bias errors)
 - ▶ **Regional/local** (ionospheric & tropospheric delays)
 - ▶ Receiver/user (multipath & receiver errors)
- ▶ Precise Point Positioning (PPP)
 - ▶ Single-station based positioning
 - ▶ **State Space Representation** (SSR) corrections
 - ▶ Orbits, clocks & biases (RTCM or IGS SSR)
 - ▶ **One-way communication**
 - ▶ High convergence time due to unmodeled atmospheric errors
 - ▶ Highly affected by the ionospheric disturbances



IGS RTS: Real-Time Data Centers

- ▶ IGS RTS stations: **~340** (as of September 2026, ~90% stable)
- ▶ Most stations supporting multi-GNSS: GPS, Galileo, **BDS**, GLONASS, QZSS



IGS RTS Stations: <https://network.igs.org/>

IGS RTS: Real-Time Data Centers

Agency	Content
BKG, Germany	Global and European observation data, IGS RTS Products products.igs-ip.net
CDDIS, USA	Global observation data, IGS RTS products cddis-caster.gsfc.nasa.gov
Geoscience Australia	Observation data of stations located in Australia and Asia-Pacific auscors.ga.gov.au
UCAR, USA	Global observation data, IGS RTS products rt.igs.org
WHU, China	Relay caster for users from China ntrip.gnsslab.cn
CAS, China	Relay caster for users from China https://igs.bdsmart.cn/

IGS RTS: Real-Time Analysis Centers

- ▶ **11 RTACs** provide real-time GNSS orbit and clock corrections, with an increasing number also generating code and **phase bias** products for PPP-AR (ambiguity resolution).
- ▶ **5 RTACs** are providing global real-time **ionospheric VTEC** products.
- ▶ **RT-ACC** generates **combined** multi-GNSS RTS products and supports quality monitoring.
- ▶ IGS RTS product supports **a 10cm real-time position accuracy** with fixed ambiguities.

IGS RTS: Real-Time Analysis Centers

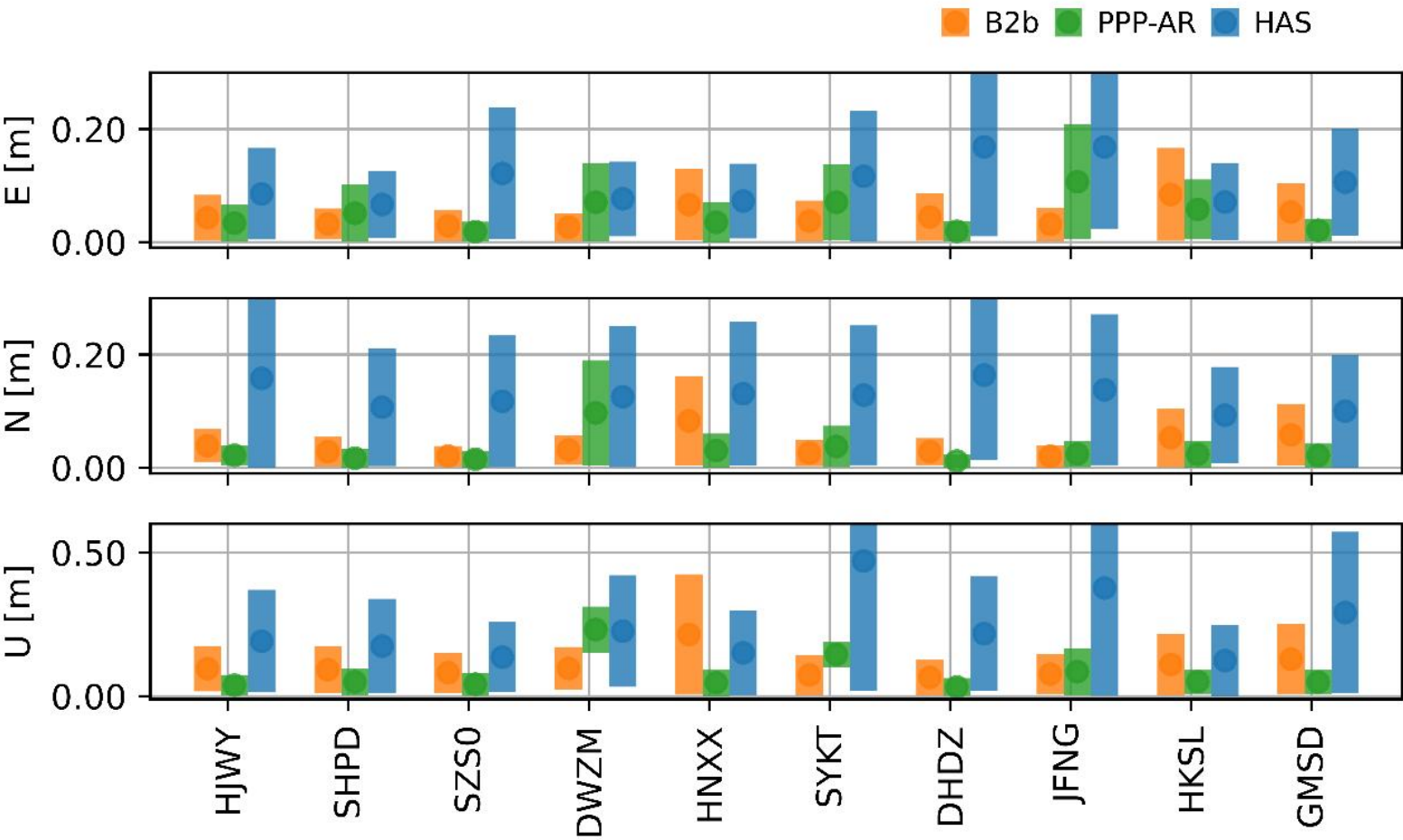
RTAC	Mountpoints	SSR Corrections		PPP	PPP-AR
APM	SSR*00APM#	GPS+GLO+GAL+BDS Orb+Clk	[S;C]	Y	
BKG	SSR*00BKG#	GPS+GLO+GAL Orb+Clk+Cbia	[S;C;B]	Y	
CAS	SSR*00CAS#	GPS+GLO+BDS+GAL Orb+Clk	[S;C]	Y	
	SSR*01CAS#	GPS+GAL+BDS Orb+Clk+Cbia+Pbia+GIM	[S;C;B;P;I]	Y	☒ (2025)
CHC	SSR*00CHC1	GPS+GLO+GAL+BDS Orb+Clk+Cbia+Pbia	[S;C;B;P]	Y	☒ (2025)
CNES	SSR*00CNE#	GPS+GLO+GAL+BDS Orb+Clk+Cbia+Pbia	[S;C;B;P]	Y	☒ (2012)
GFZ	SSR*00GFZ#	GPS+GLO+GAL+BDS Orb+Clk+Cbia	[S;C;B]	Y	
GMV	SSR*00GMV#	GPS+GLO+GAL+BDS Orb+Clk+Cbia	[S;C;B]	Y	
JPL	SSRA##JPL0	GPS+GLO+GAL Orb+Clk	[S;C]	Y	
NRCan	SSRA00NRC0	GPS Orb+Clk+Cbia	[S;C]	Y	
SHAO	SSR*00SHA#	GPS+GLO+GAL+BDS Orb+Clk+Cbia	[S;C;B]	Y	
	SSR*01SHA#	GPS+GLO+GAL+BDS Orb+Clk+Cbia+Pbia	[S;C;B;P]	Y	☒ (2015)
UPC	IONO00UPC1	GIM	[I]	N	
WHU	SSR*00WHU#	GPS+GLO+GAL+BDS Orb+Clk	[S;C]	Y	
	OSBC00WHU1	Cbia+Pbia	[B;P]		☒ (2017)

Note: S (Orbit), C (Clock), B (Code bias), P (Phase bias), I (GIM)

IGS RTS Contributors: <https://igs.org/rtts/contributors/#real-time-analysis-centers>

IGS RTS: RT-PPP vs. PPP-B2b & HAS

► Real-Time PPP performance comparison



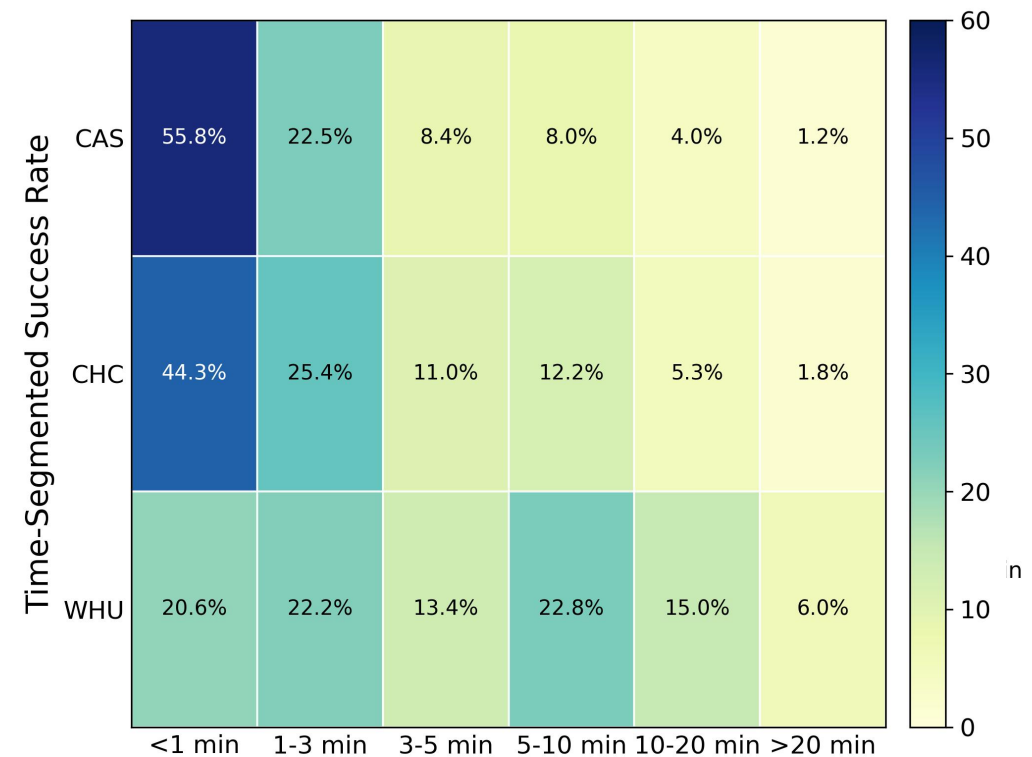
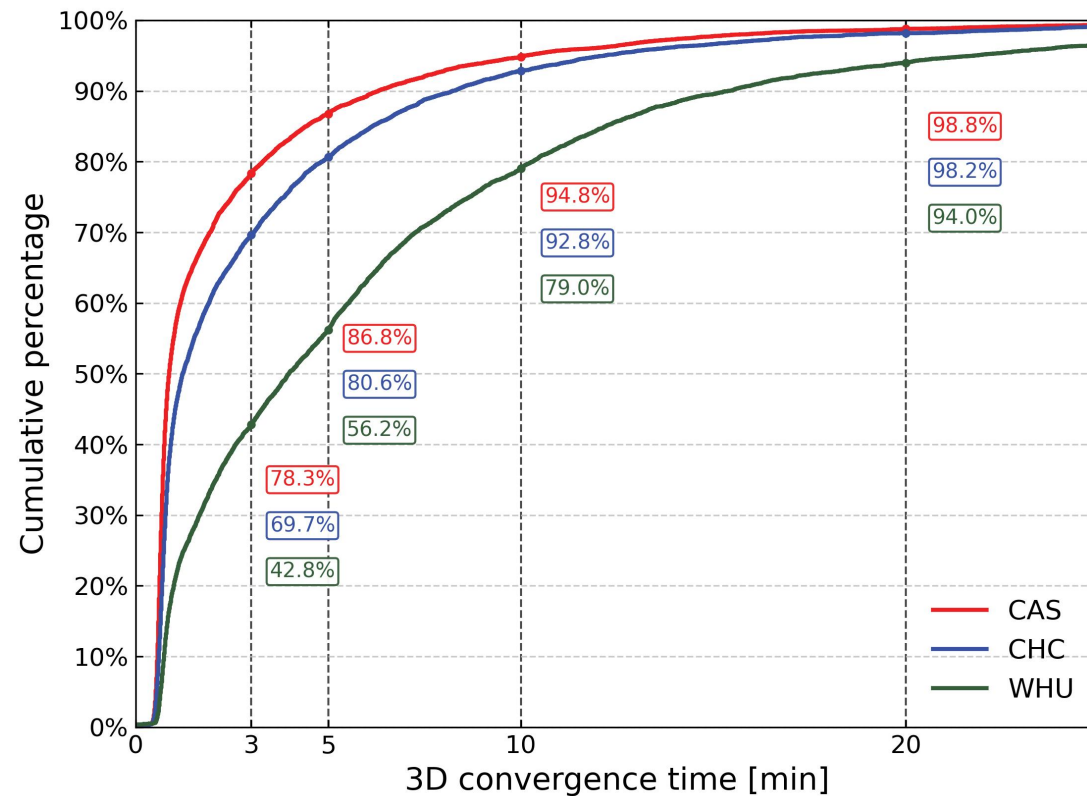
GAL-HAS: 0.253m (CEP95)

B2b-PPP: 0.129m (CEP95)

RT-PPP: 0.062m (CEP95)

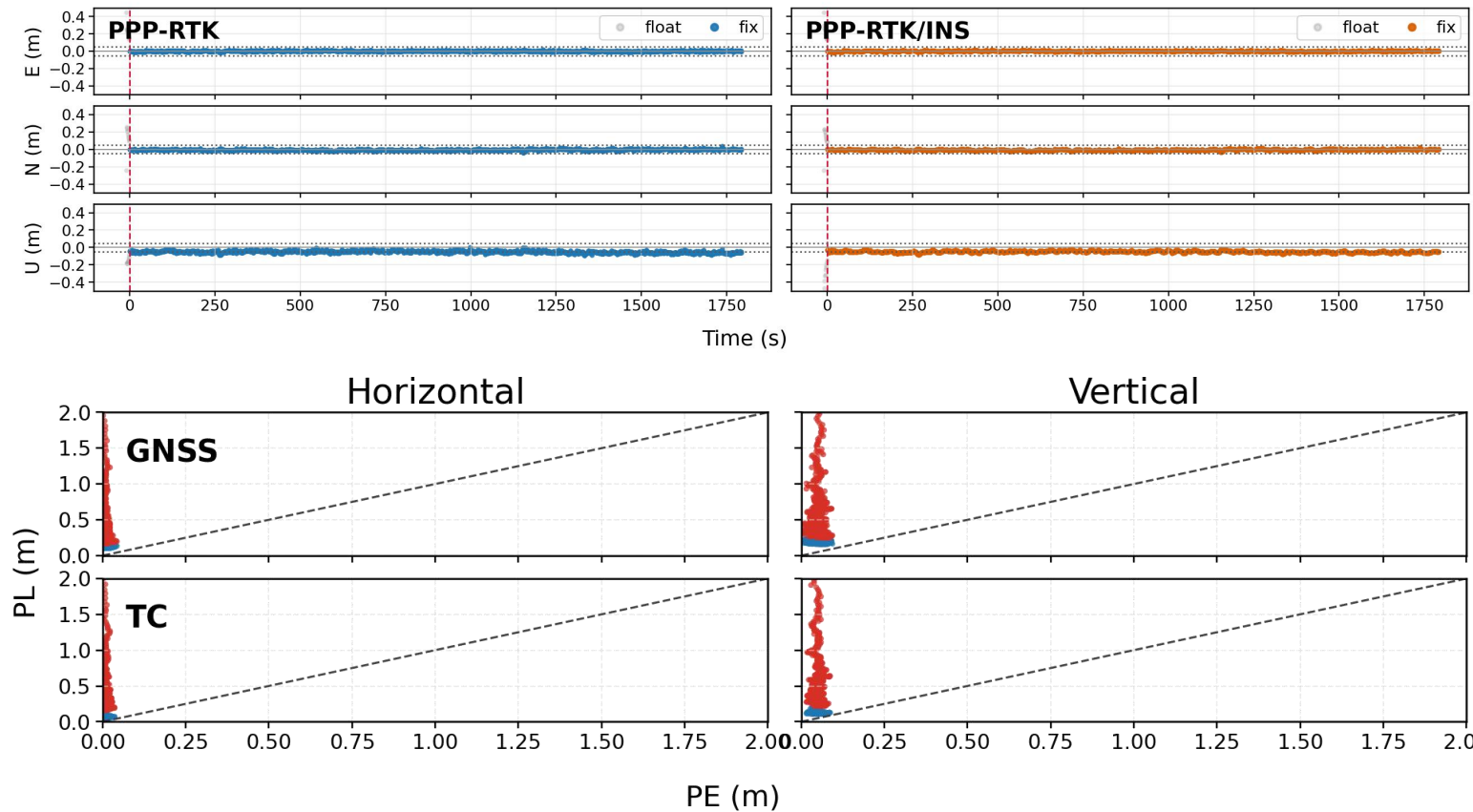
Geodetic applications: Terrestrial High-Accuracy Positioning

- CAS real-time PPP-RTK service via internet: **PPP-AR** (ambiguity resolution) streams
- **PPP-AR experiments**: 20 stations, 1-Hz data, 30-min reconvergence



Geodetic applications: Terrestrial High-Accuracy Positioning

- CAS real-time PPP-RTK service via internet: **PPP-RTK** (...+ion&trop) streams

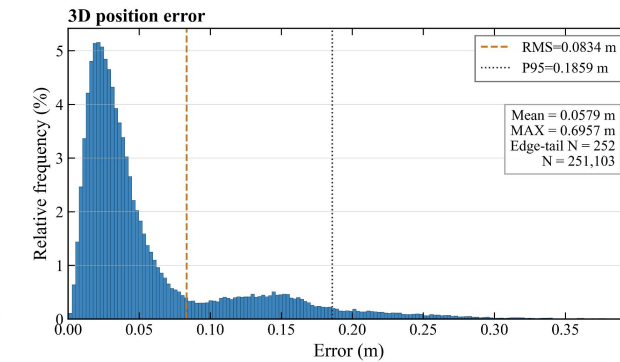
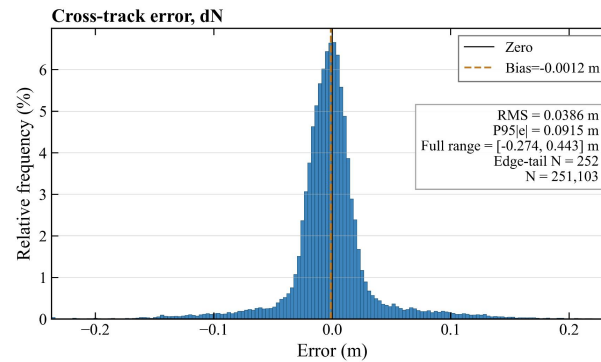
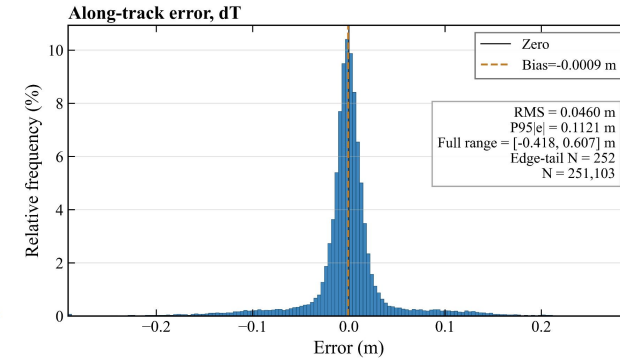
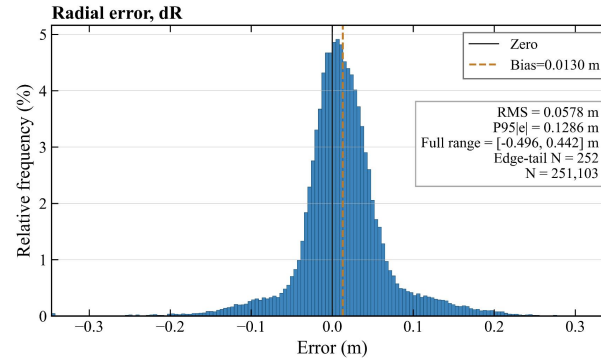
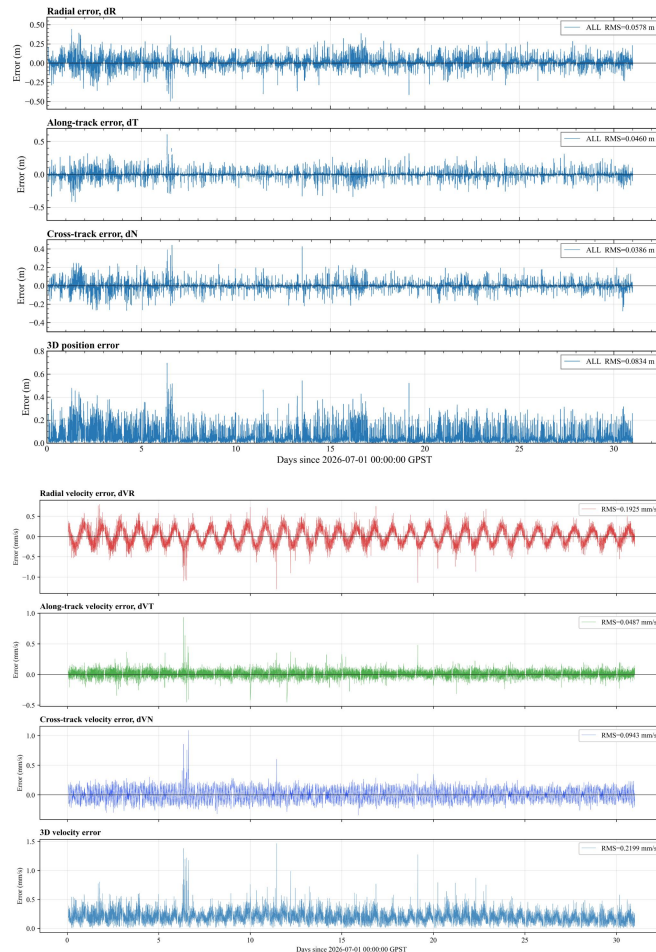


PPP-RTK Performance

- H component: 2.0cm
- V component: 3.5cm
- Convergency time: <15s

Geodetic applications: LEO Precise Orbit Determination (POD)

► Sentinel-6A POD using CAS real-time PPP-AR streams

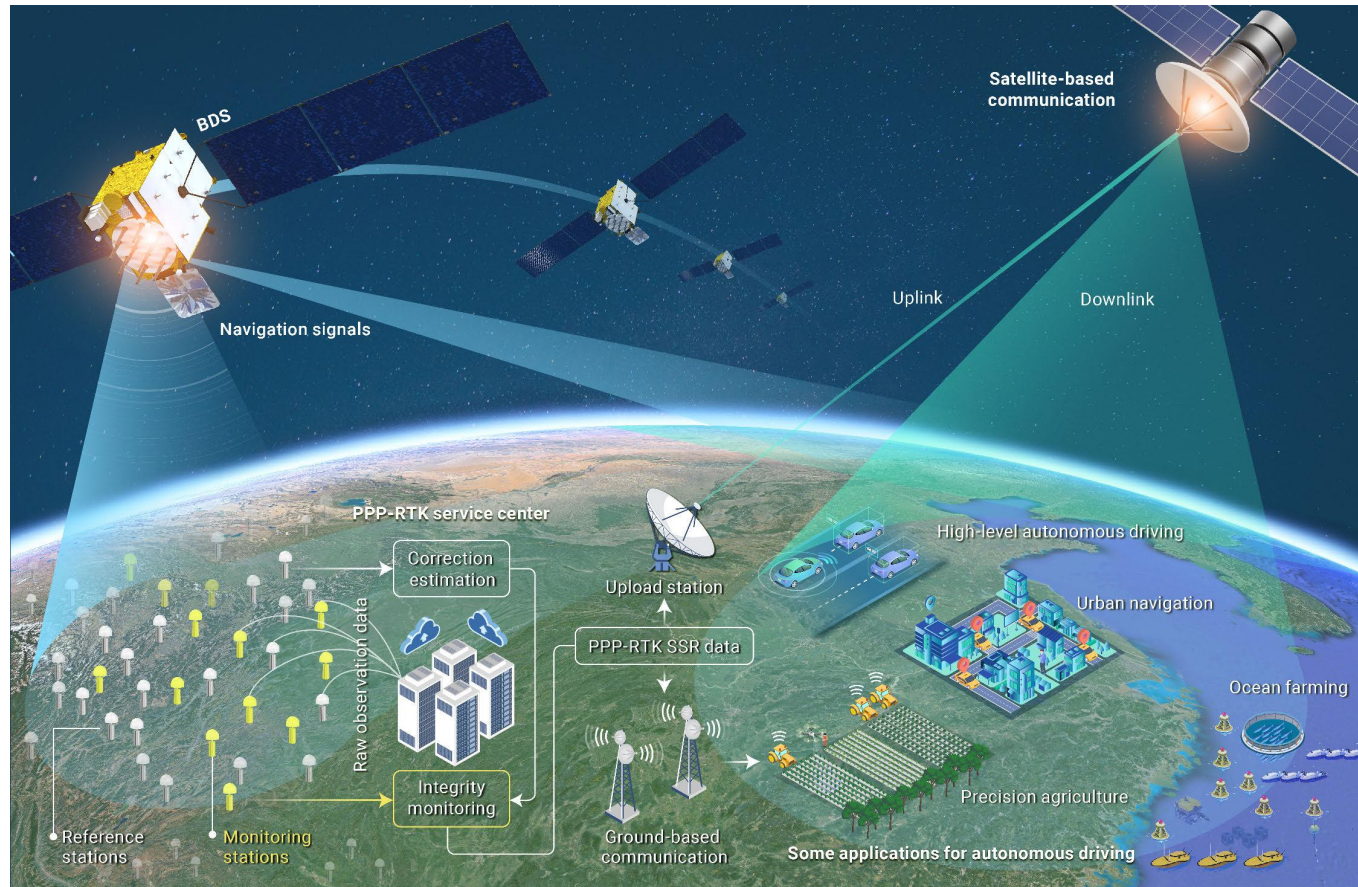


POD performance in July 2026

- R: 5.78cm, T: 4.60cm, N: 3.86cm
- AR fixing rate: 74.6%

Geodetic applications: Tiantong TSTAR service

- **TSTAR**: Tiantong **S**-band Tiered **A**rchitecture for **R**ead-time high accuracy service



- **PPP**: 5cm/10cm (95%), 15min
- **PPP-AR**: 5cm/10cm (95%), 3min
- **PPP-RTK**: 5cm/10cm (95%), 1min
- Integrity monitoring supported

- CAS PPP-RTK service can be extended for satellite-based broadcasting via L/S/Ku/Ka bands

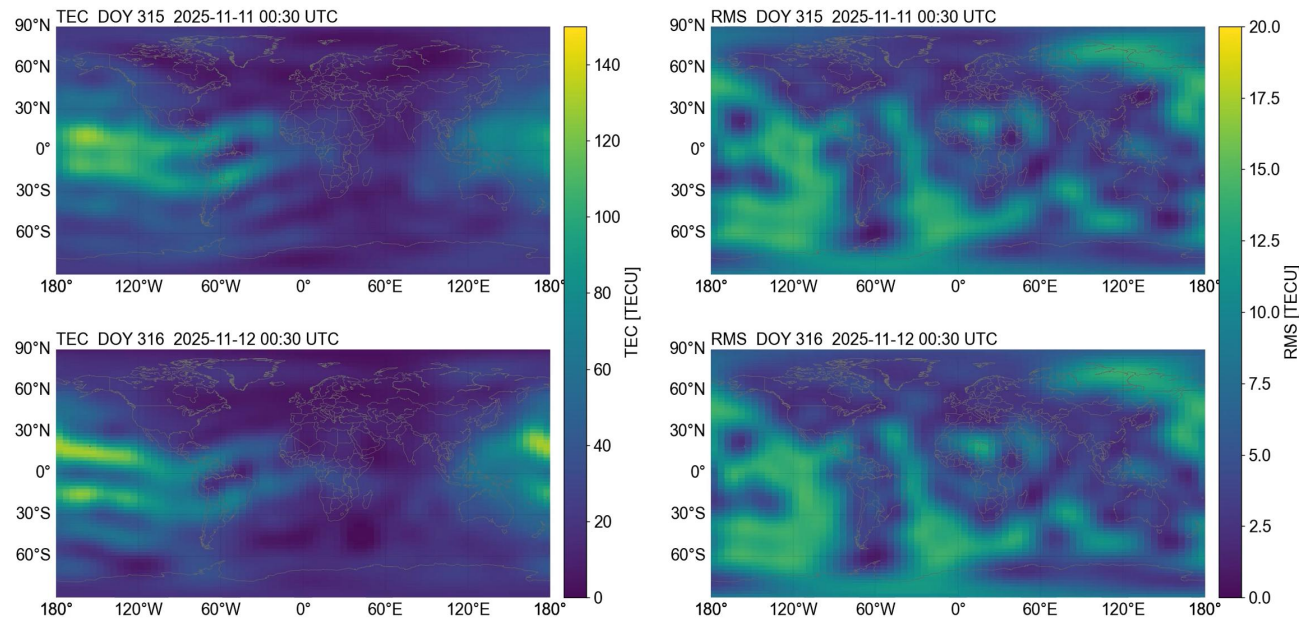
Geodetic applications: Tiantong TSTAR service

- **TSTAR** service supporting the unmanned farm planting (Shandong/China, October, 2025)



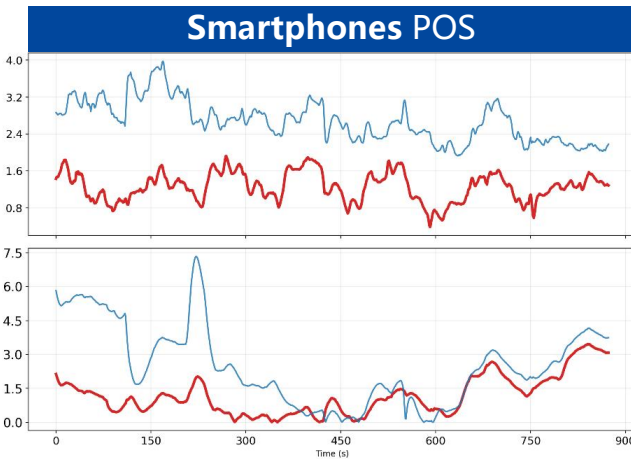
Geodetic applications: Ionospheric Space Weather Monitoring

- CAS real-time global **RT-VTEC** and **RT-RMS** maps

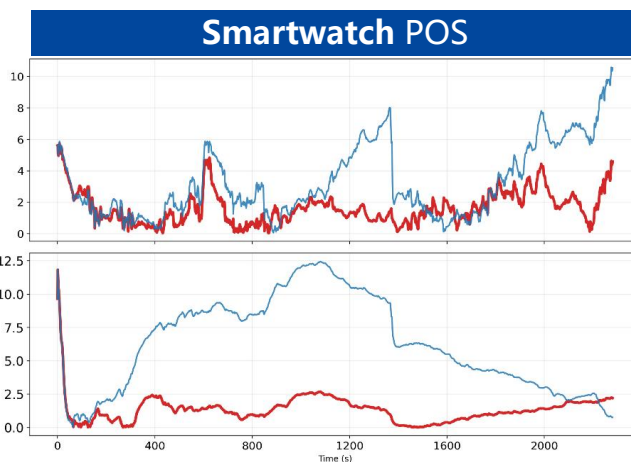


Data source: CAS
GIM: IGS-SSR **RT-VTEC**

Data source: CAS
GIM: IGS-SSR **RT-RMS**



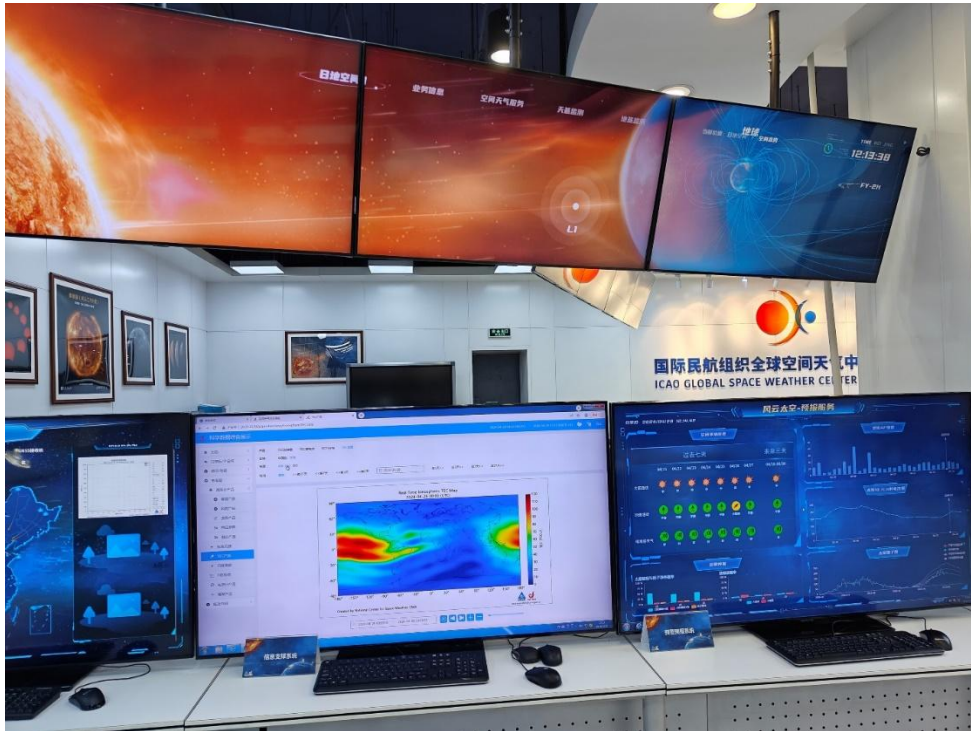
Hor. **52%**
Ver. **51%**



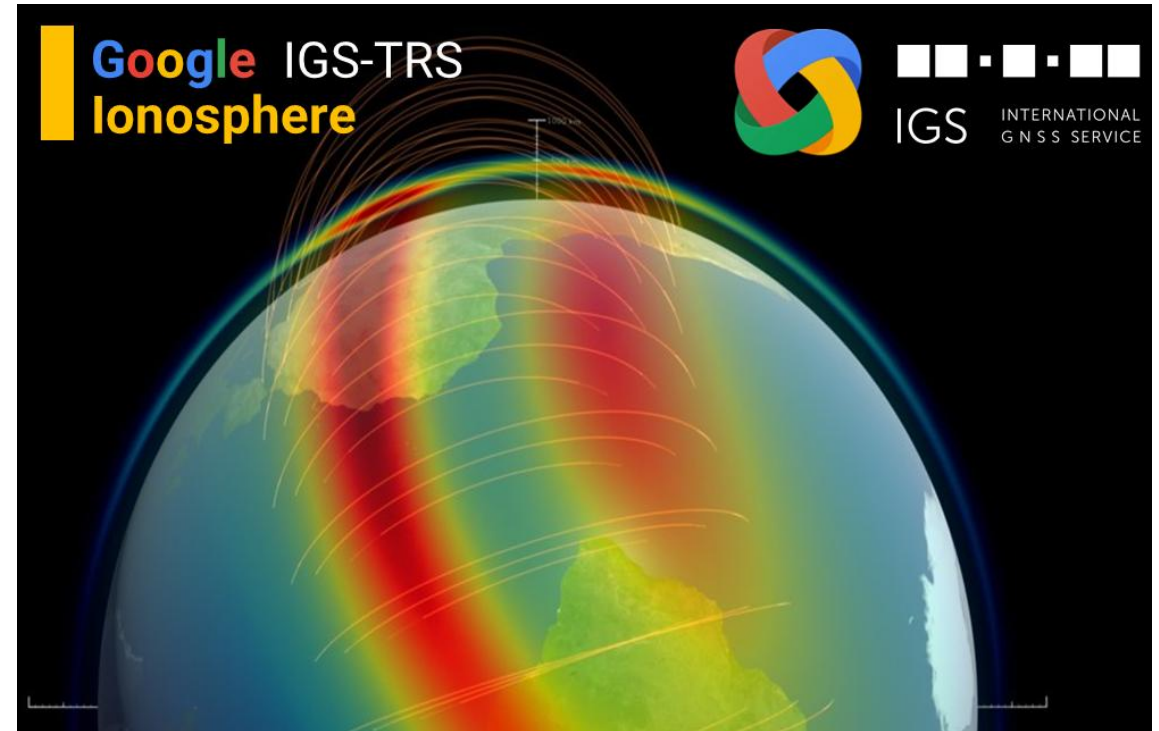
Hor. **51%**
Ver. **76%**

Geodetic applications: Ionospheric Space Weather Monitoring

- Real-time global ionospheric VTEC maps



Operational Runs at **CMA/China**
IACO Global Space Weather Center



Collaboration with **Google**
RT-VTEC & RT-RMS for million smartphones

IGS Regional Data Center (CAS)

- ▶ CAS regional real-time data center: <https://igs.bdsmart.cn>
- ▶ Permission for registered account: 1, 000 streams for one device (10 devices in total)


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IGS Real-Time Service

The IGS[®] Real-Time Service[®] provides high-precision, low-latency GNSS data streams, supporting real-time positioning, navigation, and timing applications. Through a global network of multi-GNSS stations, the IGS RTS delivers continuous, reliable data streams from GPS, GLONASS, Galileo, BeiDou and QZSS constellations. Users can access detailed information on each station and its data contributions via the NETWORK[®].

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☐ Hide Site Information

Site	Status	Delay	Receiver	Antenna	Site location
ABMF0	✔ in-service	1.52s	SEPT_POLARX5	TRM57971.00	lat:16.262°, lon:-61.528°
ABP00	✘ interrupted	-----	SEPT_POLARX5	ASH701945G_M	lat:0°, lon:0°, h:---
AC230	✔ in-service	1.52s	SEPT_POLARX5	TRM59800.99	lat:60.475°, lon:-150° h:99.212m
AC240	✔ in-service	1.52s	SEPT_POLARX5	TRM159800.00	lat:58.682°, lon:-156° h:59.402m
AC500	✘ interrupted	-----	SEPT_POLARX5	TRM59800.80	lat:0°, lon:0°, h:---
ADH10	✔ in-service	1.52s	SEPT_POLARX5	NULL	lat:24.951°, lon:55.124°, h:---
AGG00	✔ in-service	1.52s	SEPT_POLARX5TR	LEIAR25.R4	lat:-34.874°, lon:-58.140°
AIRA0	✔ in-service	2.53s	TRIMBLE_ALLOY	TRM59800.00	lat:31.824°, lon:130° h:335.809m
AJACO	✔ in-service	1.53s	LEICA_GR50	TRM115000.00	lat:41.927°, lon:8.763°, h:---
ALBHO	✔ in-service	1.53s	SEPT_POLARX5	TRM59800.00	lat:48.390°, lon:-123° h:48.516m

Total 326

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Station Table



Special issue in Satellite Navigation (IF: 12.4)

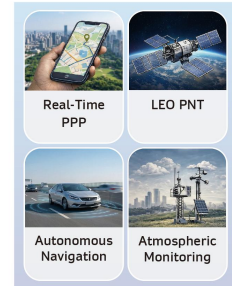
- ▶ Multi-GNSS Real-Time Service
- ▶ Guest Editors:
 - ▶ Ningbo Wang, CAS
 - ▶ Andreas Brack, GFZ
 - ▶ Andre Hausschild, DLR
 - ▶ Axel Rülke, BKG
- ▶ Topics related to the IGS RTS are welcome
- ▶ Submission deadline: **30 May 2027**



Special Issue : Multi-GNSS Real-Time Service

Rationale of Special Issue

The International GNSS Service (IGS) Real-Time Service (RTS) reached full operational deployment in 2017. Over the past decade, IGS RTS has demonstrated strong technical excellence and sustained international collaboration. As IGS RTS approaches its 10-year operational milestone, this special issue on IGS Real-Time Service provides a timely opportunity to review key achievements, highlight ongoing developments, and present state-of-the-art research and applications. Potential contributions may cover a broad range of topics, from advances in real-time GNSS data processing to application-driven case studies that illustrate the service's impact across diverse scientific and industrial fields.



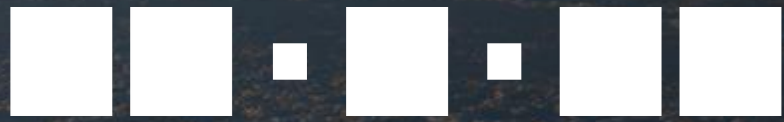
Possible Topic Lists

The topics including but not limited to:

- IGS RTS achievements over the past decades
- Research activities of the IGS real-time analysis centers (RTACs) and its RT-ACC
- IGS RTS for multi-GNSS terrestrial and LEO positioning, timing and navigation (PNT)
- IGS RTS for geoscience, atmospheric remote sensing and space weather monitoring
- Cutting-edge research on real-time GNSS data processing and case studies illustrating the service's impact across various industries and scientific fields

Guest Editors

Andre Hauschild (DLR, Germany) former Chair of the IGS RTC
Axel Rülke (BKG, Germany) Chair of the IGS RTC
Andreas Brack (GFZ, Germany) Head of GFZ RTAC
Ningbo Wang (CAS, China) Vice-Chair of the IGS RTC



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Ningbo Wang

Email: wangningbo@aoe.ac.cn