IVS Infrastructure Developments

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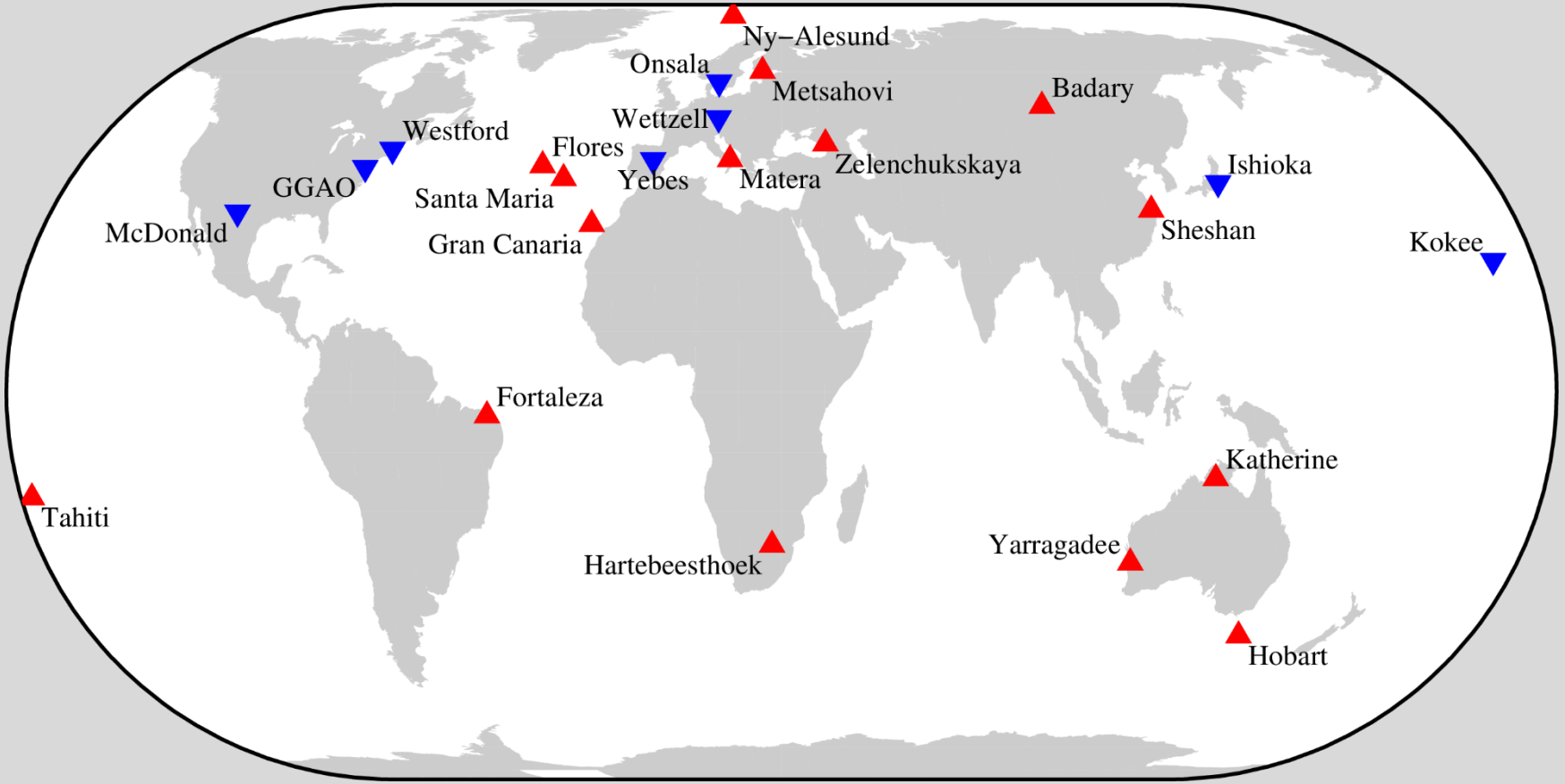
Comparison: S/X vs. VGOS

	Legacy S/X System	VGOS System	Benefit
Antenna size	5–100 m dish	12–13 m dish	reduced cost
Slew speed	~20–200 deg/min	≥ 360 deg/min	more observations for troposphere
Sensitivity	200–15,000 SEFD	≤ 2,500 SEFD	more homogeneous
Frequency range	S/X band [2 bands]	~2–14 GHz [1 broadband w/ 4 bands]	increased sensitivity, data precision
Recording rate	128, 256, 512 Mbps	8, 16, 32 Gbps	increased sensitivity
Data transfer	usually e-transfer, some ship disks	e-transfer, ship disks when required	
Signal processing	analog/digital	digital	stable instrumentation

Projected VGOS Network by Early 2020s



▼ VGOS antenna broadband ready

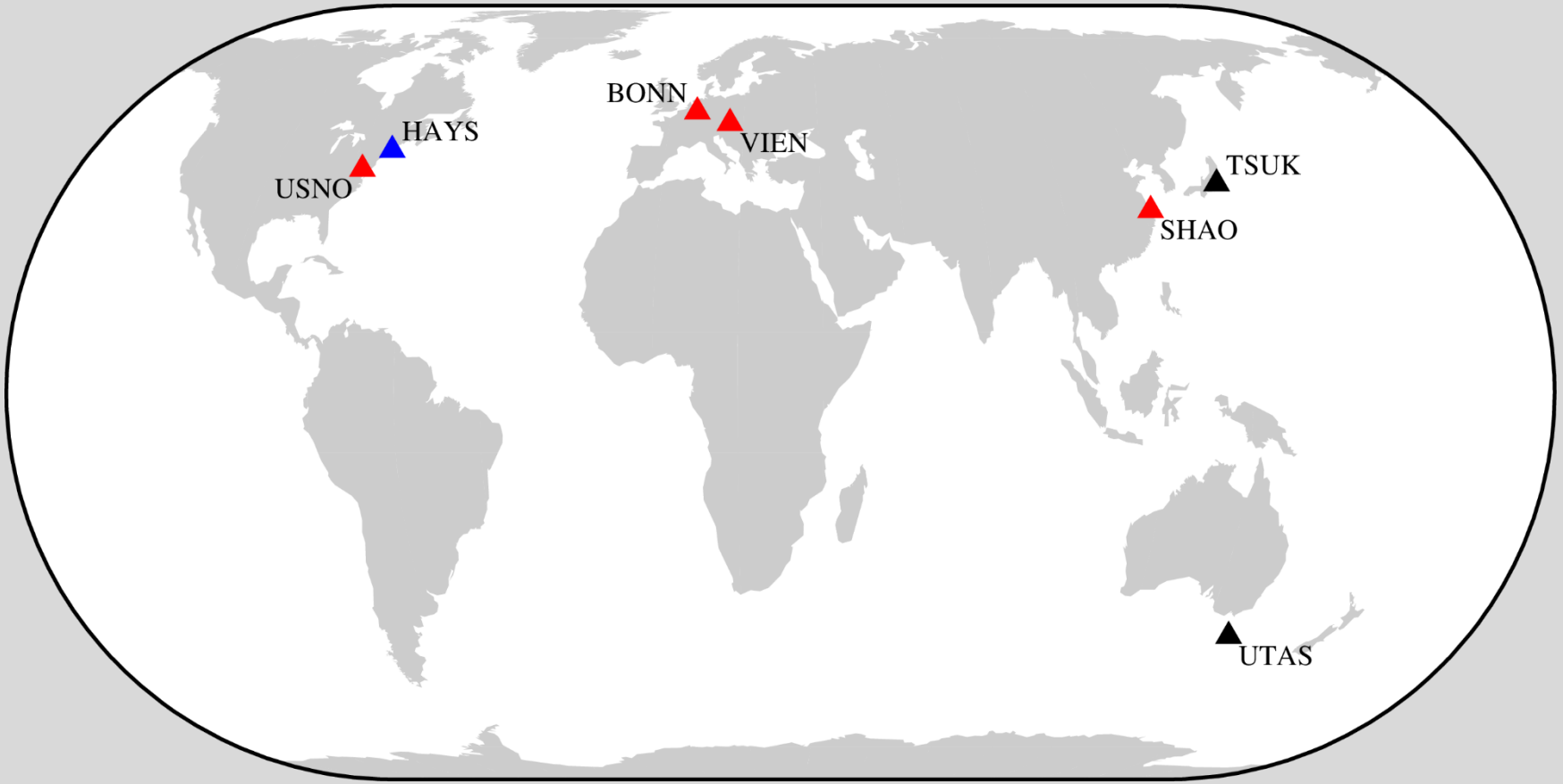
▲ VGOS antenna under construction or planned

Milestone Achievements to Date

- VGOS network is growing
  - January 2019; VGOS results are made available operationally based on a limited observing network
  - Early 2020; eight stations participate in regular VGOS sessions

- Geodetic results from limited network are very encouraging
  - Standard deviation of *VGOS observable error* is about *1 mm*, thus ten times better than legacy S/X
  - WRMS scatter of *postfit delay residuals* about mean is about *4 mm*, thus a few times larger than expected from instrumental noise ("*precision*")
  - WRMS scatter of *baseline length* estimates over 2–4 years is between 1–8 mm ("*repeatability*"), largely due to the vertical component
  - WRMS scatter of length of *VGOS* prototype baseline (i.e., Westford-GGAO) over 4 years is mm level, which is commensurate with the equivalent *GPS* baseline ("*accuracy*")

Rollout of VGOS Correlation Capabilities



▲ Active VGOS correlation center

▲ Under verification for VGOS correlation

▲ Possible future VGOS correlation center

State of VGOS Correlation

- Verification phase
  - Correlator centers at Bonn, Shanghai, USNO, and Vienna
  - Each center has unique data transport challenges
    - Accepts disk modules, e-transfer only, limited network capacity

- VGOS correlation knowledge transfer
  - Correlation workshop held in May 2019
    - Transfer procedures, software versions, lessons learned to other centers to increase VGOS observing frequency
    - https://www.haystack.mit.edu/workshop/TOW2019/VGOSNotebook.htm
  - Hands-on blind-test correlation of Intensives-like (single baseline, 1-hour observing) VGOS session
    - Completing evaluation, updating procedures
    - https://www.haystack.mit.edu/geo/vlbi_td/BB/051.pdf

State of VGOS Correlation (cont.)

- Final verification of correlation centers
  - Correlate a realistic 24-hour VGOS network session
  - Bonn to receive all disk modules and processes it start to finish
  - Due to data transport challenges, all other correlation centers will receive the same session correlation output and complete post correlation to finish processing
  - Verify and validate VGOS correlation end-to-end process
  - Expect new official VGOS correlation centers by Summer 2020

- Next step “mixed-mode” correlation
  - Simultaneous observing with legacy VLBI and VGOS networks
  - Requires understanding of VGOS correlation and post-processing
  - Expect training to launch in Fall 2020, workshop in May 2021

VGOS: Data Transport

Year	# of sites	Hours of obs/day	Data/day/site (TB)	Data/day/correlator (TB)
2019	8	4	7.2	58
2020	10	8	14.4	144
2021	16	8	14.4	230
2022	20	10	18.0	360
2023	24	12	21.6	518
2024	24	24	43.2	1037

Year	Data rate at each site (Gbps)	Network speed (Gbps)	Data rate at correlator (Gbps)	Network data rate at correlator (Gbps)
2019	0.7	1.0	5	8
2020	1.3	1.9	13	19
2021	1.3	1.9	21	30
2022	1.7	2.4	34	48
2023	2.0	2.8	48	68
2024	4.0	5.6	96	134

Future Steps

- VGOS network expansion to 24+ stations in next few years
- Increase data storage and data transfer capacities at stations and correlation facilities
- Transfer VGOS correlation capability to numerous correlators to allow for high-cadence VGOS sessions
- Tie VGOS TRF to legacy VLBI TRF (using mixed VGOS–S/X sessions)
- Further avenues of improvement:
  - instrumentation development (e.g., ongoing bandwidth doubling)
  - atmosphere modeling
  - radio source structure imaging
- Transition IVS production system from legacy VLBI to VGOS
- Eventual 24/7 observing