Comparison of simultaneous VGOS and legacy VLBI sessions

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VGOS vs. legacy S/X sessions

- The VLBI Global Observing System (VGOS) represents the next-generation VLBI system, which consists of a growing network of small, stiff and fast-slewing radio antennas performing broadband observations.

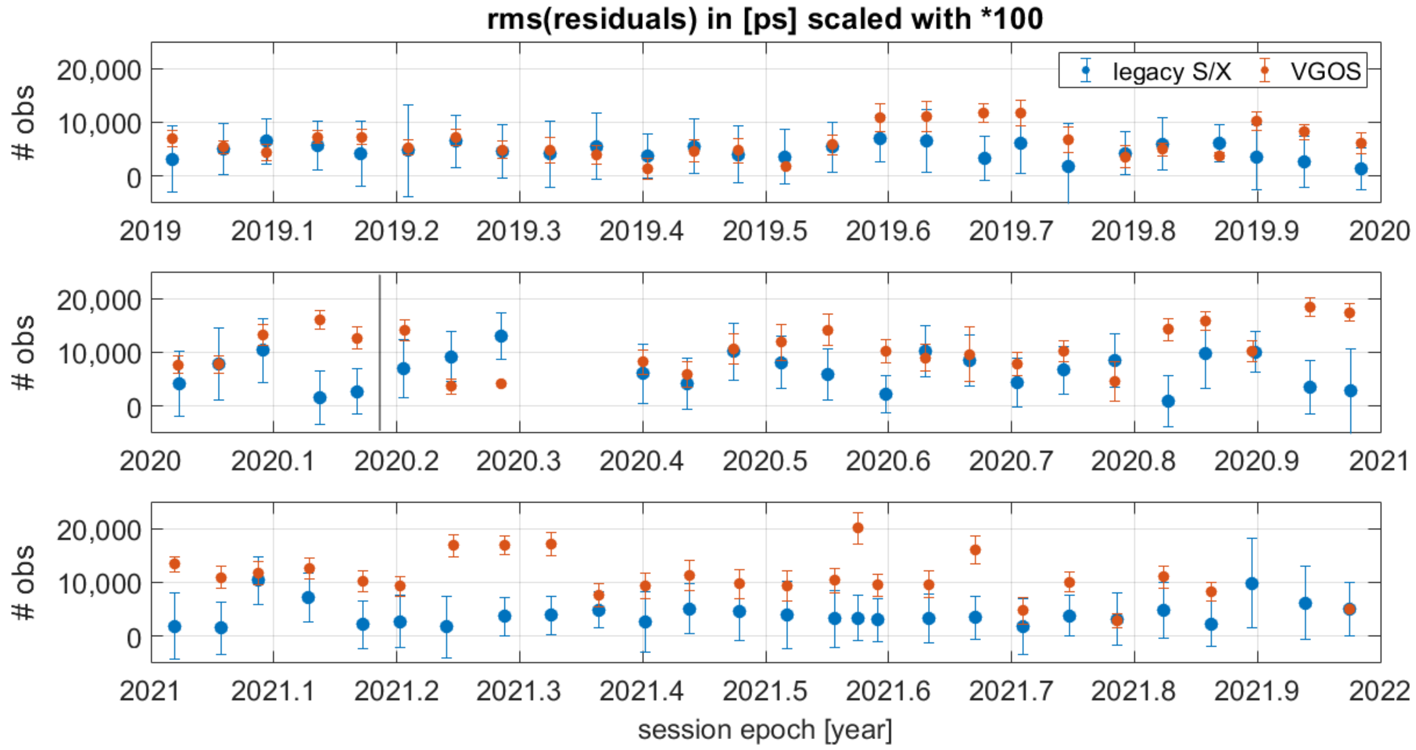
- After first experimental VGOS observations in 2014 and initial global measurement efforts during the Continuous VLBI Campaign in 2017 (CONT17), an operational series of about 75 bi-weekly VGOS sessions has become available.

- Between 2019 and 2021, these sessions (red) have accompanied the legacy S/X rapid turnaround sessions (blue, compare figure).

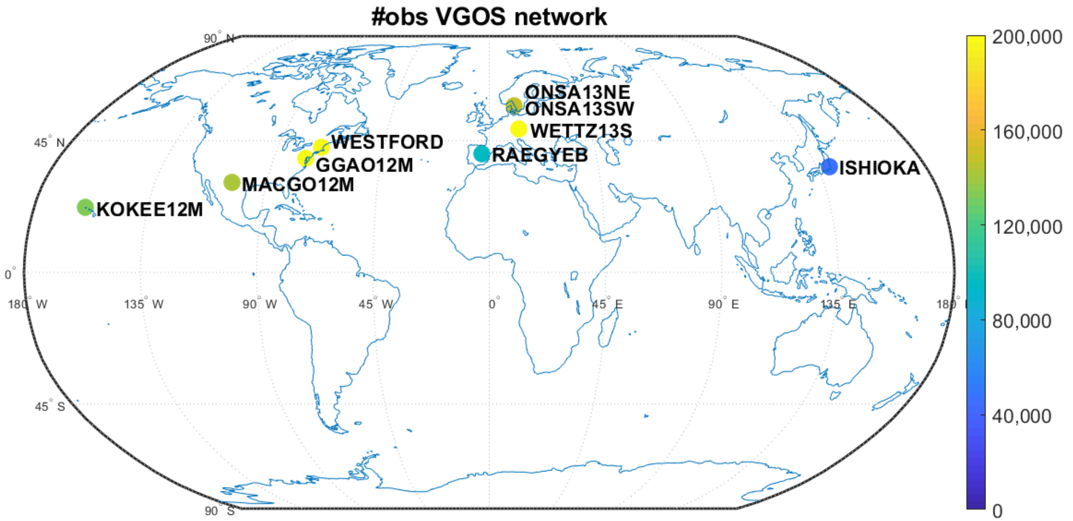
- Generally, there are more observations and smaller post-fit residuals in the VGOS sessions (compare figure).

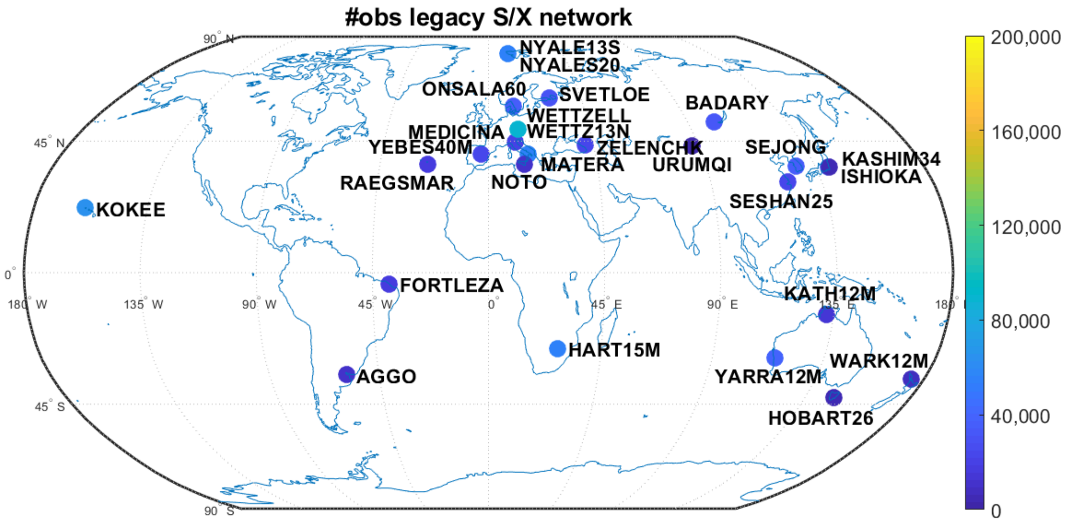
- There are no sessions between 20APR14VG and 20MAY26VG. 21NOV23VG and 21DEC09VG are not available yet.

- For the ITRS realization 2020, basically the VGOS sessions up to March 2020 have been included.



VGOS vs. legacy S/X station networks

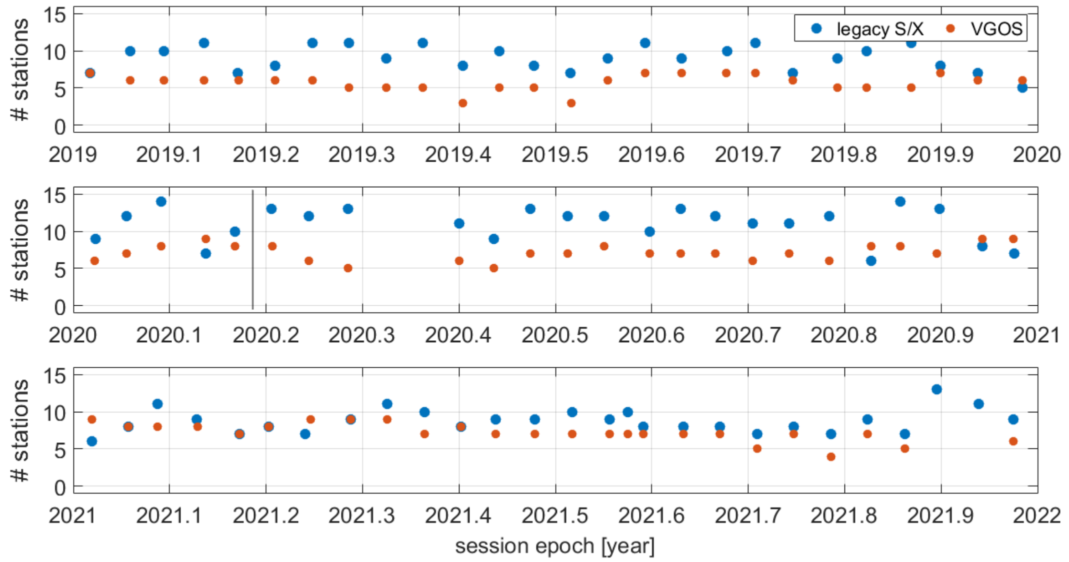




- At the end of 2021, the operational VGOS network consists of 9 stations and is only covering the Northern hemisphere (top left figure). Usually, less than 9 stations participate in a session.

- In contrast, the accompanying legacy S/X sessions generally contain larger networks (10+ stations) with a much better global coverage, compiled from a total of 26 stations (top right and bottom right figures).

- However, the VGOS stations collected more observations.



Comparison of VGOS and legacy S/X results

- In summary, the VGOS sessions contain more observations, both in total and per antenna. Furthermore, the broadband measurements are more precise than the measurements in the legacy S/X bands. However, the VGOS station network is inferior, apparently.

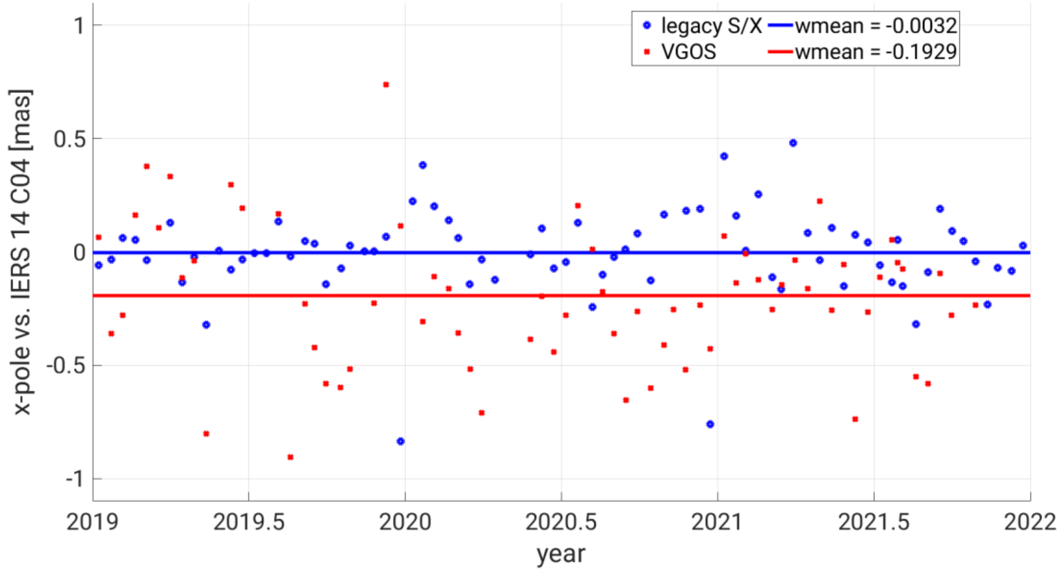
- To compare the geodetic results, we analysed the simultaneous VGOS and legacy S/X sessions with our DGFI Orbit and Geodetic parameter estimation Software (DOGS), in particular DOGS-RI for creating VLBI normal equations and DGOS-CS for their solution:

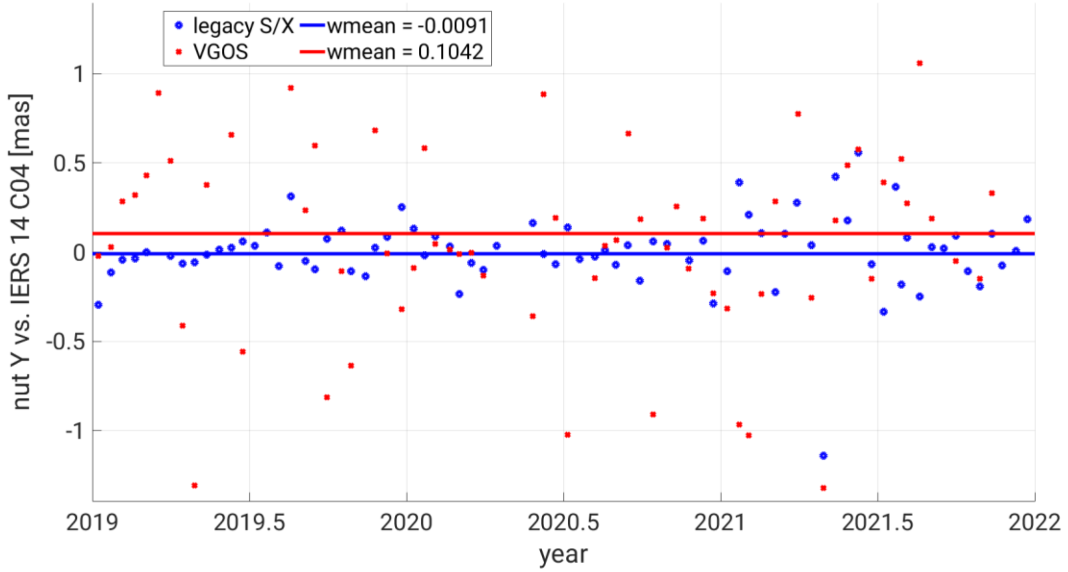
	VGOS	legacy S/X
solution type	session-wise, group delay	
default parameterization (if not listed)	dgf2020a	
non-tidal atmospheric loading	included (ESMGFZ)	
tidal ocean loading	EOT20	
a priori TRF	“DTRF2020VP“ (NOT a VGOS datum station: ISHIOKA, MACGO12M, WETTZ13S)	
a priori CRF	ICRF3 S/X (NNR w.r.t. defining sources)	
resolution tropospheric zenith delays	0.25 h	1.0 h
resolution tropospheric gradients	1.0 h	6.0 h

- “**DTRF2020VP**” is DGFI-TUM’s preliminary ITRS 2020 realization for VLBI including the VGOS sessions. The networks have been tied by:

three common stations (ISHIOKA, RAEGYEB, WESTFORD)	local ties	the combination of velocities
the combination of EOP	18 ONTIE sessions	three mixed mode sessions

EOP w.r.t. IERS 14 C04

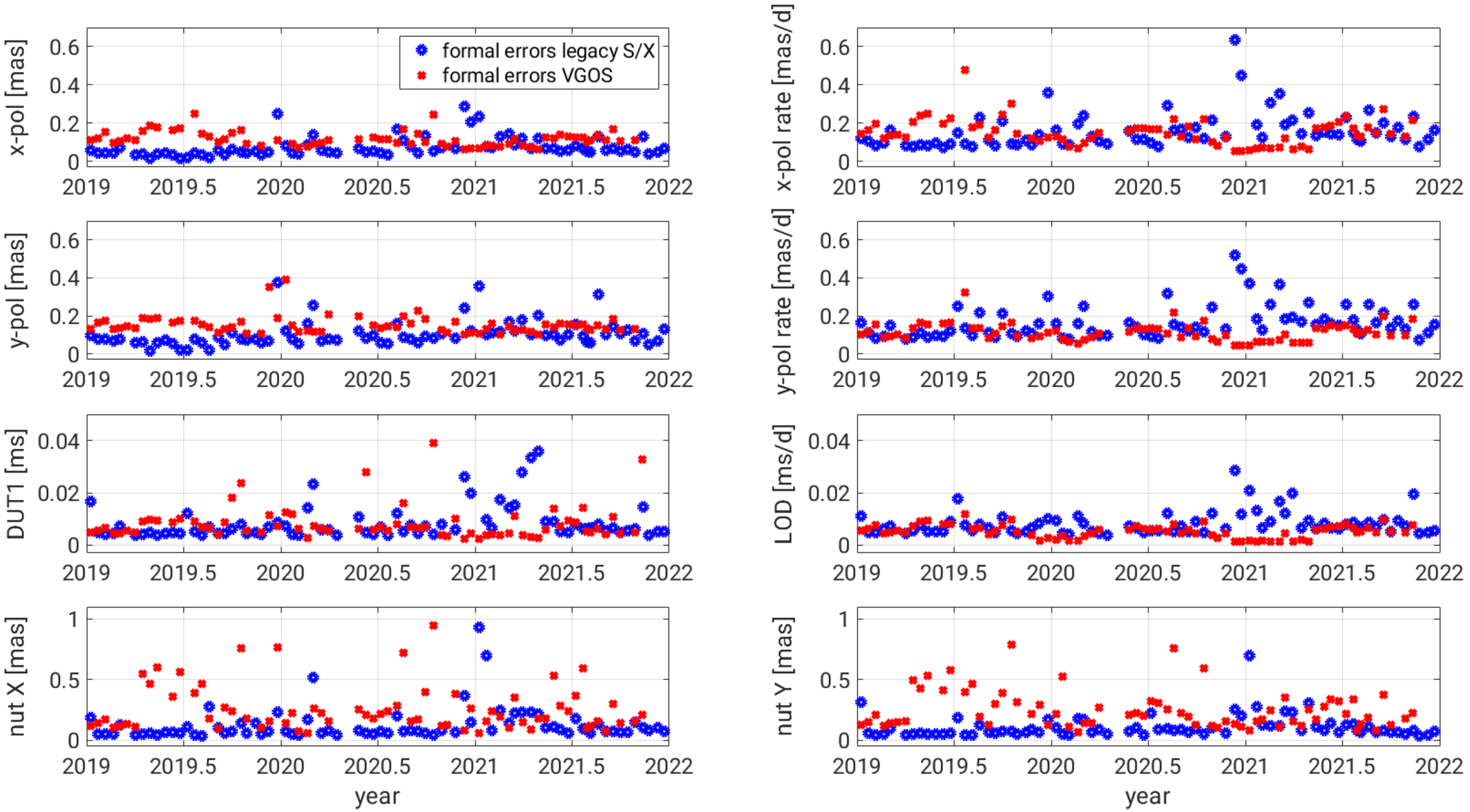




differences to IERS 14 C04	wmean legacy S/X	wmean VGOS	WRMS legacy S/X	WRMS VGOS
x-pol [µas]	-3.2	**-192.9**	107.4	**266.1**
x-pol rate [µas/d]	18.3	9.0	215.1	297.8
y-pol [µas]	-36.8	**-112.4**	115.5	**255.7**
y-pol rate [µas/d]	-14.7	**116.3**	222.7	285.0
DUT1 [µs]	9.0	5.1	10.9	13.8
LOD [µs/d]	2.1	6.4	16.2	14.6
nut X [µas]	-8.7	-1.7	109.7	**454.1**
nut Y [µas]	-9.1	**104.2**	109.6	**443.9**

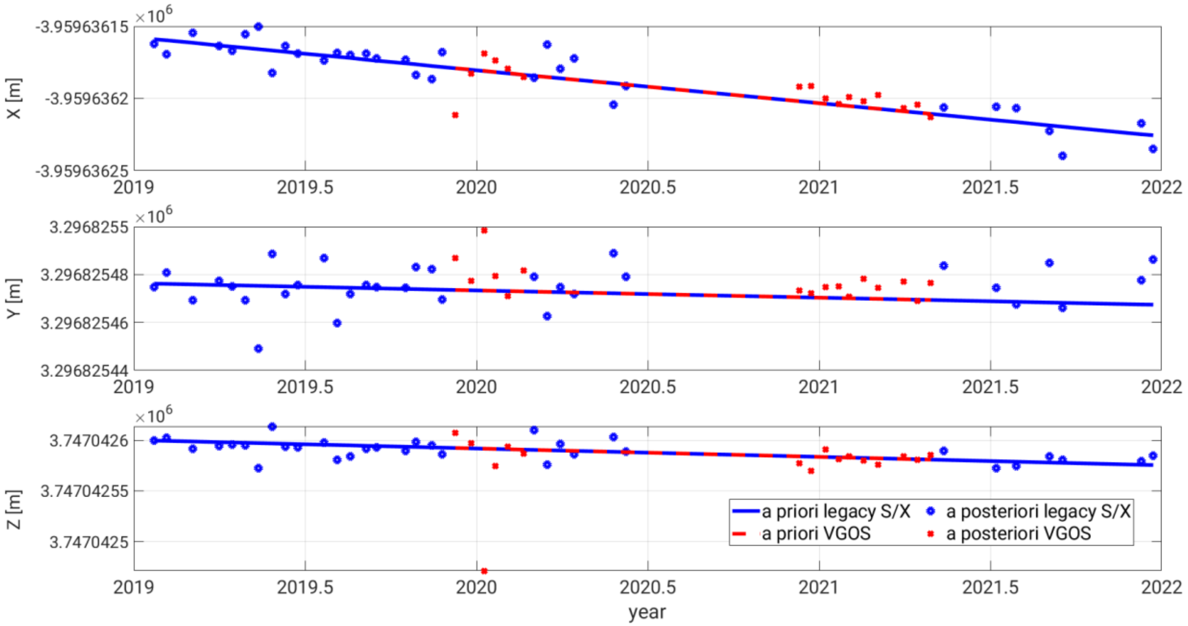
- We observe offsets w.r.t. IERS 14 C04 for the terrestrial and celestial poles in the VGOS sessions. Its size also depends on the chosen datum stations (not shown here).
- This might be due to the restricted station network, or to a residual rotation between VGOS and legacy networks in the "DTRF2020VP".
- The WRMS values of the differences w.r.t. the IERS 14 C04 series are generally larger for VGOS, especially for nutation.

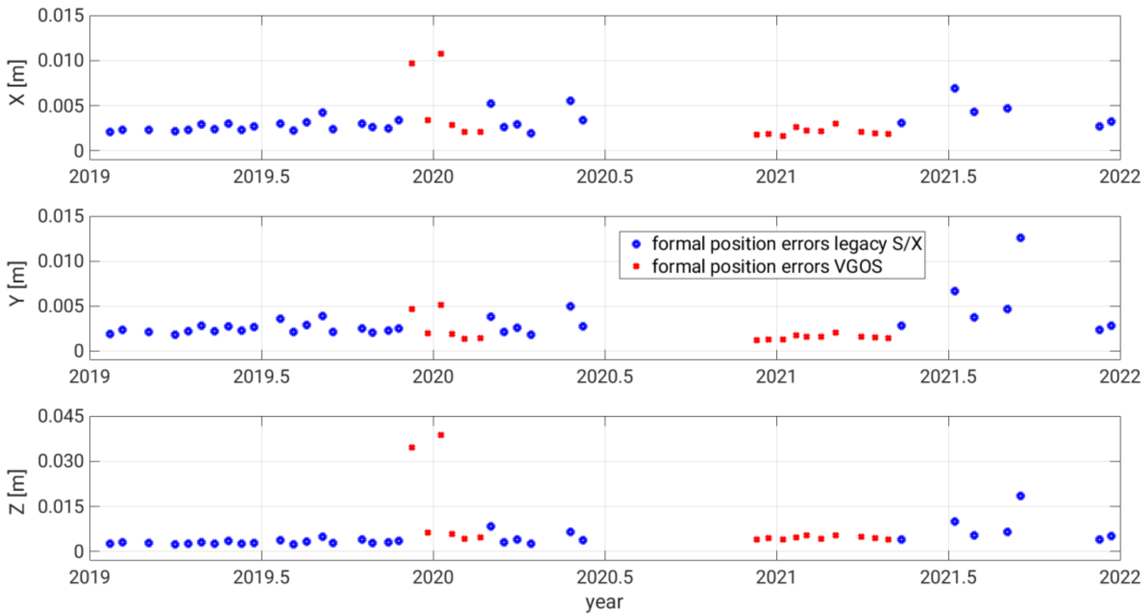
Formal errors: EOP



- The formal errors for the estimated EOP seem to be larger for the VGOS sessions, but the patterns are quite diverse.
- In the period from end of 2020 to mid of 2021 (compare the EOP rates), ISHIOKA is performing VGOS observations.

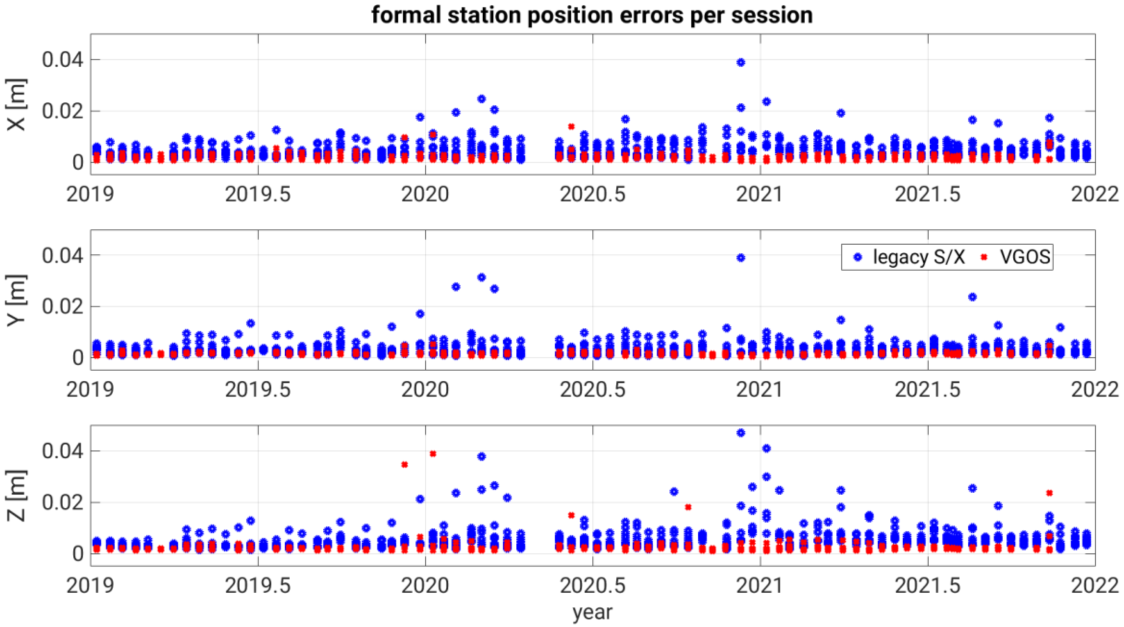
ISHIOKA participates in both session types

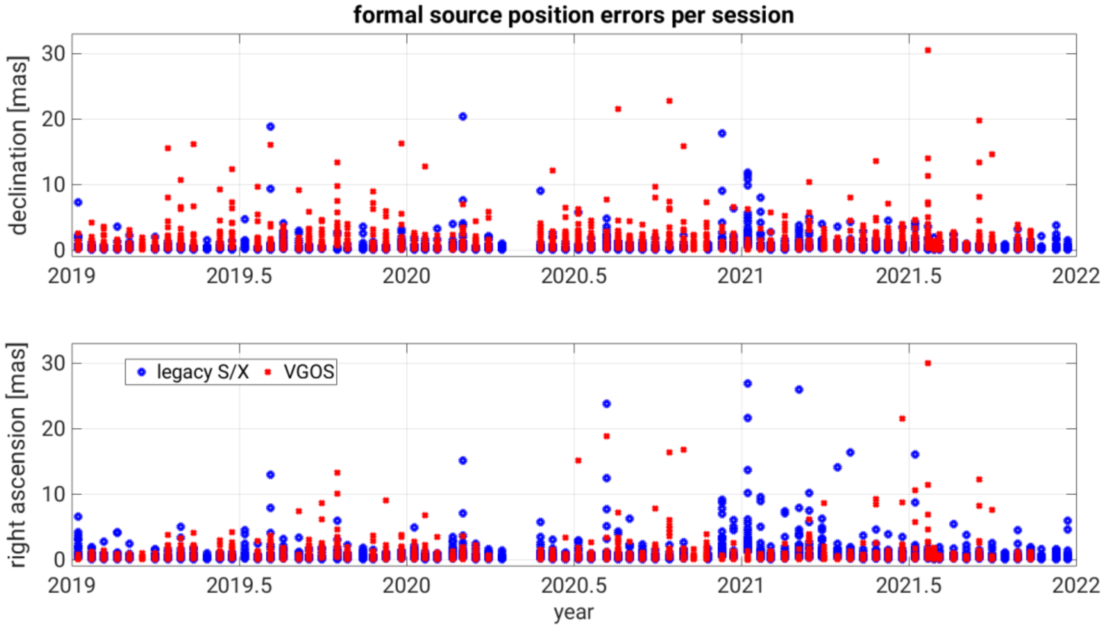




- ISHIOKA has been switching back and forth between legacy S/X and VGOS sessions.
- Looking at the VGOS station network, ISHIOKA is significantly improving the network geometry and in particular the sky coverage in connection with the KOKEE12M station. This might explain the lower formal errors of the EOP rates when ISHIOKA participates.
- The estimated station coordinates (ISHIOKA is not included in our geodetic datum) do not reveal a significant difference between VGOS and legacy S/X positions (left figure). The formal position errors appear to be slightly smaller in the recent VGOS sessions (right figure).

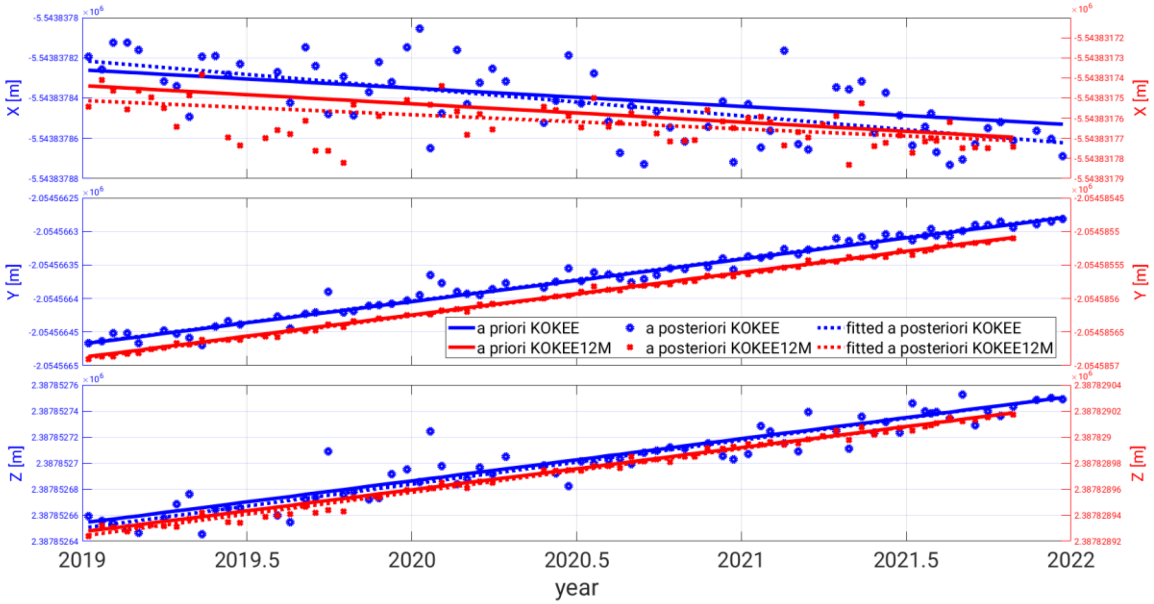
Formal errors: station and source coordinates





- The formal errors of the VGOS group delays are significantly smaller than those of the legacy S/X group delays (e.g., Niell et al., 2018).
- This is transferred to the formal errors of the estimated station positions (left figure): in general, the formal errors are smaller for the VGOS sessions / stations.
- However, as we saw above, this does not necessarily hold for the EOP.
- For the source coordinates, the formal errors of the VGOS sessions appear to be at least as large as those of their legacy counterparts, especially for the declination parameters (right figure).

VGOS / legacy co-location sites: station velocities



- The combined station velocities of "DTRF2020VP" at co-location sites are basically equal, of course (solid lines in figure, grey rows in table).

fitted (#sess.)	KOKEE (71)	KOKEE12M (66)	ONSALA60 (17)	ONSA13NE (64)	ONSA13SW (55)	WETTZELL (63)	WETTZ13S (66)	YEBES40M (17)	RAEGYEB (35)
VELX [mm/y]									
in DTRF2020VP	-9.089	-9.094	-13.866	-13.857	-13.860	-15.701	-15.701	-10.692	-10.701
VELY [mm/y]									
in DTRF2020VP	63.279	63.282	14.569	14.574	14.572	17.069	17.069	19.355	19.355
VELZ [mm/y]									
in DTRF2020VP	32.364	32.366	10.975	10.990	10.978	10.477	10.477	11.740	11.730

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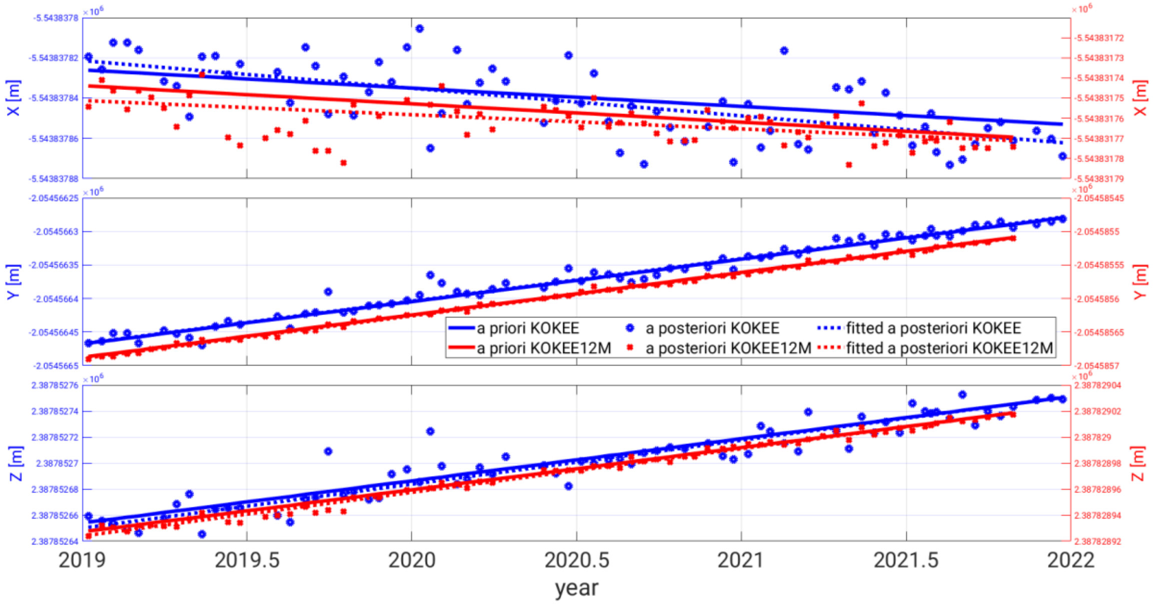

- The combined station velocities of “DTRF2020VP” at co-location sites are basically equal, of course (solid lines in figure, grey rows in table).
- The velocities fitted to the a posteriori positions of our session-wise solutions partly differ strongly, however (dashed lines, black rows).
- Amongst others, this is due to the short / sparse observation periods.

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VELX [mm/y]	-13.718	-7.061	-11.525	-15.273	-15.354	-15.961	-17.030	-10.052	-9.550
in DTRF2020VP	-9.089	-9.094	-13.866	-13.857	-13.860	-15.701	-15.701	-10.692	-10.701
VELY [mm/y]	63.466	63.602	14.550	13.829	13.365	17.419	16.713	20.469	19.587
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VELZ [mm/y]	33.744	33.522	8.276	10.129	9.246	10.226	8.141	9.192	14.625
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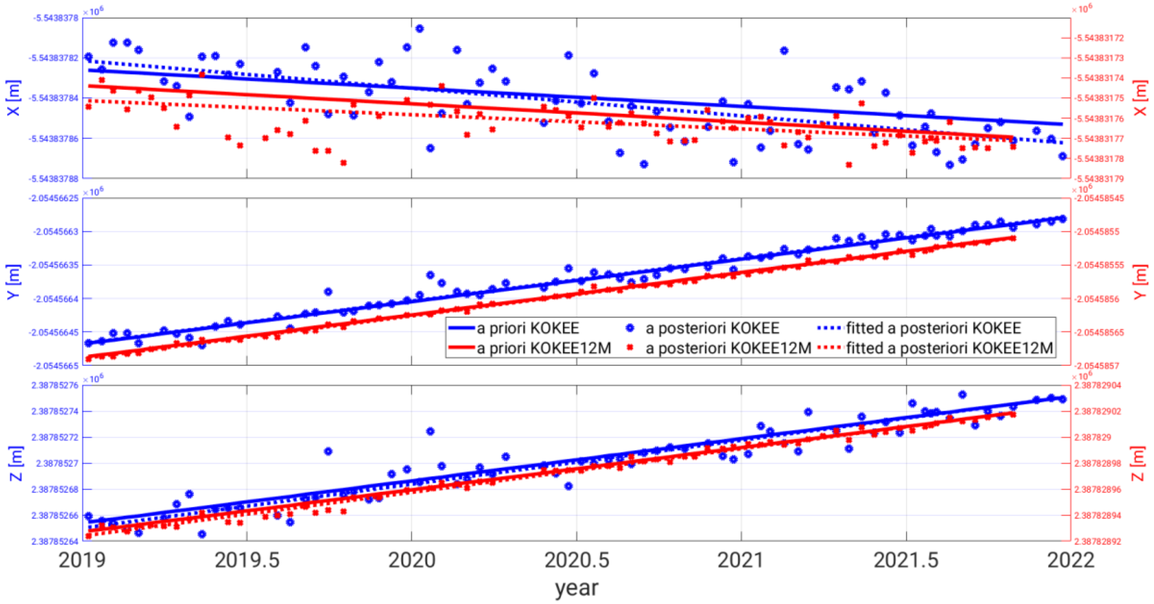

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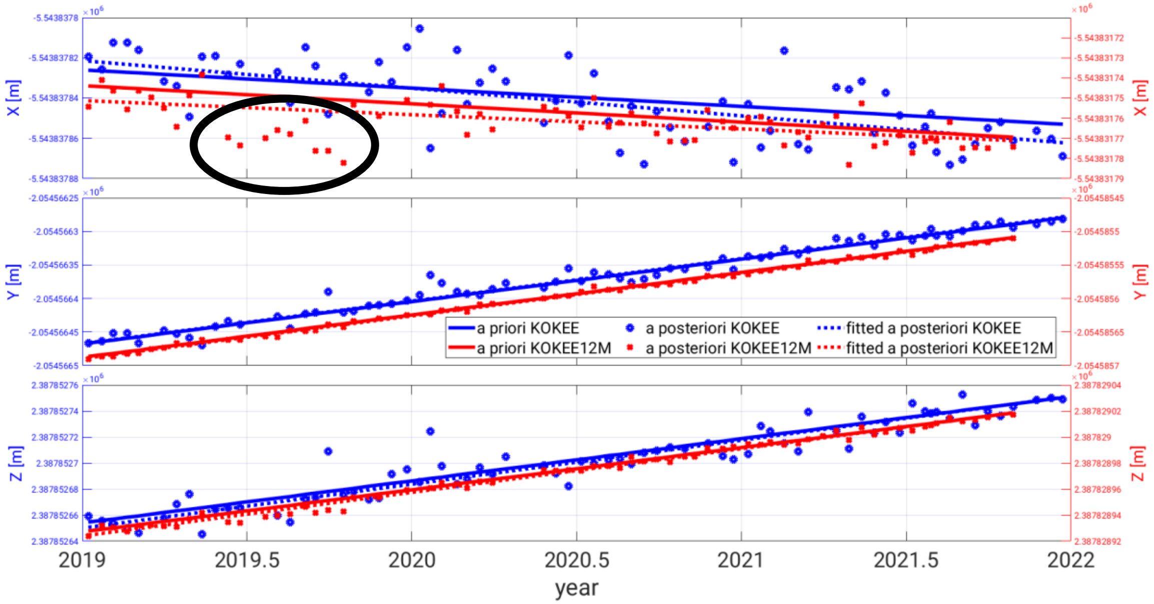

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- The velocities fitted to the a posteriori positions of our session-wise solutions partly differ strongly, however (dashed lines, black rows).
- Amongst others, this is due to the short / sparse observation periods.
- The marked sessions do NOT include ISHIOKA. If we remove them, KOKEE12M’s fitted VELX gets much closer to its a priori (“DTRF2020VP”) value.

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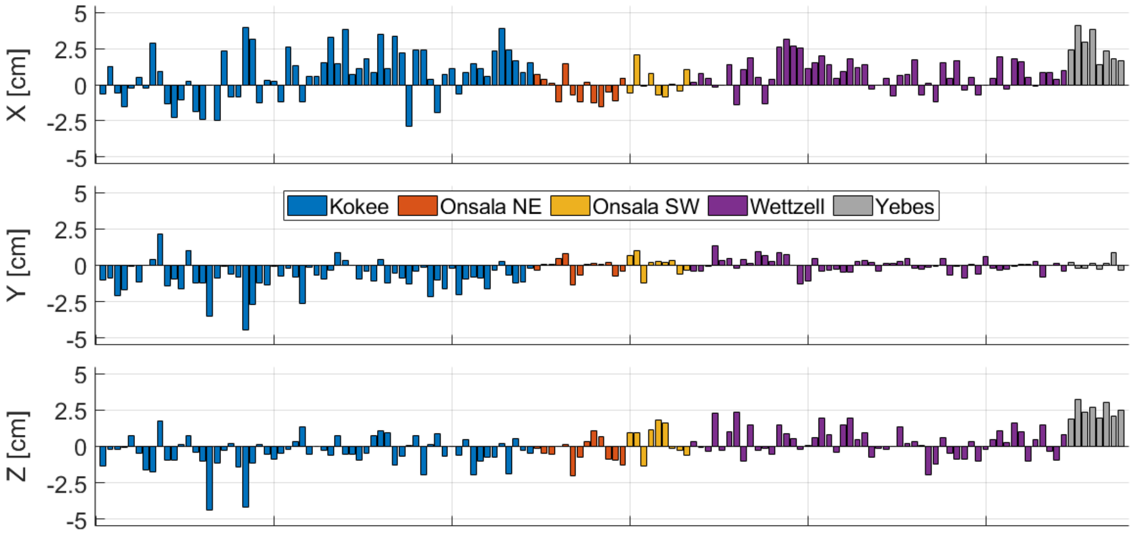
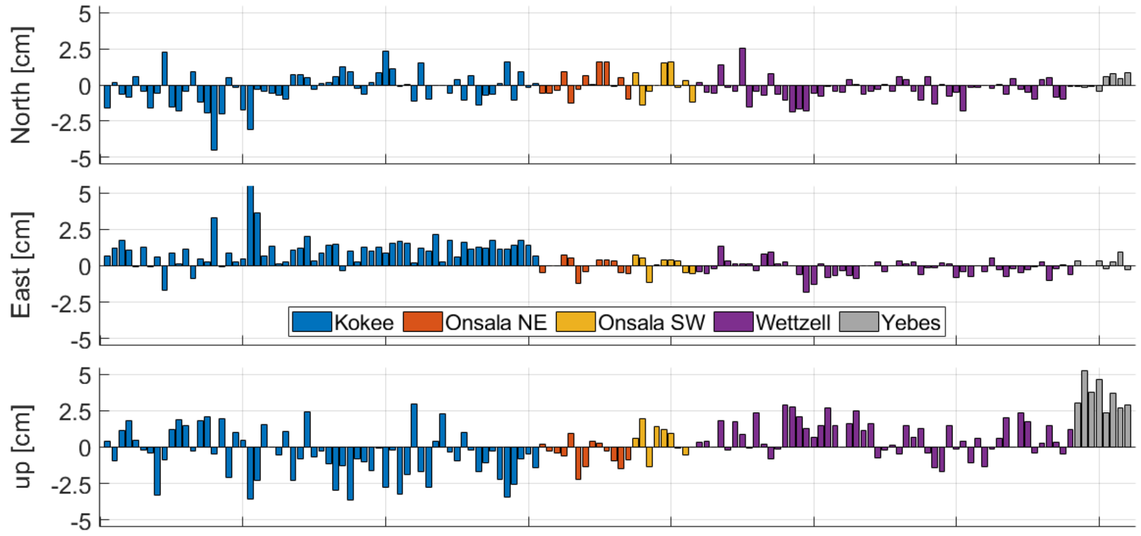
VGOS / legacy co-location sites: local ties (LT)





- We computed "cross-session" local ties for all epochs t with both a VGOS and a legacy S/X session containing a co-location site, and compared them to the official local ties:

$$\left(S_i^{VGOS}(t) - S_i^{legacy}(t)\right) - LT_i \,, \qquad (1)$$

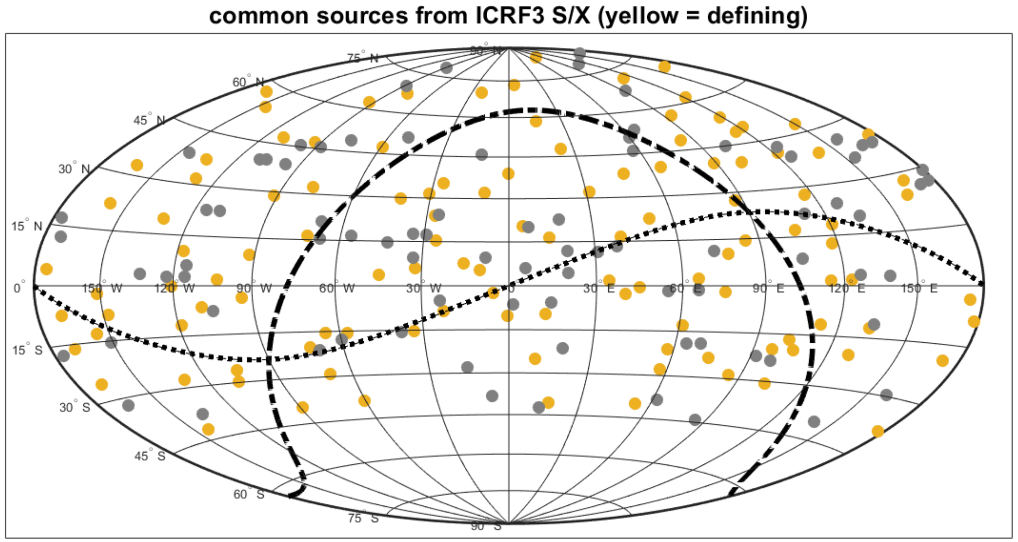
with the S_i $(i = X, Y, Z)$ representing the estimated station coordinates per session.

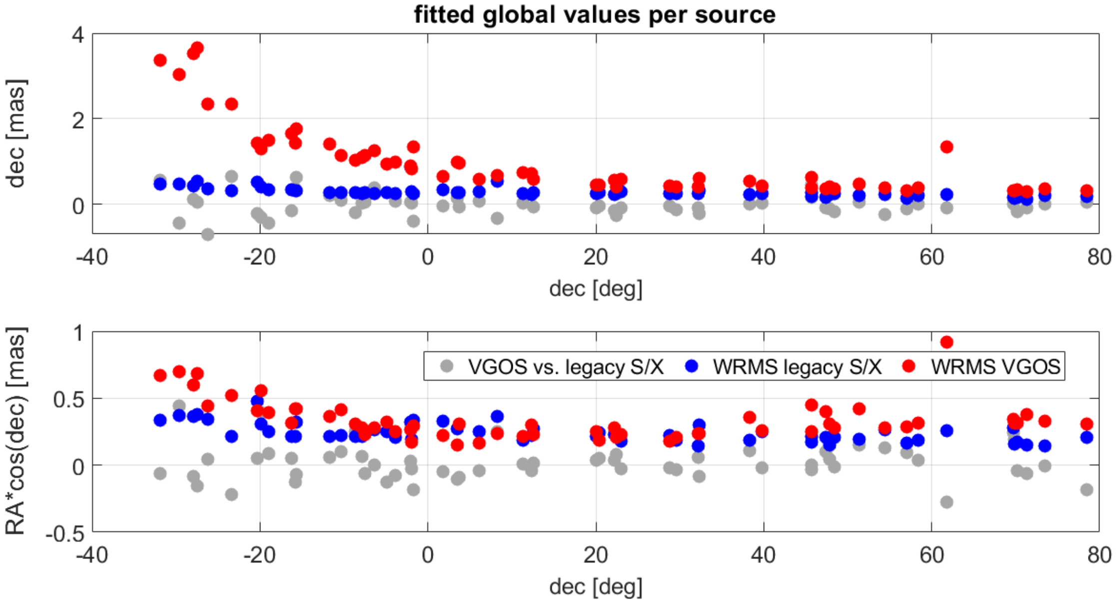
- This measure is quite noisy, but the differences (1) in XYZ (left figure) and NEU (right figure) might indicate a systematic discrepancy for Yebes (legacy, VGOS, LT?) in the up component and maybe Kokee in the Y / East component.

- Do the many positive offsets for X across stations indicate a small X-translation between our combined VGOS and legacy S/X networks?

Source positions

- There are 203 sources which have been observed in both VGOS and legacy S/X sessions (top figure).
- Our a priori CRF for both observation modes is ICRF3 S/X. However, VGOS actually measures in broadband, and source positions are frequency and time dependent.
- Out of the 203 common sources,
  - 116 are ICRF3 S/X defining sources, and
  - 58 are contained in at least 20 sessions for both observation modes.
- We fitted constant coordinates at epoch 2015.0 (the ICRF3 reference epoch) to the estimated source coordinates of the VGOS and legacy S/X sessions, respectively.
- The bottom figure (referring to the 58 most observed sources) shows that the fitted coordinates actually differ between VGOS and legacy S/X, but the differences are generally smaller than the scatter of the estimated source coordinates (which is generally larger for VGOS).
- The next slide shows an example: source 0202+319





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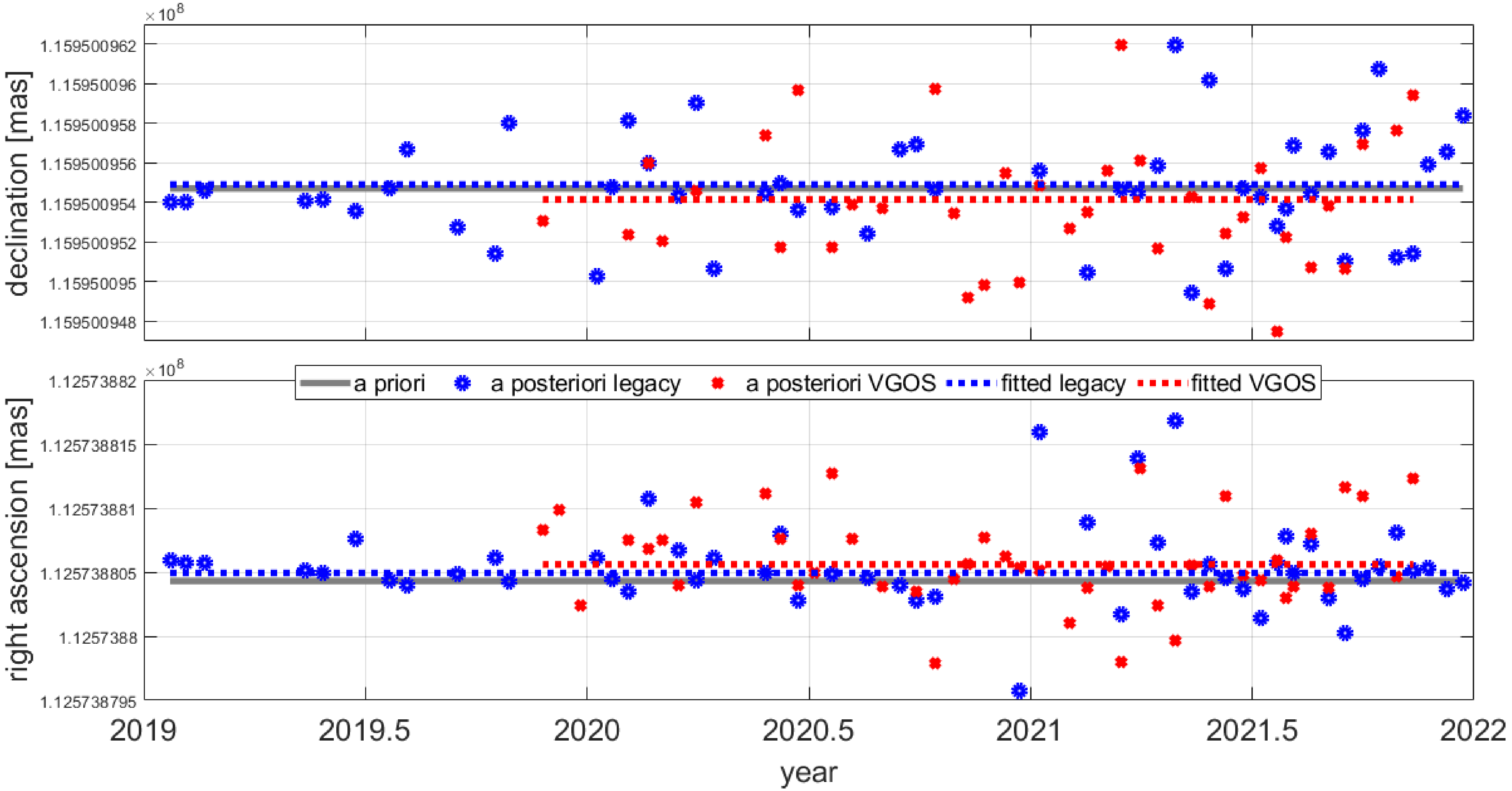

Summary

- Even though the VGOS station network does not contain Southern hemisphere stations, the corresponding sessions already provide promising geodetic results.
- Nevertheless, we observe some discrepancies w.r.t. the results obtained with the legacy S/X sessions, in particular for polar motion (and nutation) and fitted station velocities.
- Potential reasons: the network distribution (also: ISHIOKA in or out), the preliminary a priori TRF, the short observation history, the choice of datum stations, handling of local ties, ...
- The broadband nature of VGOS gives rise to potential source position offsets w.r.t. the legacy S/X observations. However, we could not determine statistically significant offsets yet.
- To conclude, the combination of VGOS and legacy S/X observations and networks needs further research, but the combination of source positions seems feasible.

References

- Niell A., Barrett J., Burns A., et al. (2018): **Demonstration of a Broadband Verly Long Baseline Interferometer System: A New Instrument for High-Precision Space Geodesy**. Radio Science, 53, pp. 1269-1291.

- Niell A., Barrett J., Capallo R, et al. (2021): **VLBI measurement of the vector baseline between geodetic antennas at Kokee Park Geophysical Observatory, Hawaii**. Journal of Geodesy, 95:65.