First Results K2-Ws VGOS Intensives

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First Lesson

The author list says it all:

VLBI is a collaborative effort

- Schedulers
- Station Personnel
- Correlators
- Analysts
- Folks who provide the money!

Preview

Look at 2 networks:

Kokee-Wettzell (S/X)

Kokee12M-Wettzell13S (VGOS)

Beginning on 2021-01-01 began scheduling K2-Ws intensives at the same time as normal Kk-Wz intensives.

Motivation:

VGOS antennas move faster, resulting in more observations. This should improve the results. Does it?

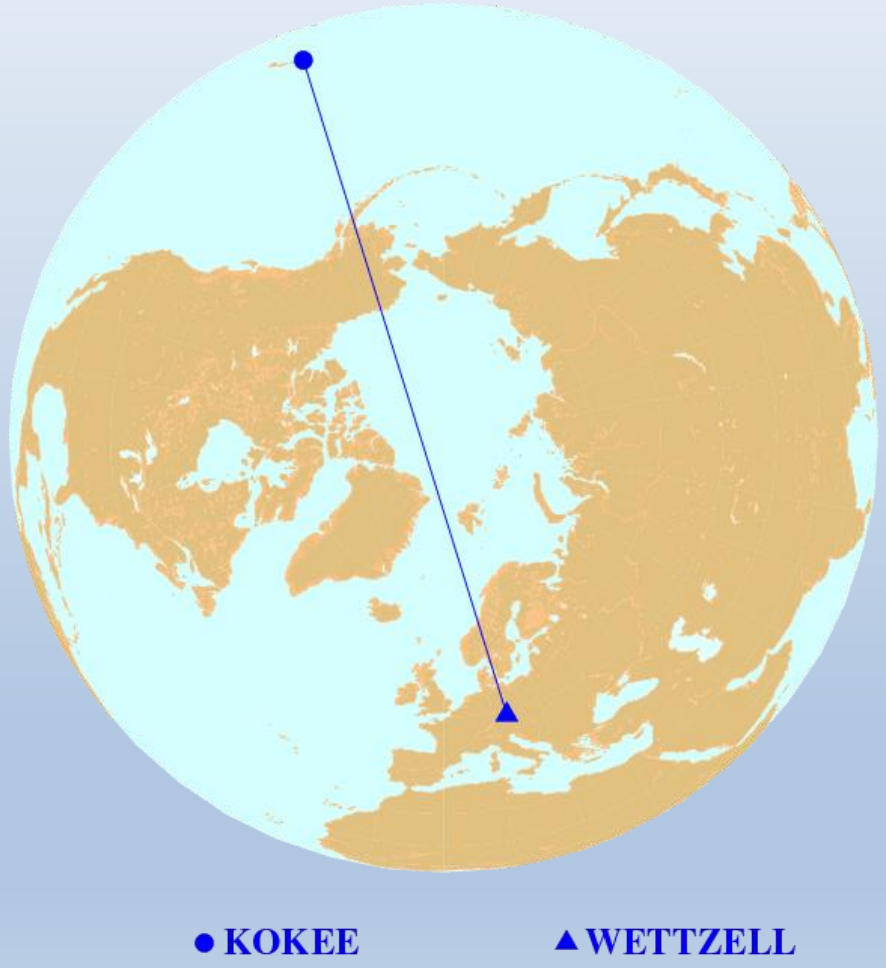
Question:

- How do VGOS-Ints compare to standard S/X intensives?
- How do they compare to the R1/R4
- How do they compare to external series (JPL (thanks Richard!)

Alternative Analysis Strategies

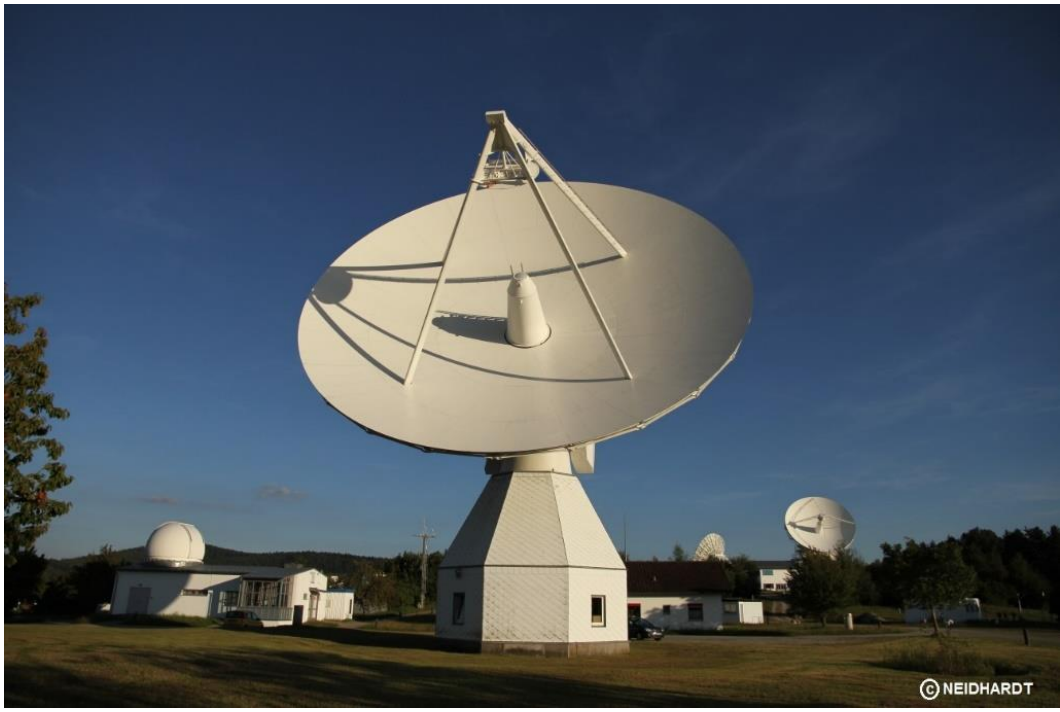
The Baseline

Intensives require long E-W baselines to measure UT1.



Team One: Grizzled Veterans

Kokee



Wettzell

Team Two: The New Kids

Kokee12M

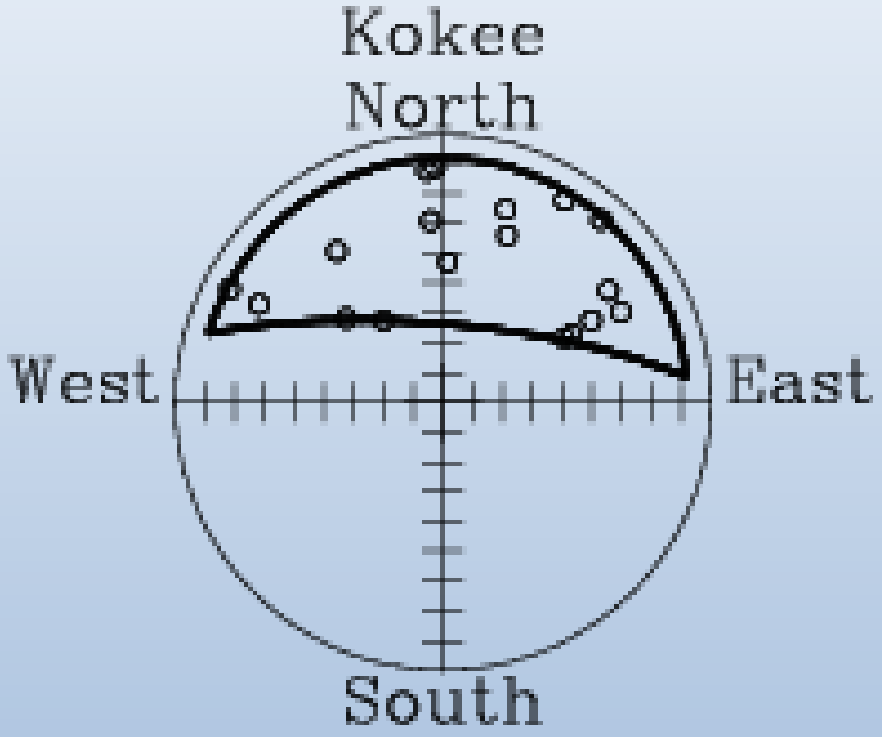
Wettzell13S

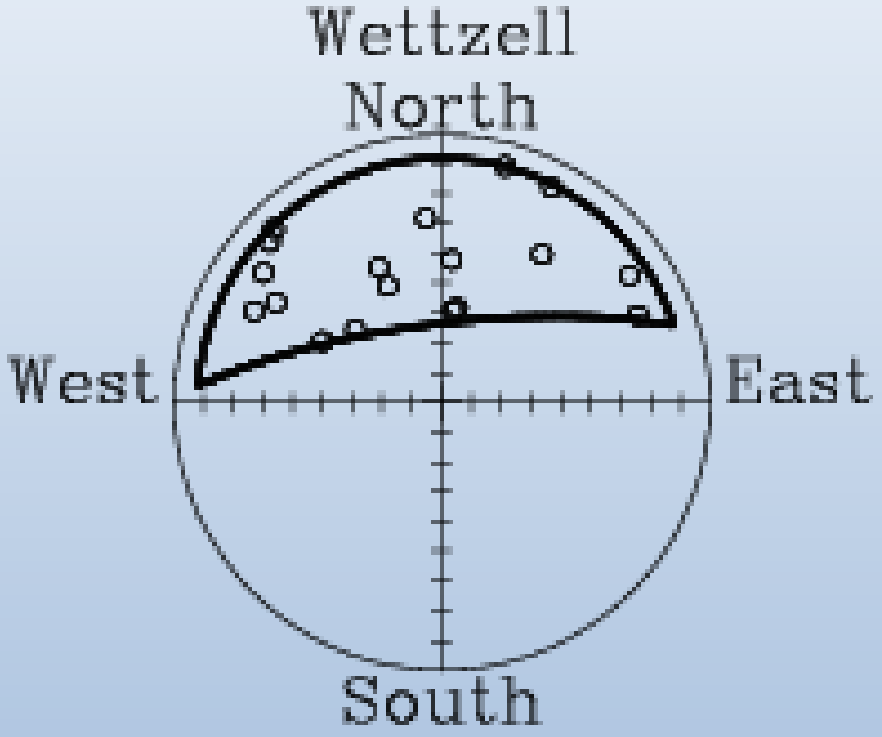
Comparison

	Kokee	Wettzell	Kokee12M	Wettzell13M
Size	20M	20M	12M	13M
SEFD	2000 750	750 1115	3000 3000	1400 1050
Band	S/X	S/X	Broadband	Broadband
Mbps	128		8192	
Az slew (deg/sec)	2	3	5	12
El slew (deg/sec)	2	1.5	1.1	6

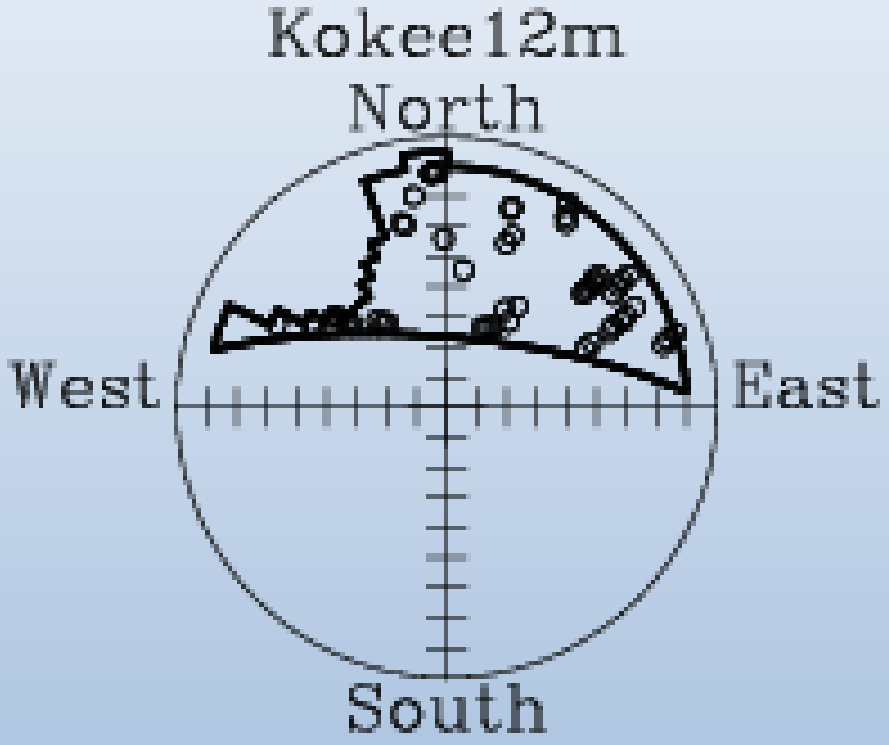
VGOS antennas make up for higher SEFDs by collecting more bits.

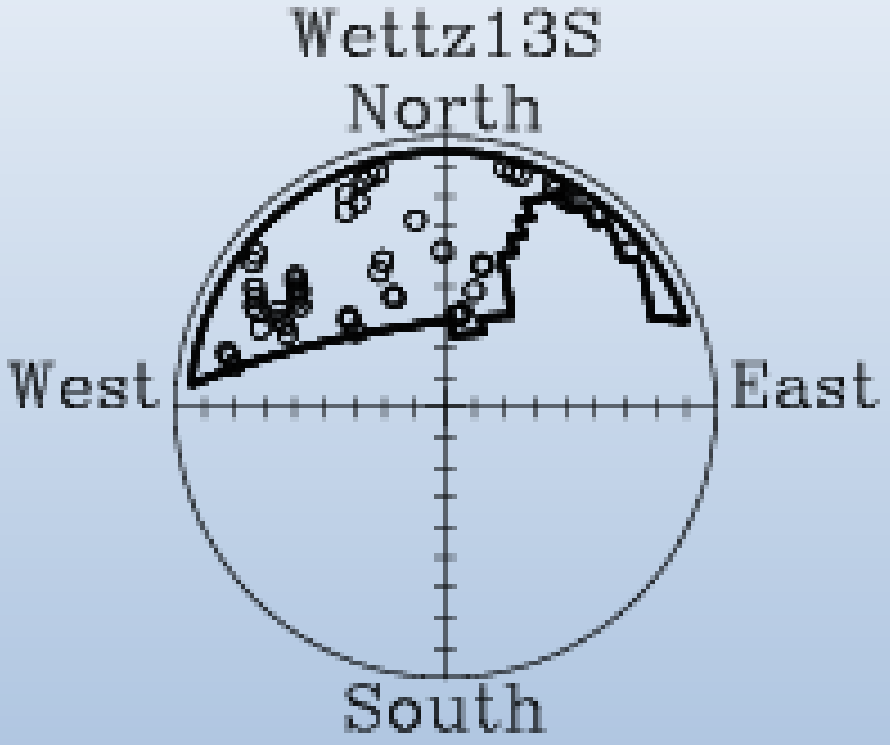
Typical Schedule Kokee-Wettzell





Typical Schedule Kokee12-Wettzell13S





Bite missing in the corner is due to Kokee 20M

Do Standard Analysis

Data for each session is reweighted until $\chi^2 \cong 1$.

$$\sigma_j^2 = \sigma_{j,meas}^2 + \sigma_{rewt}^2$$

Same constant is added to all observations in a session

Estimate

1. Atm offset at Kokee
2. Atm offset at Wettzell
3. Clk offset at Wettzell
4. Clk rate at Wettzell
5. Clk^2 at Wettzell
6. UT1

Data Sets

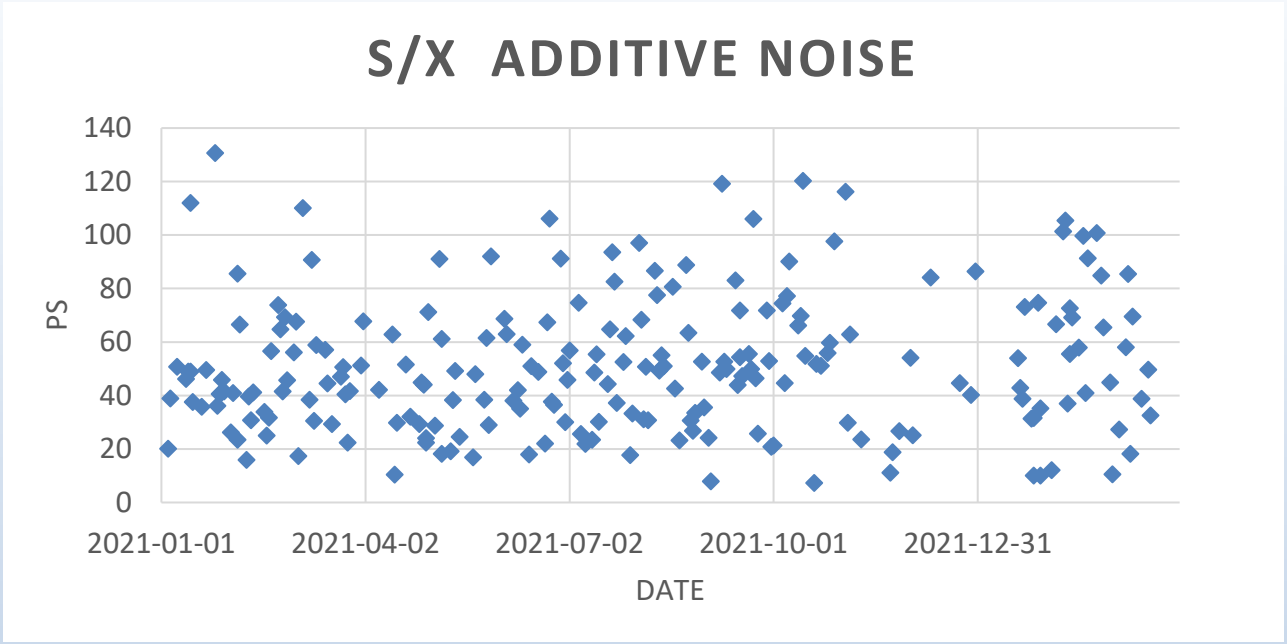
	Span	Band	Comments
KOKEE-WETTZELL	2021-01-01 to 2022-03-25	S/X	Only look at Kk-Ws
KOKEE12M-WETTZ13S	2021-01-01 to 2022-01-25	VGOS	Scheduled at same time as INT01
KOKEE12M-WETTZ13S	2022-01-31 to 2022-03-25	VGOS	Scheduled at same time as INT01 Lower SNR targets, shorter scans
Rapids	2021-01-04 to 2022-03-14	S/X	Use all R1/R4s within 1-day of intensives

S/X intensives scheduled by Merri Sue Carter of USNO

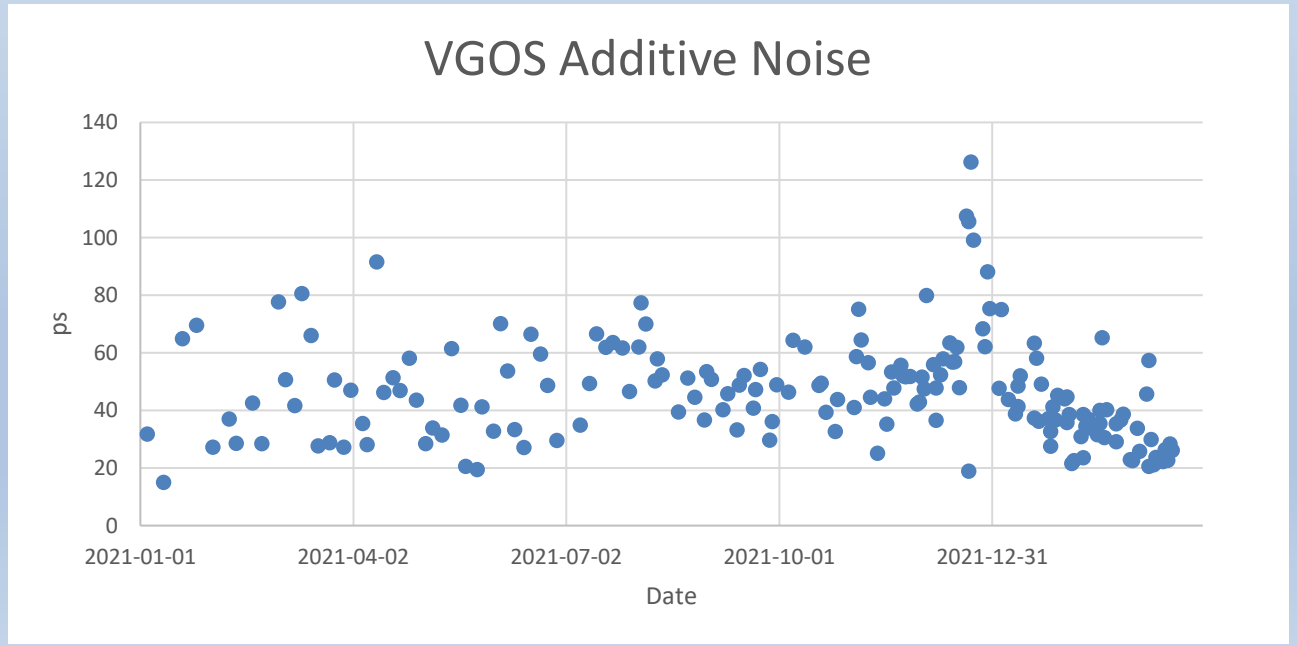
VGOS intensives scheduled by Karen Baver of NVI/GSFC.
See her poster at this meeting!

R1 done by Cynthia Thomas (NVI/GSFC). R4 by Merri Sue Carter.

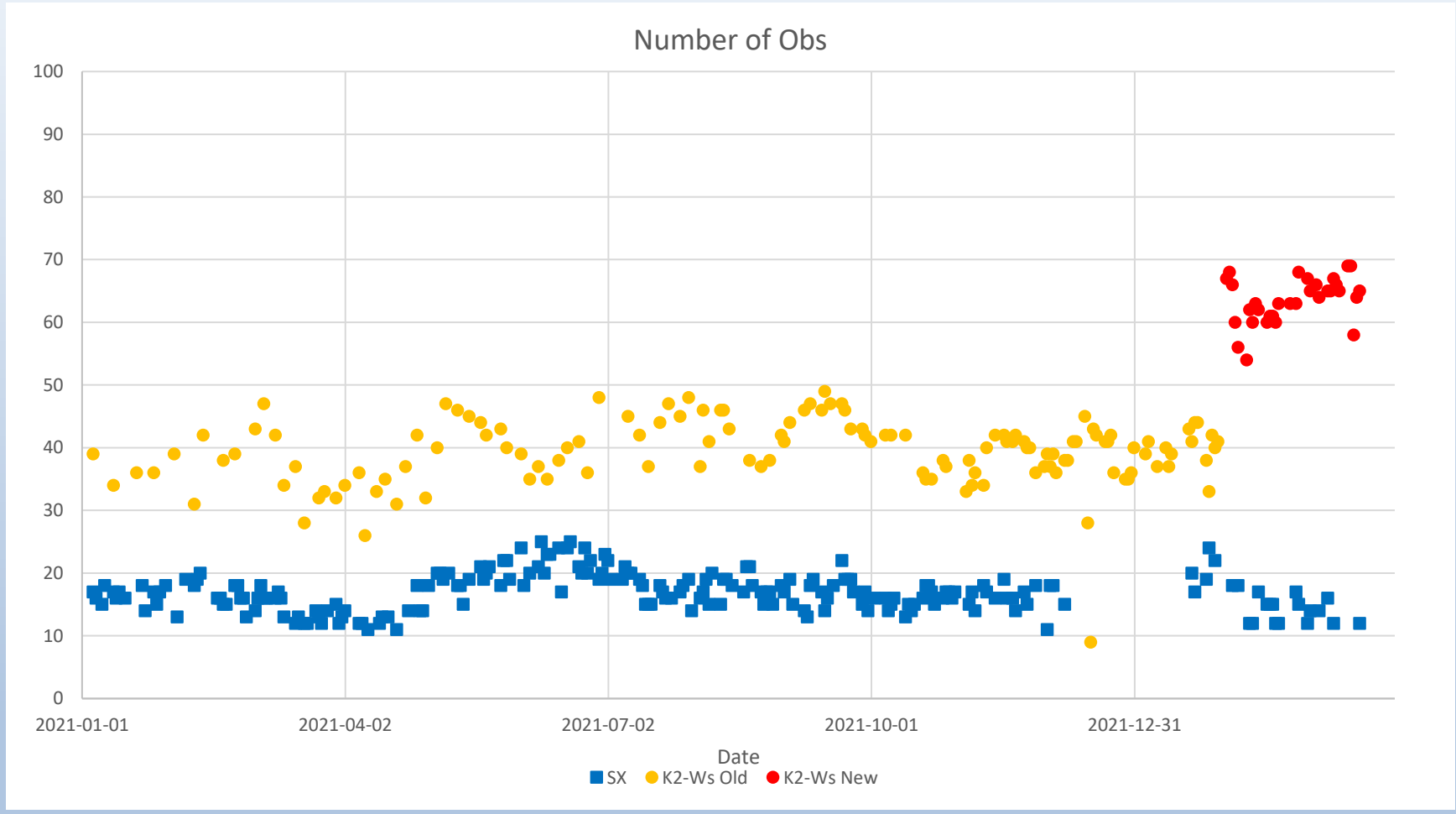
Keep only good data.
Discard all sessions with #obs <10 or Sigma >40



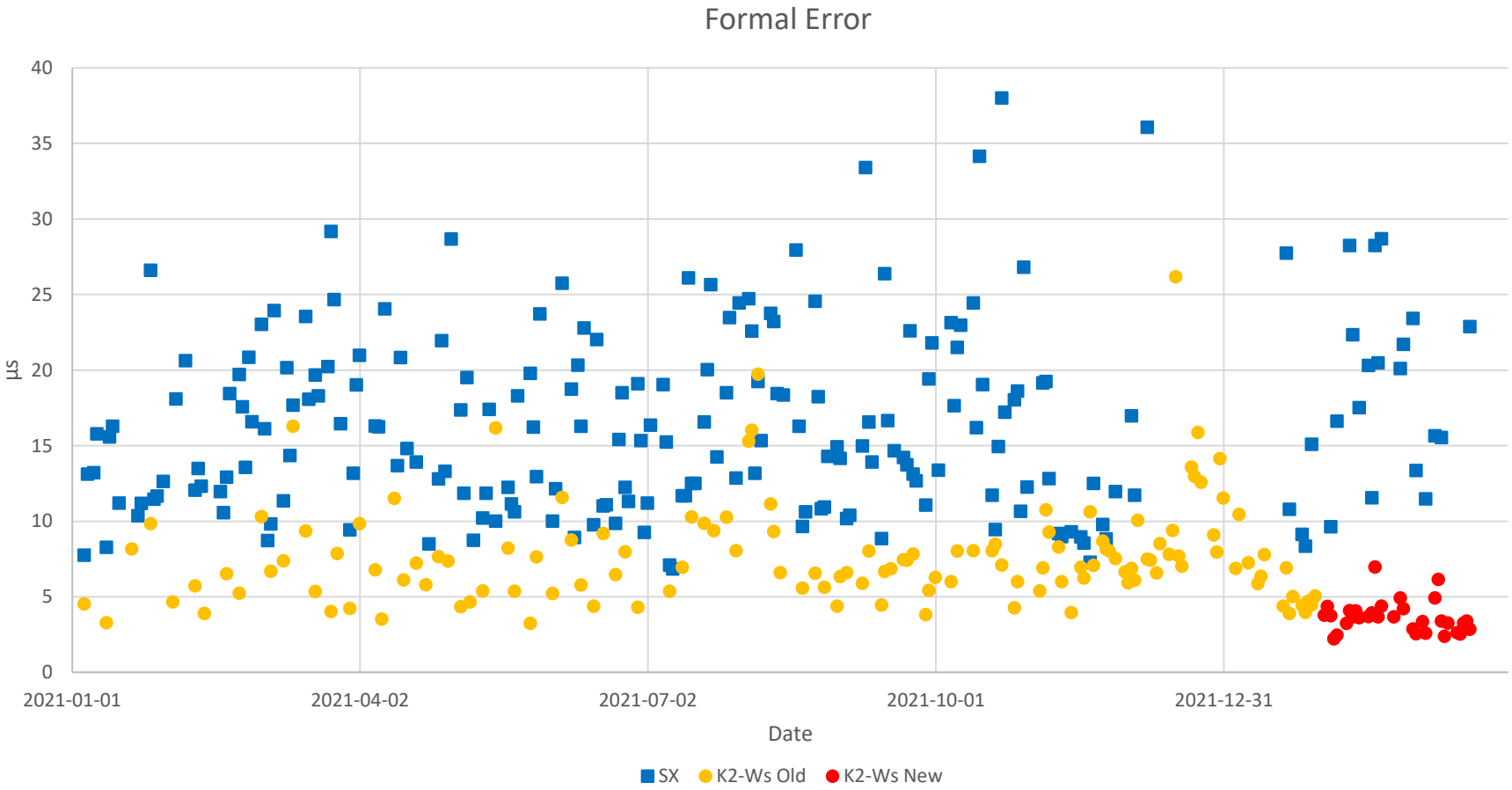
This means there is unmodeled noise during the session.



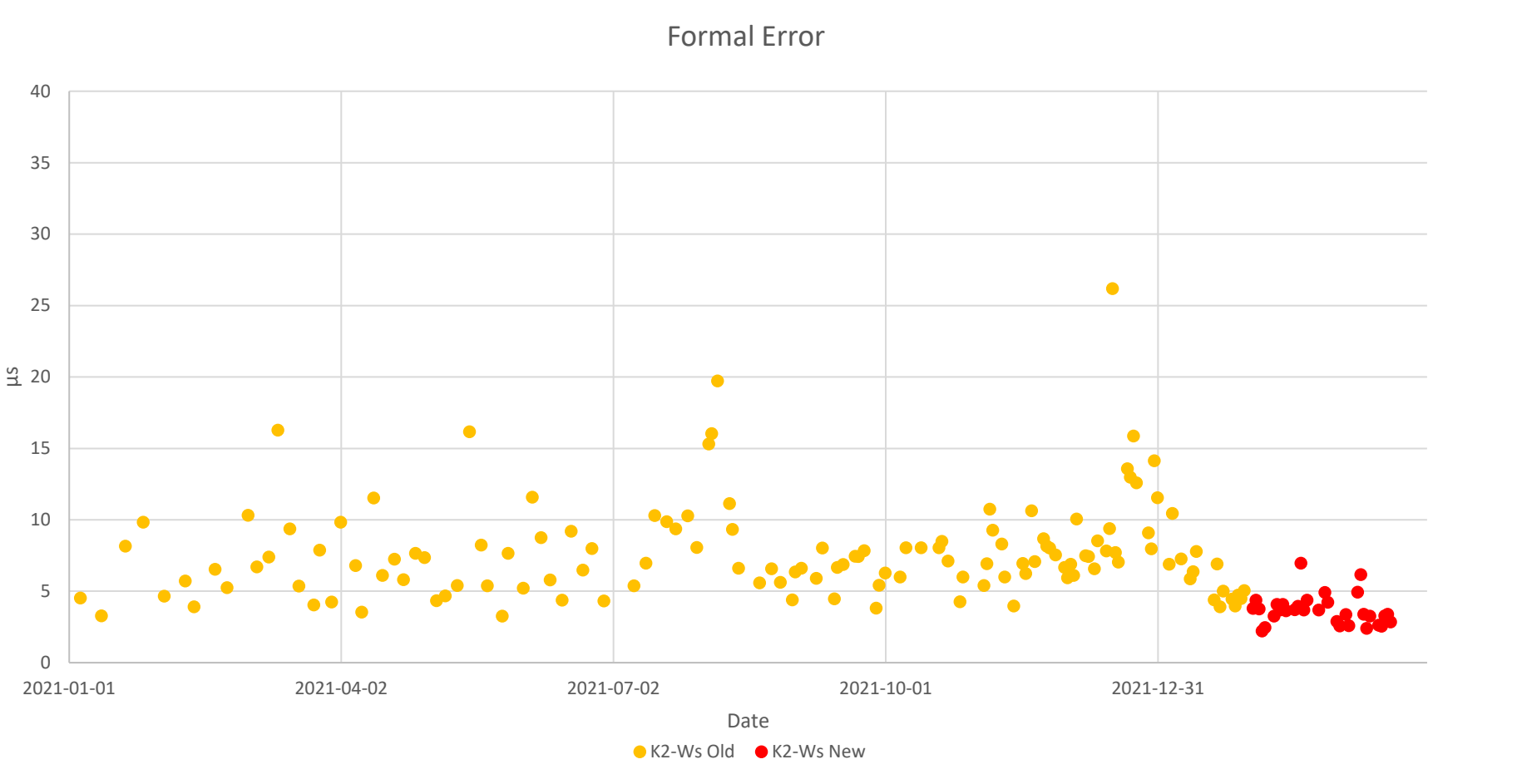
Number of Observations



Formal Errors: S/X & VGOS



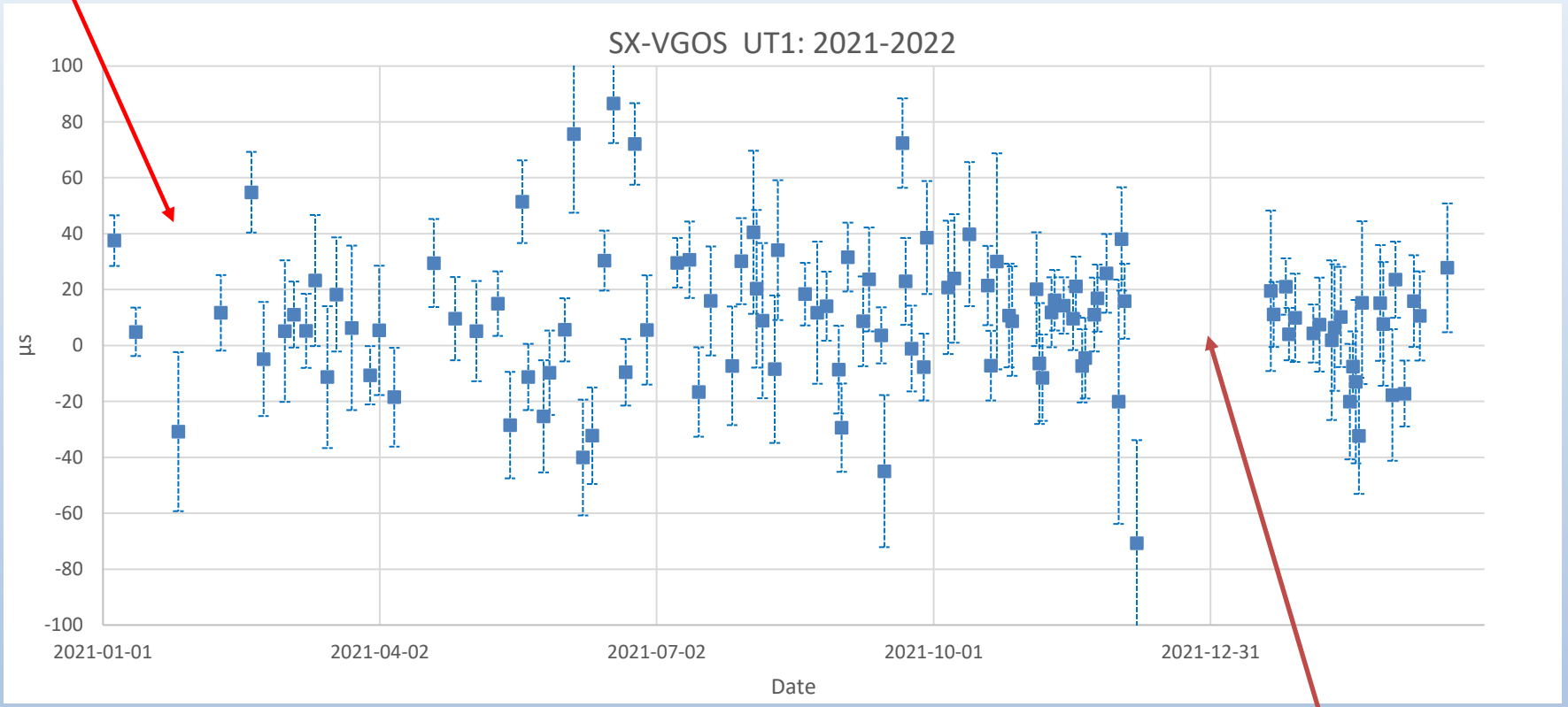
Formal Errors: VGOS Only



Formal error of VGOS Intensives is ~ a few µs. Is this realistic?

Fewer VGOS at start

Comparison of S/X vs VGOS



All units µs

S/X –VGOS UT1				
	#	Average	StdDev	Expected
Summary	109	9.3	24.6	19.5

Gap because fiberoptics was down at Kokee

More unmodeled Error

Actual scatter: $\sigma_{Actual} = \sqrt{\frac{1}{N_{sess}}\sum \Delta UT1_j^2 - \left[\frac{1}{N_{sess}}\sum_j \Delta UT1_j\right]^2} = 24.6\mu s$

Expected scatter: $\sigma_{Expected} = \sqrt{\frac{1}{N_{sess}}\sum_j \sigma_{j,FE}^2} = 19.5\mu s$

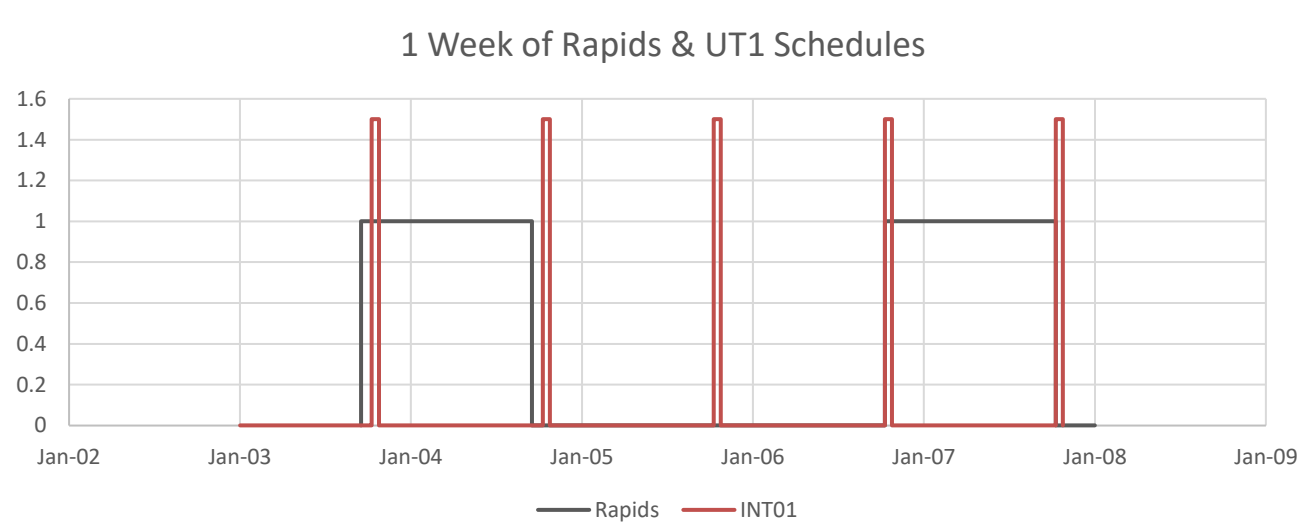
Unmodeled error: $\sigma_{Unmodeled} = \sqrt{\sigma_{Actual}^2 - \sigma_{Expected}^2} = 15.0\mu s$

Unmodeled error is as large as modeled error (after reweighting).

Where does this come from? Atmosphere? Sources?

Comparison of S/X vs VGOS

R1s start at 17:00
R4s start at 18:30
INT01s start at 18:30



Extrapolation error $\approx 35\mu s T^{3/2}$

For 0.5 day have: $35\mu s \cdot \frac{1}{2}^{3/2} = 2\mu s$

For 1.5 day have: $35\mu s \cdot \frac{3}{2}^{3/2} = 60\mu s$

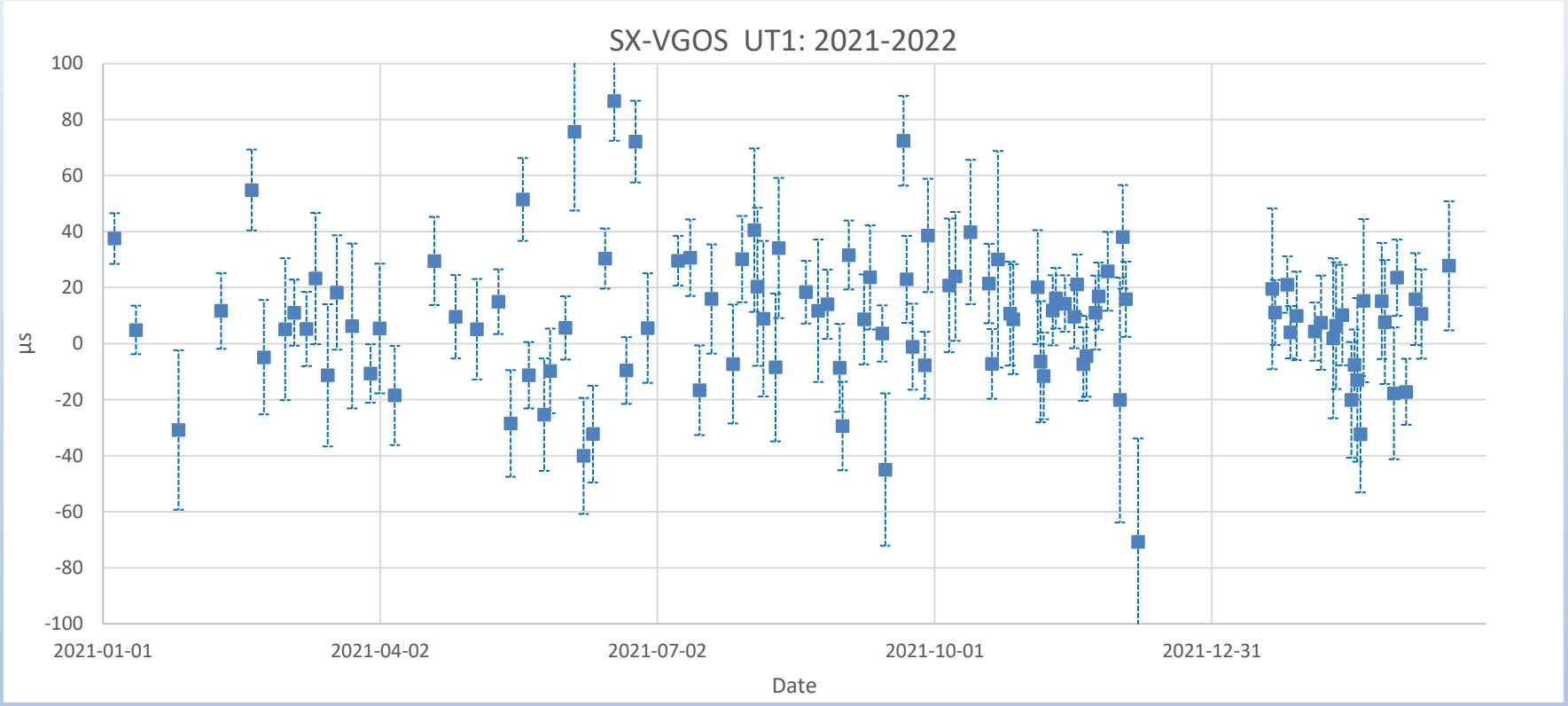
UT1 epoch is center of session.

Extrapolate UT1 from rapids to adjacent INT01s

This means can do 4 comparisons/week.

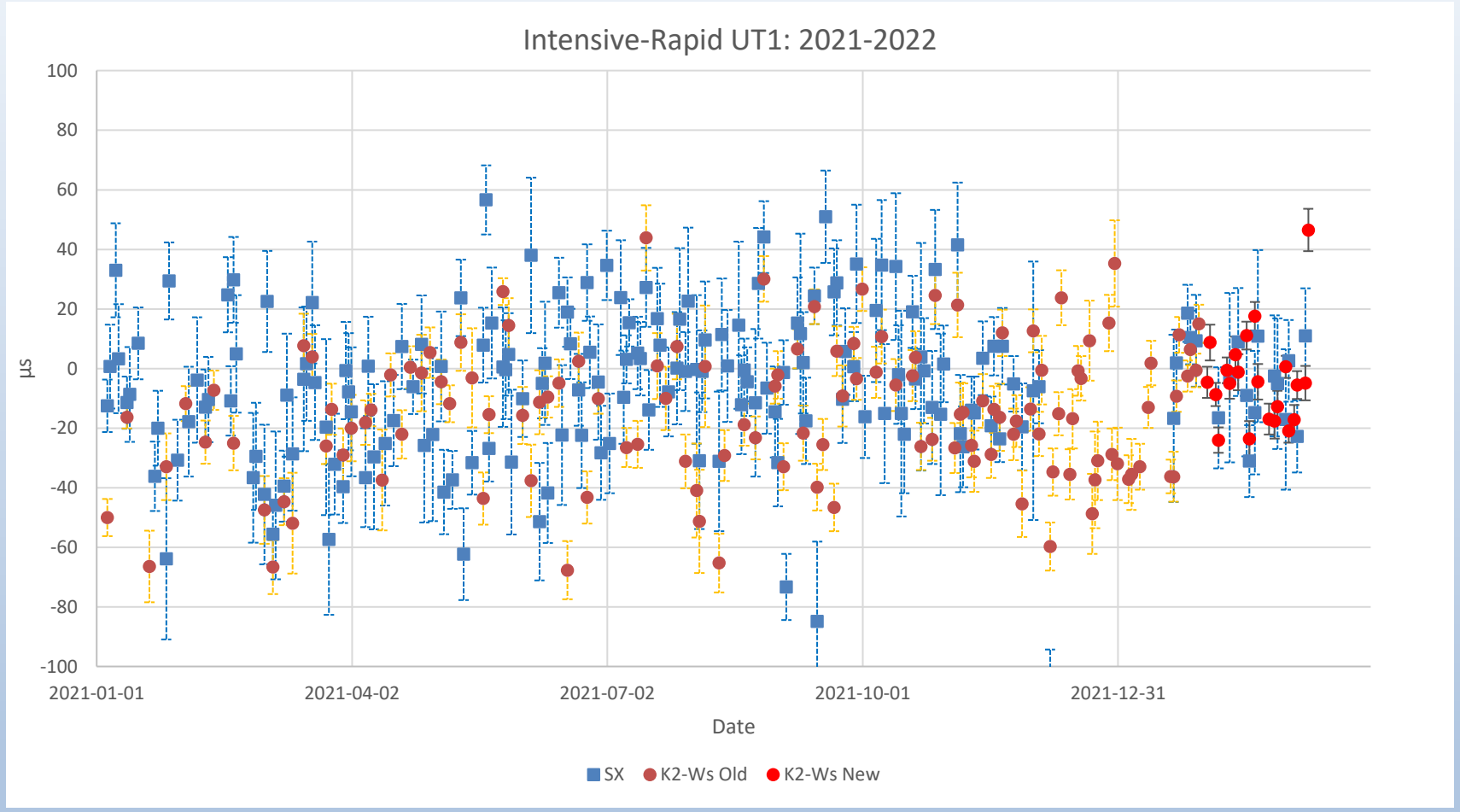
Extrapolation too large for middle INT01

Comparison of S/X vs VGOS



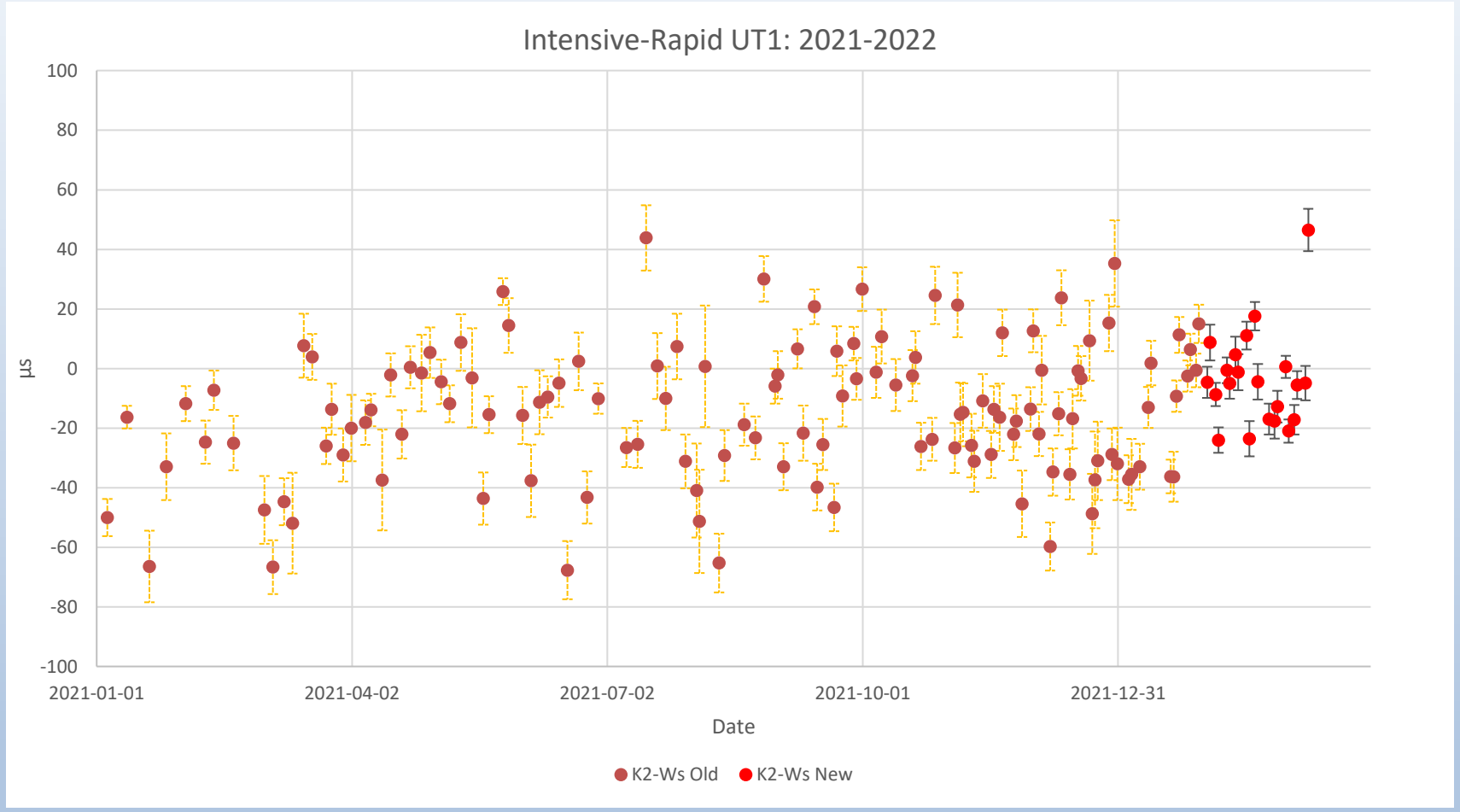
S/X –VGOS UT1					
	#	Average	StdDev	Expected	Unmodeled Error
Summary	109	9.3	24.6	19.5	15.0

Comparison with R1/R4: S/X & VGOS



At the level of the scatter, the results are consistent with S/X

Comparison with R1/R4: VGOS only



Some evidence new strategy helps. Scatter looks smaller.

Standard Comparison to R1/R4

Standard: Intensive UT1 - R1/R4 UT1					
	#	Average	Stddev	Expected	Unmodeled
S/X	178	-5.7	25.5	18.3	17.7
K2-Ws Old	127	-15.2	22.5	9.4	20.5
K2-Ws New	25	-4.3	14.2	5.1	13.3

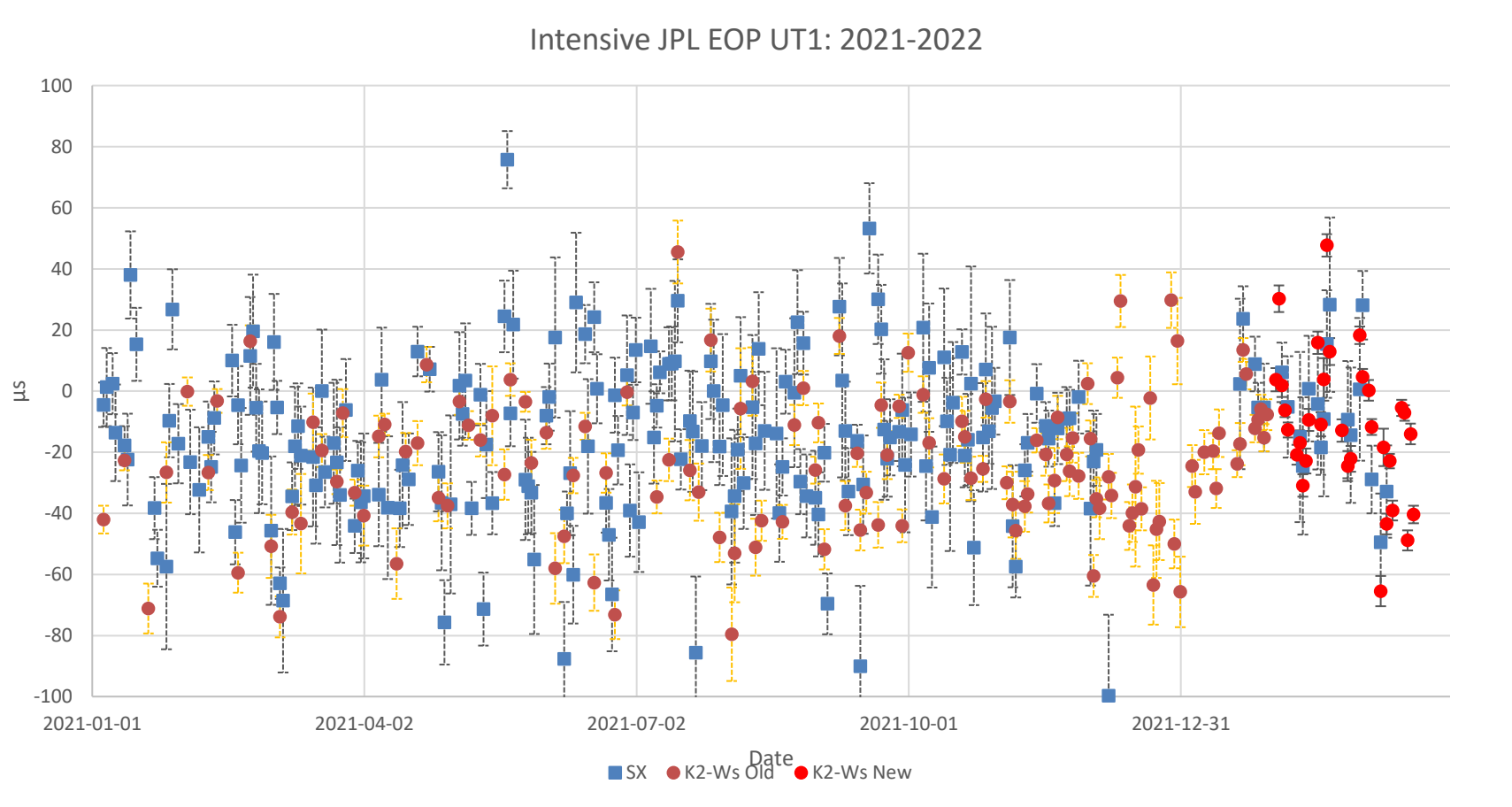
Old VGOS is 10% better than S/X

New VGOS is much better (40%) than S/X

(But small numbers)

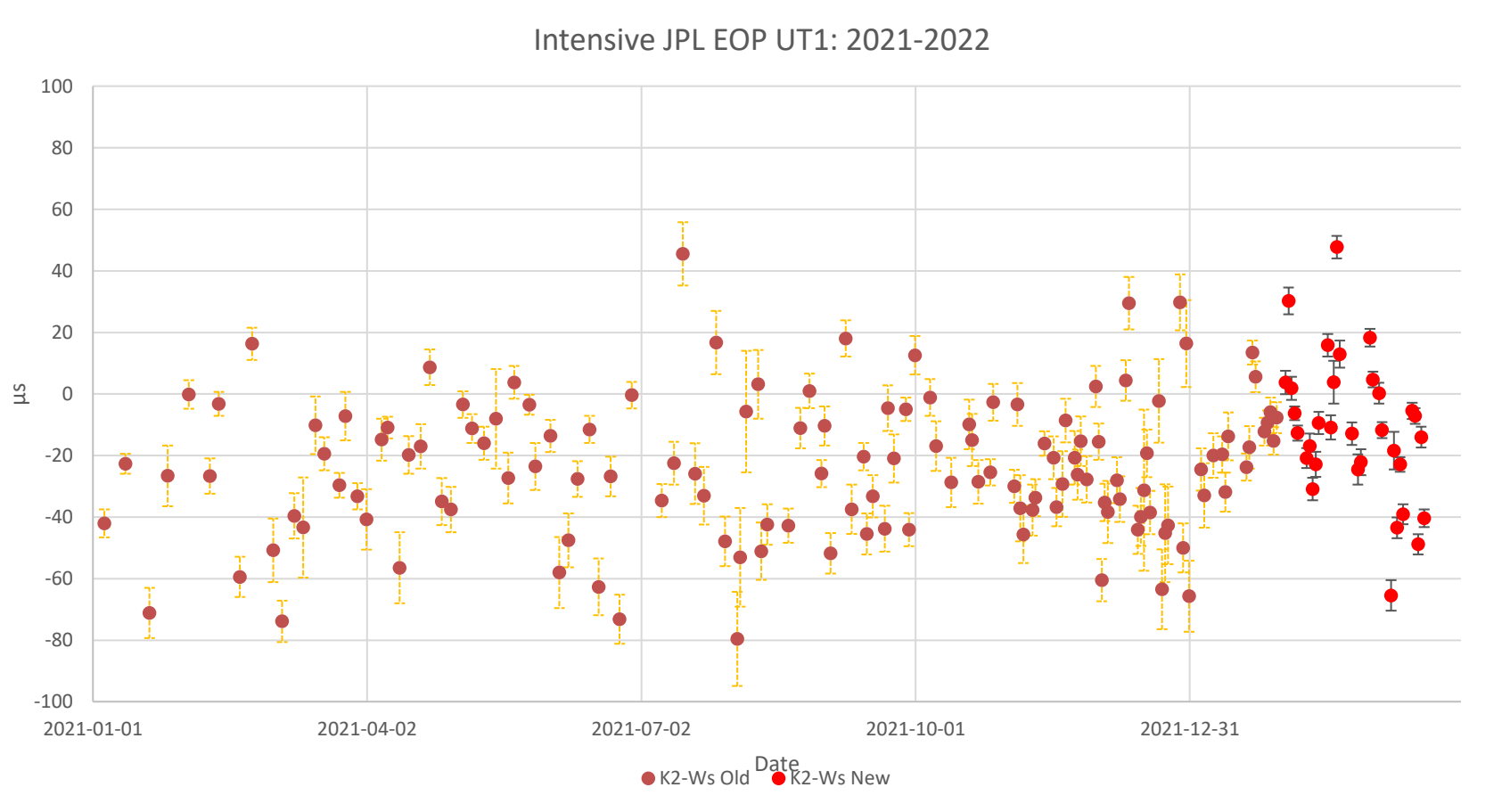
Still lots of unmodeled error.

Comparison with JPL EOP: S/X & VGOS



Only look through 2022-02-28. Reason: want to make sure JPL includes rapids

Comparison with JPL Finals: VGOS Only



Summary Comparison to JPL

With respect to R1/R4			
	Count	Average	Stddev
S/X	208	-14.7	25.5
K2-Ws Old	134	-23.7	22.5
K2-Ws New	19	-2.9	20.7

JPL EOP Finals as of 2022-03-22.
Only used data through 2022-02-28.
Reason: latest R1/R4s not in JPL series yet.

Two Alternative Analysis Strategies

1. Elevation dependent

$$\sigma_j^2 = \sigma_{j,meas}^2 + [10ps \cdot M(El_{K2}]^2 + [10ps \cdot M(El_{Wz}]^2$$

$$\sigma_j^2 \cong \sigma_{j,meas}^2 + \left[10ps \cdot \frac{1}{Sin(El_{K2})}\right]^2 + \left[10ps \cdot \frac{1}{Sin(El_{Wz})}\right]^2$$

2. Assume observations are correlated due to atmospheric turbulence. (Truehaft & Lanyi; Nillsson.) The covariance depends on the ray-paths of the two observations at the two stations.

$$Cov_{jk} = \delta_{jk}\sigma_{j,meas}^2 + \frac{SF_{K2}(\hat{r}_{j,K2}, \hat{r}_{k,K2})}{Sin(el_{j,K2}) \cdot Sin(el_{k,K2})} + \frac{SF_{WS}(\hat{r}_{j,WS}, \hat{r}_{k,WS})}{Sin(el_{j,Ws}) \cdot Sin(el_{k,Ws})}$$

Note that: $SF_{K2}(\hat{r}_{j,K2}, \hat{r}_{j,K2}) = AC_{n,K2}^2 \cong 10ps^2$

1 is a limiting case of 2 where you ignore off diagonal terms.

Elevation Dependent Weigthing

Standard: Intensive UT1 - R1/R4 UT1					
	#	Average	Stddev	Expected	Unmodeled
S/X	178	-5.7	25.5	18.3	17.7
K2-Ws Old	127	-15.2	22.5	9.4	20.5
K2-Ws New	25	-4.3	14.2	5.1	13.3

El Dependent Weighting: Intensive UT1 - R1/R4 UT1					
	#	Average	Stddev	Expected	Unmodeled
S/X	177	-5.3	25.0	14.5	20.9
K2-Ws Old	126	-16.4	19.3	8.4	17.4
K2-Ws New	25	-2.8	12.8	6.3	11.2

Elevation dependent weighting is better:

- Lower StdDev. For VGOS a 10% improvement.
- Higher expected error (still too optimistic)
- Lower Unmodeled Error

Using Correlated Atmosphere

Standard: Intensive UT1 - R1/R4 UT1					
	#	Average	Stddev	Expected	Unmodeled
S/X	178	-5.7	25.5	18.3	17.7
K2-Ws Old	127	-15.2	22.5	9.4	20.5
K2-Ws New	25	-4.3	14.2	5.1	13.3

Using Correlated Atmosphere: Intensive UT1 - R1/R4 UT1					
	#	Average	Stddev	Expected	Unmodeled
S/X	175	-4.3	25.9	15.2	21.0
K2-Ws Old	127	-15.8	19.2	8.8	17.1
K2-Ws New	25	-0.2	13.1	7.7	11.4

Results similar to Elevation dependent weighting.

- Lower StdDev for VGOS (but not as good as el-weighting)
- Higher expected error (still too optimistic)
- Lower Unmodeled Error (for VGOS)

Summary of Alternative Strategies

StDev With respect to R1/R4				
	#	Standard Reweight	El dependent Weighting	Turb Correlation
S/X	178	25.5	25.9	25.9
K2-Ws Old	127	22.5	19.3	19.2
K2-Ws New	25	14.2	12.8	13.1

El dependent weighting and Turb correlation give similar results.
For the VGOS sessions and the K2-Ws baseline the results are improved.

Recommendation: Everyone should use El-dependent weighting.

Summary

- Have been running K2-Ws VGOS Intensives since 2021-01-01.
- Changed the observing strategy 2022-01-31
- RMS difference between S/X and VGOS 24.6 µs
  - Significant unmodeled error
- Comparing to R1/R4
  - RMS of S/X 25.0 µs
  - RMS ‘old’ VGOS 22.5 µs
  - RMS ‘new’ VGOS 14.2 µs
- Comparison to JPL EOP.
  - Results for S/X and old VGOS about the same as above.
  - New VGOS scatter is 20.7 µs
- Using elevation dependent weighting or (turbulence) reduces scatter by 10% for VGOS Ints.
  - RMS ‘new’ VGOS 12.8 µs
  - Turbulent model is about the same as el-weighting, but more complicated.

Questions

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