The IERS Rapid Service / Prediction Center Mission, Challenges, and Developments

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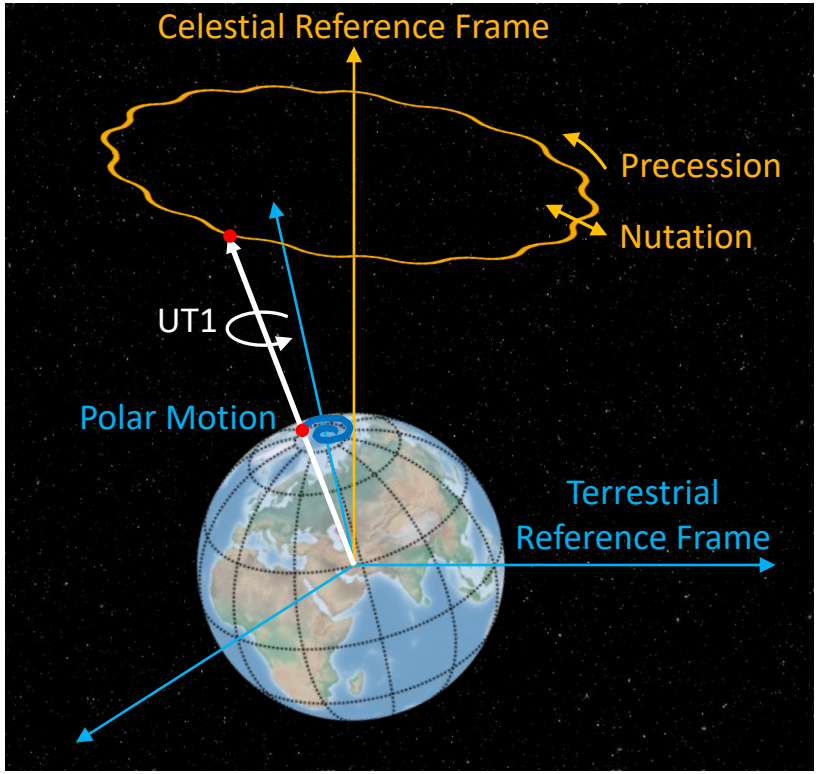
Why Are EOPs Important?

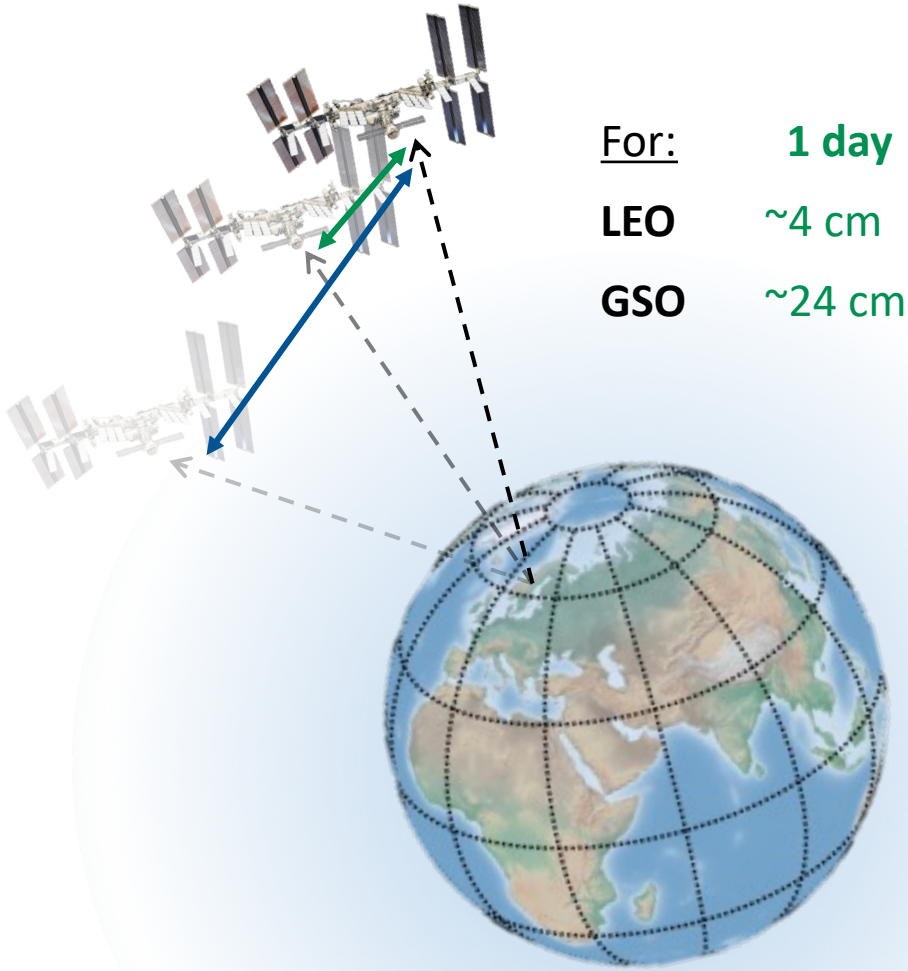
Earth Orientation Parameters (**EOPs**) provide a *rotational relationship* between the Terrestrial Reference Frame (**TRF**) of the Earth, and the Celestial Reference Frame (**CRF**) used for satellite navigation and other applications requiring an accurate relationship between frames.

- EOPs are *highly variable* – measurements and predictions are required for real-time users
- Accurate, precise *daily* EOPs are critical in supporting modern society

Rotation → UT1-UTC
Polar Motion → PMx, PMy
Celestial Pole Offsets → dX, dY

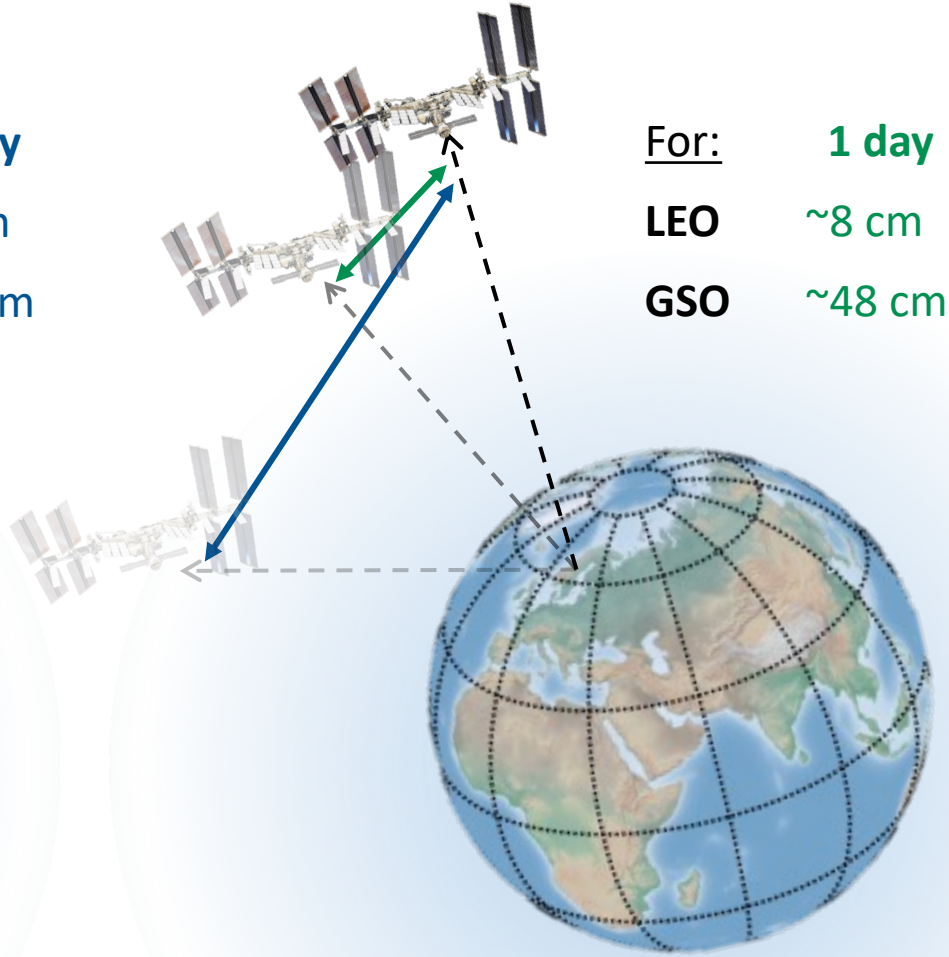


Error in UT1—UTC at Spacecraft Altitude sans Updates



For:	1 day	10 day
LEO	~4 cm	~25 cm
GSO	~24 cm	~159 cm

Using RS/PC Stored Predictions



For:	1 day	10 day
LEO	~8 cm	~186 cm
GSO	~48 cm	~1158 cm

Using Extrapolated Historical LOD Values

Brief Overview of EOP Combination

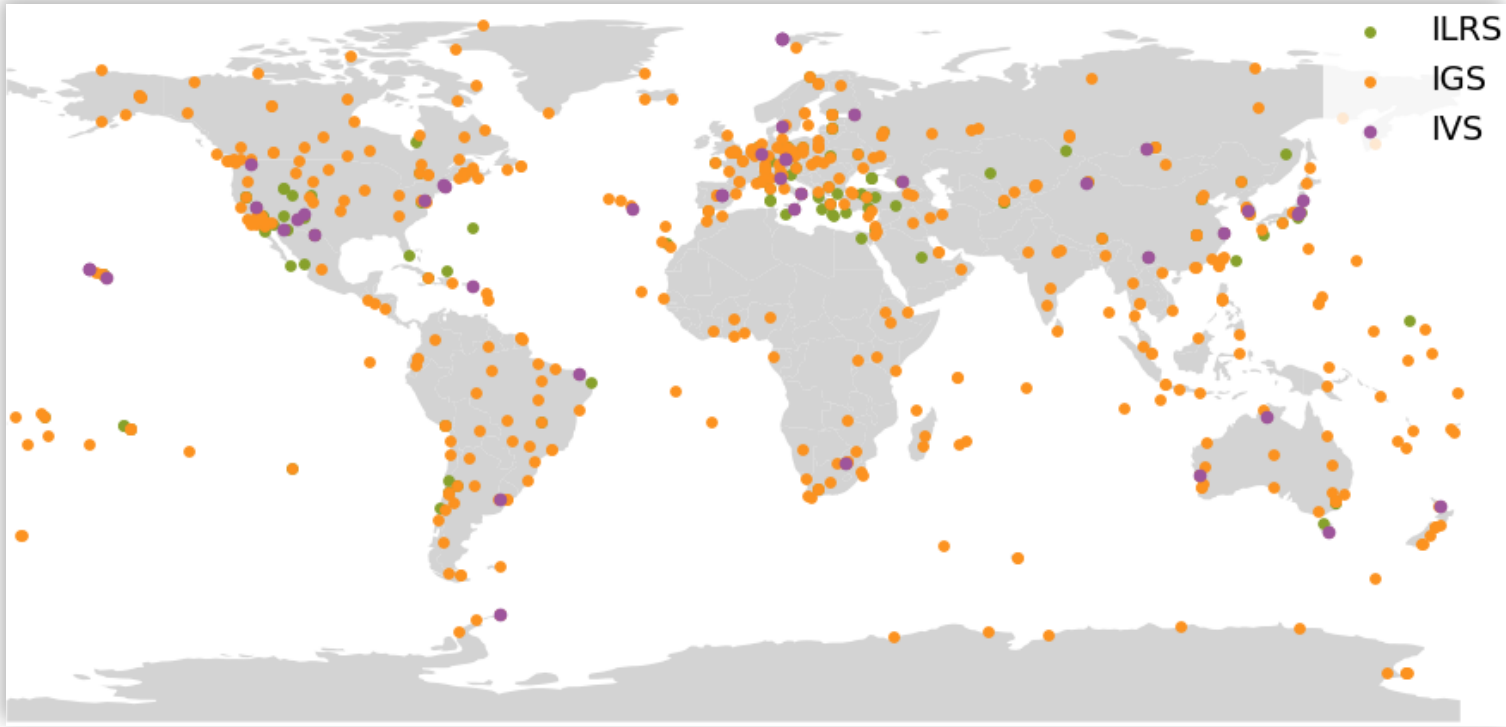
- Combine observational data to create a best estimate of 5 Earth Orientation Parameters:
  - Polar Motion x, Polar Motion y, UT1—UTC, dX, dY
    - 24h VLBI is the only technique that observes all 5 EOPs
  - Use multiple techniques to validate accuracy of observations
    - GPS, VLBI, SLR, UTGPS, AAM
  - Utilize diversity of observation networks to ensure accuracy and redundancy
  - Use contributors with varied analysis software
    - To detect software errors
  - Generate predictions for:
    - 1 year for Polar Motion, UT1—UTC
    - 90 days for dX, dY
- Daily human-approved solution


VLBI Telescopes


GPS Receivers


Atmospheric Data


Laser Ranging



EOP Data Integration – Combination Considerations

- Number of Observations
  - Length and density of time-series
    - Minimum 60 observations over 4 months – *prefer more/longer*
    - Will be doing a study in the future to determine criteria
- Accuracy/precision of time-series w.r.t. ”truth”
  - Do reported EOP errors correlate with accuracy of observation?
  - Identify if any unexplained signal is present in data
  - Impact on combined EOP solution
- Frequency and latency of observation
  - Consistency of scheduled sessions
  - Time required for a session to go from observation through analysis
- Reliability
  - Frequency of station outages for observing or data transfers
- Geography of baseline/network
  - Is the configuration optimized for the EOP it is attempting to measure?
  - Improvement in diversity of observations

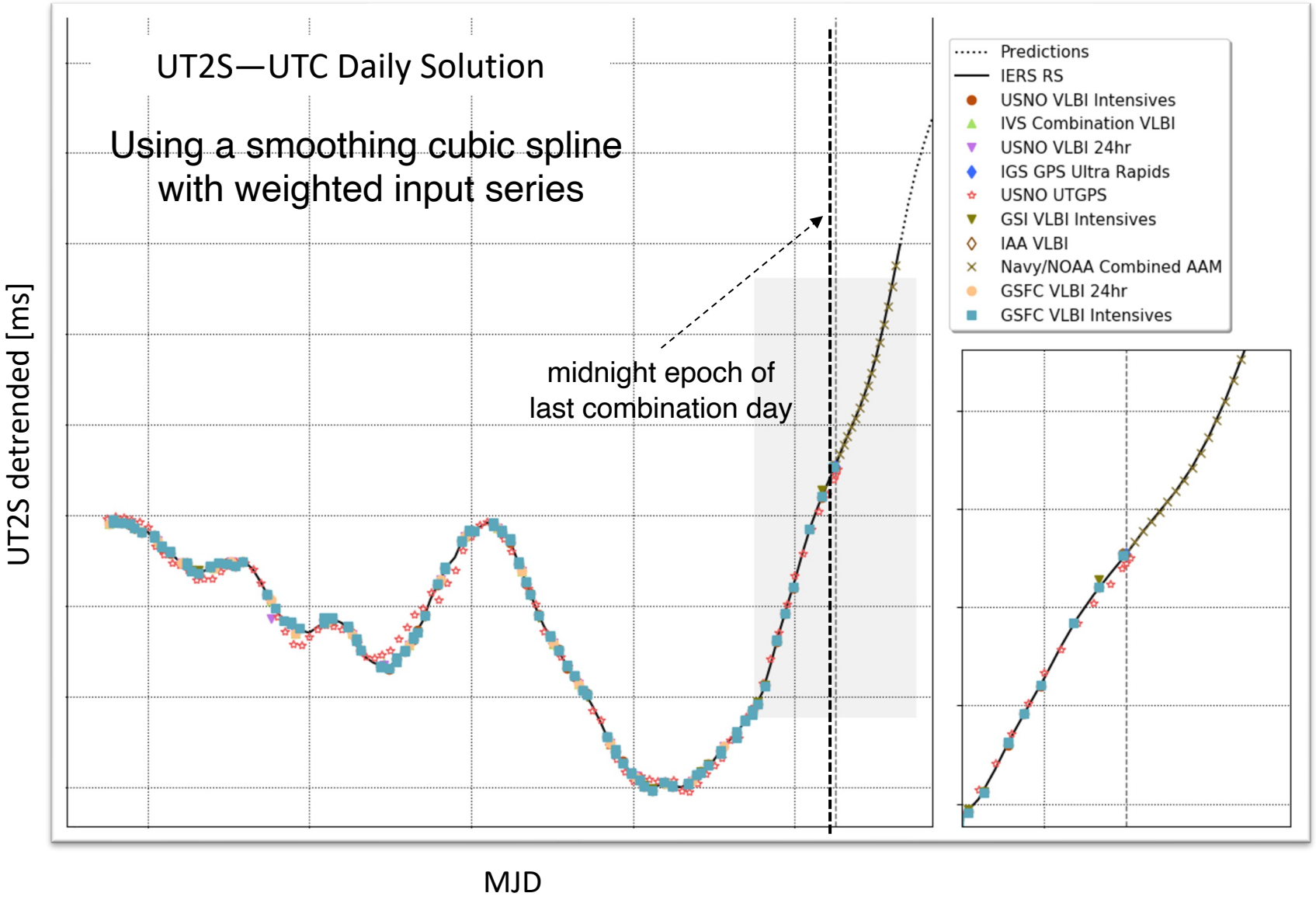
EOP Combination Contributors

Technique	Contributor	Latency*	Product	EOP
GNSS (IGS)	IGS Finals	<= 21.5 days	IGS Combination	PM x,y
	IGS Rapids	29 hrs		
	IGS Ultra rapids	17 hrs		PM x,y, UT1—UTC†
VLBI (IVS + 1 VLBA)	GSFC VLBI AC USNO VLBI AC	22 hrs	1hr Intensives	UT1—UTC
	GSI VLBI AC	9 hrs		
	GSFC VLBI AC USNO VLBI AC	~ 2 weeks	24hr R1/R4	PM x,y, UT1—UTC, dX, dY
	IAA VLBI AC	N/A		
	IVS Combination AC	2-3 weeks		
SLR	ILRS	2.5 – 7 days	Series A	PM x,y
UTGPS	USNO GPS AC	17 hrs	Derived from IGS Ultra-rapid	UT1—UTC
AAM	NOAA U.S. Navy	17 hrs	Analysis + 7.5 days predictions	UT1—UTC†

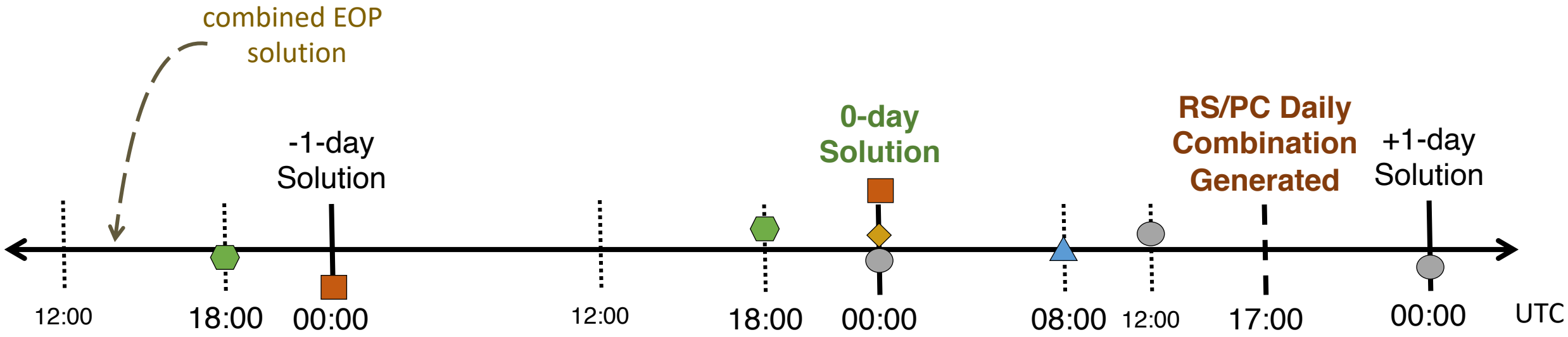
* Latency is observation mid-point to time of combination

† Integrated LOD

Generating a Combined Solution for UT1-UTC



Low-Latency Data is Critical for UT1-UTC Combination



IVS Intensive (M-F)

IVS Intensive (Sa-Su)

UTGPS

IGS Ultra rapids*

AAM Analysis / Predictions*

* Integrated LOD

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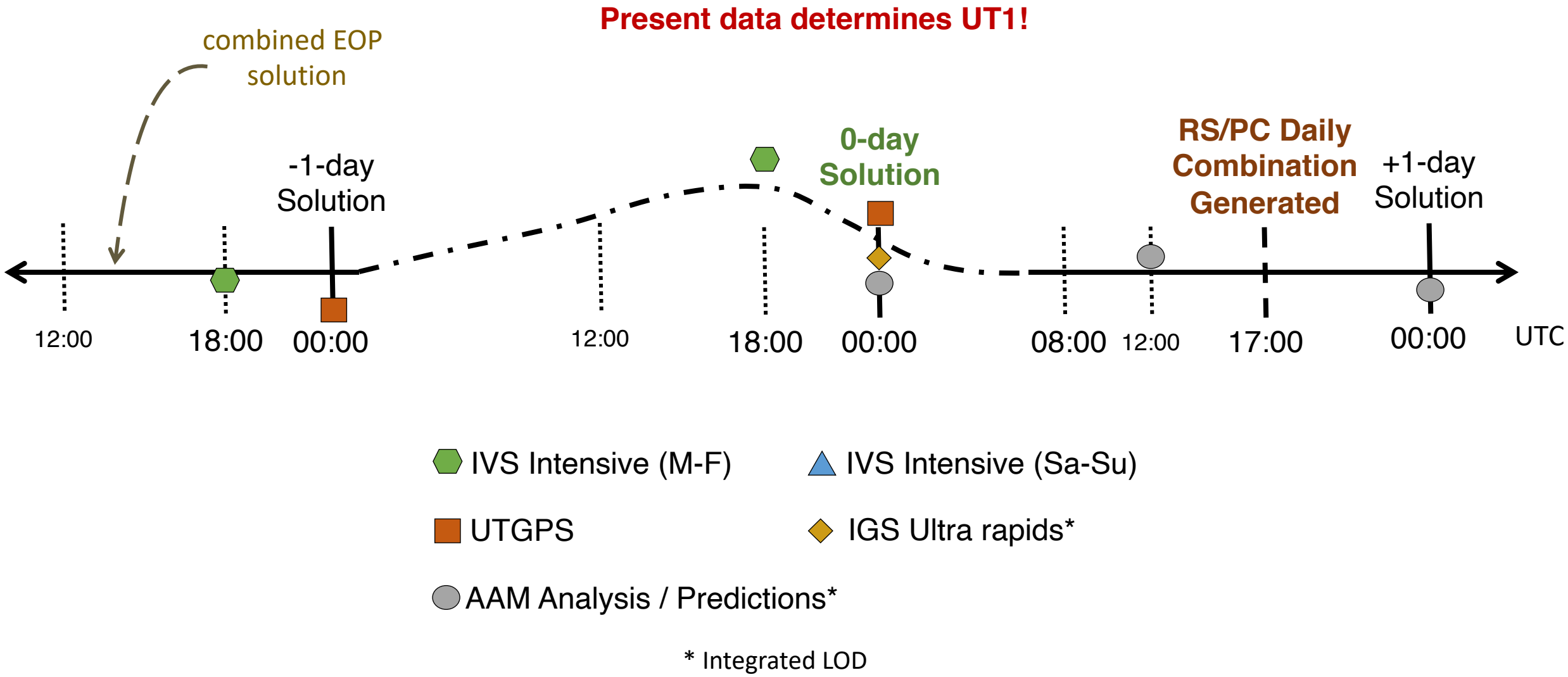
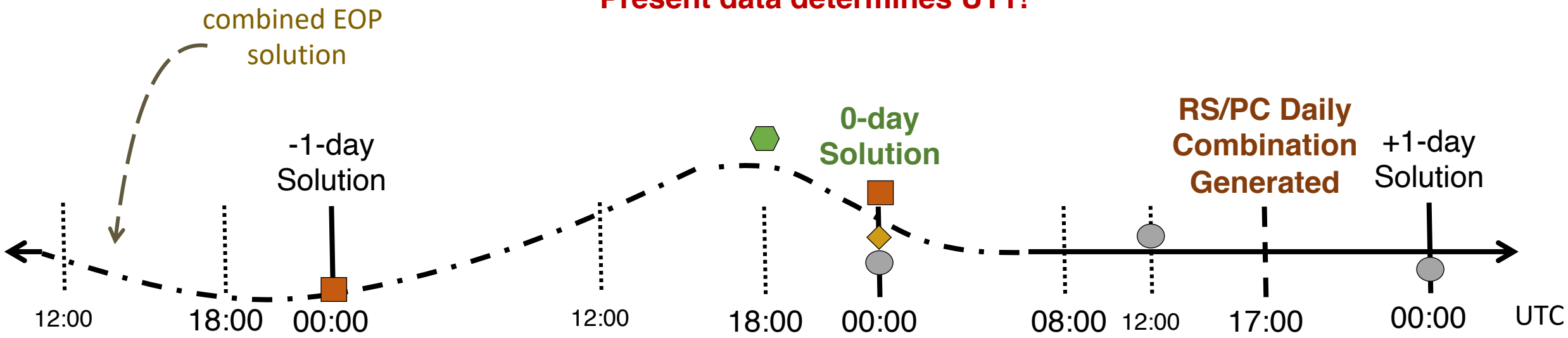


Low-Latency Data is Critical for UT1-UTC Combination

Present data determines UT1!



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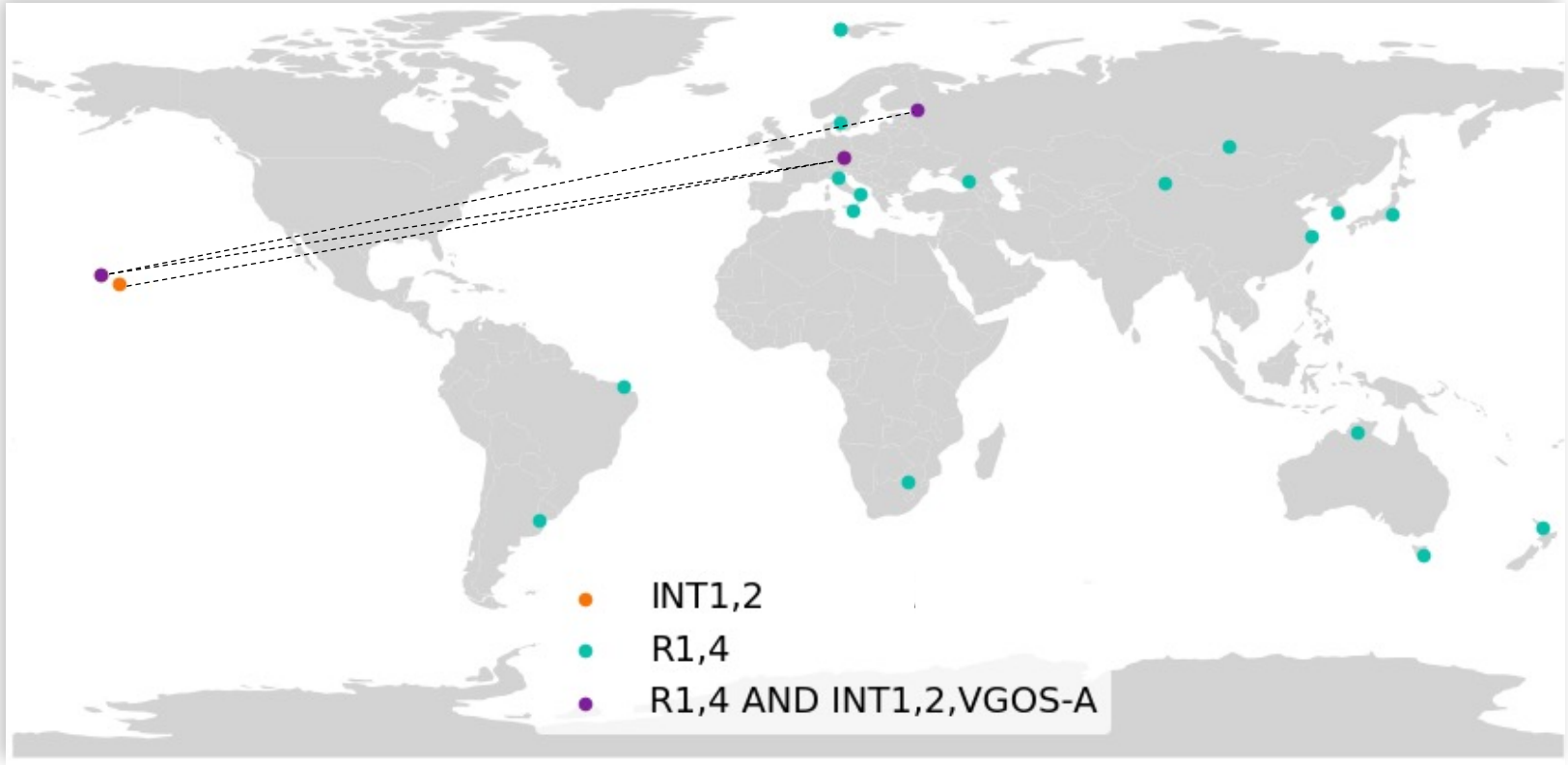
Diversity in VLBI Observations

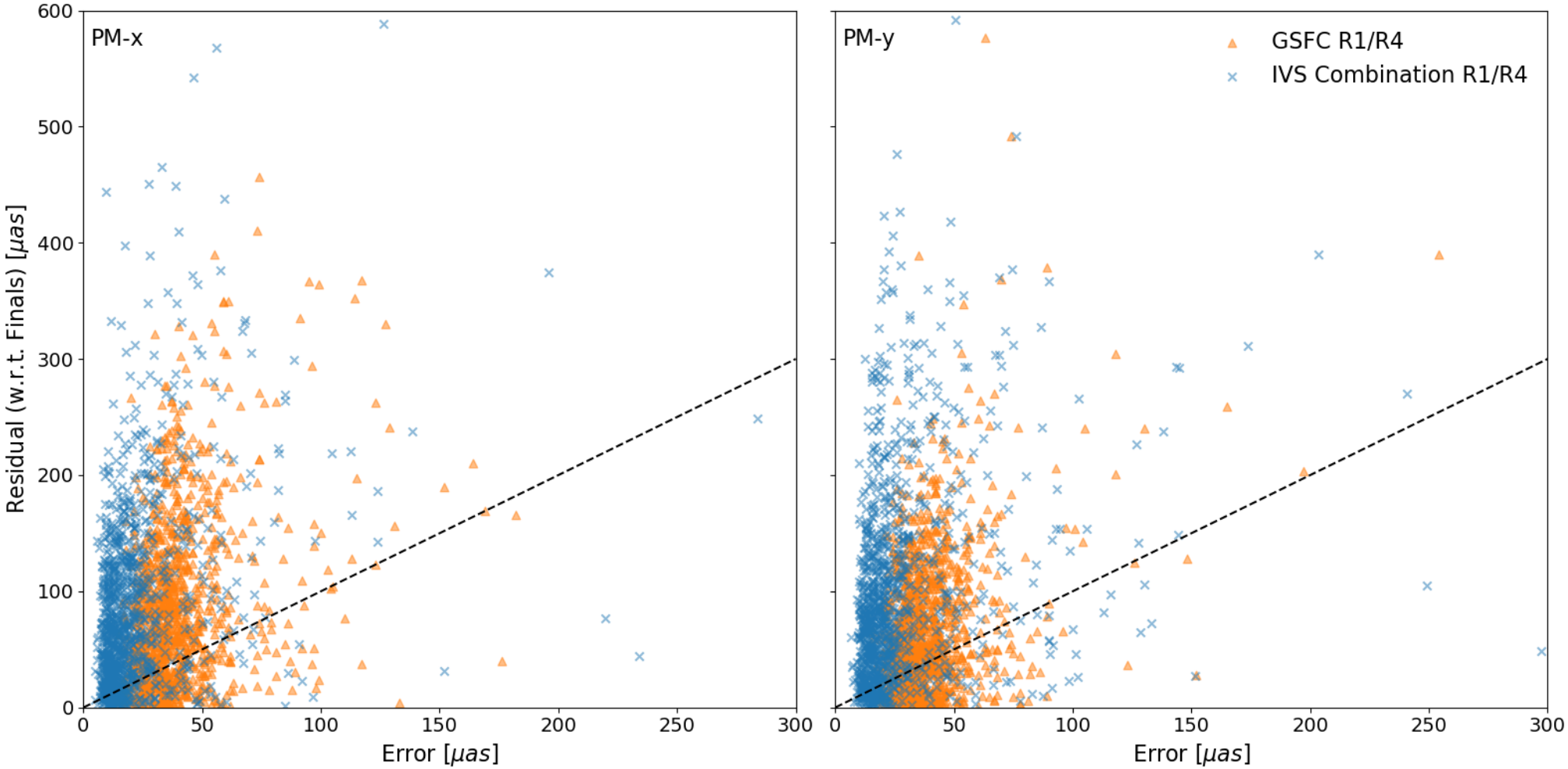
- Utilizing:
  - Multiple baselines
  - Primary baselines w/ alternates for antenna/site outage
  - Northern *and* Southern Hemisphere
- Correlators
  - Different groups, techniques, locations
- Analysis Software
  - Varied approaches to reduce unidentified bugs and systematic errors



Observation Accuracy Reporting

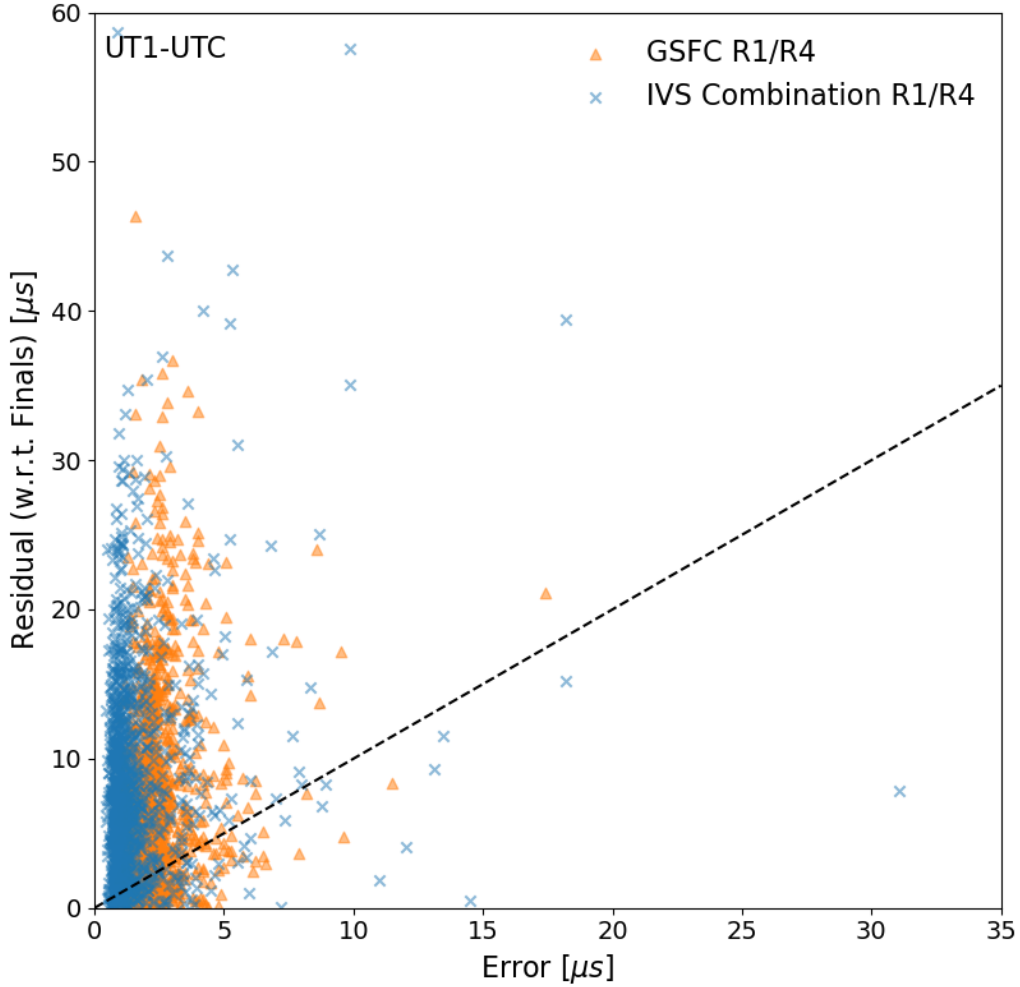
- Why is the formal error overestimating the accuracy of the observation?
  - If the formal error does not reflect the accuracy of observation, what is it for?

PM is dominated by IGS in combination, so IVS residuals are more reflective of true accuracy *(if we assume GPS EOPs are truth)*



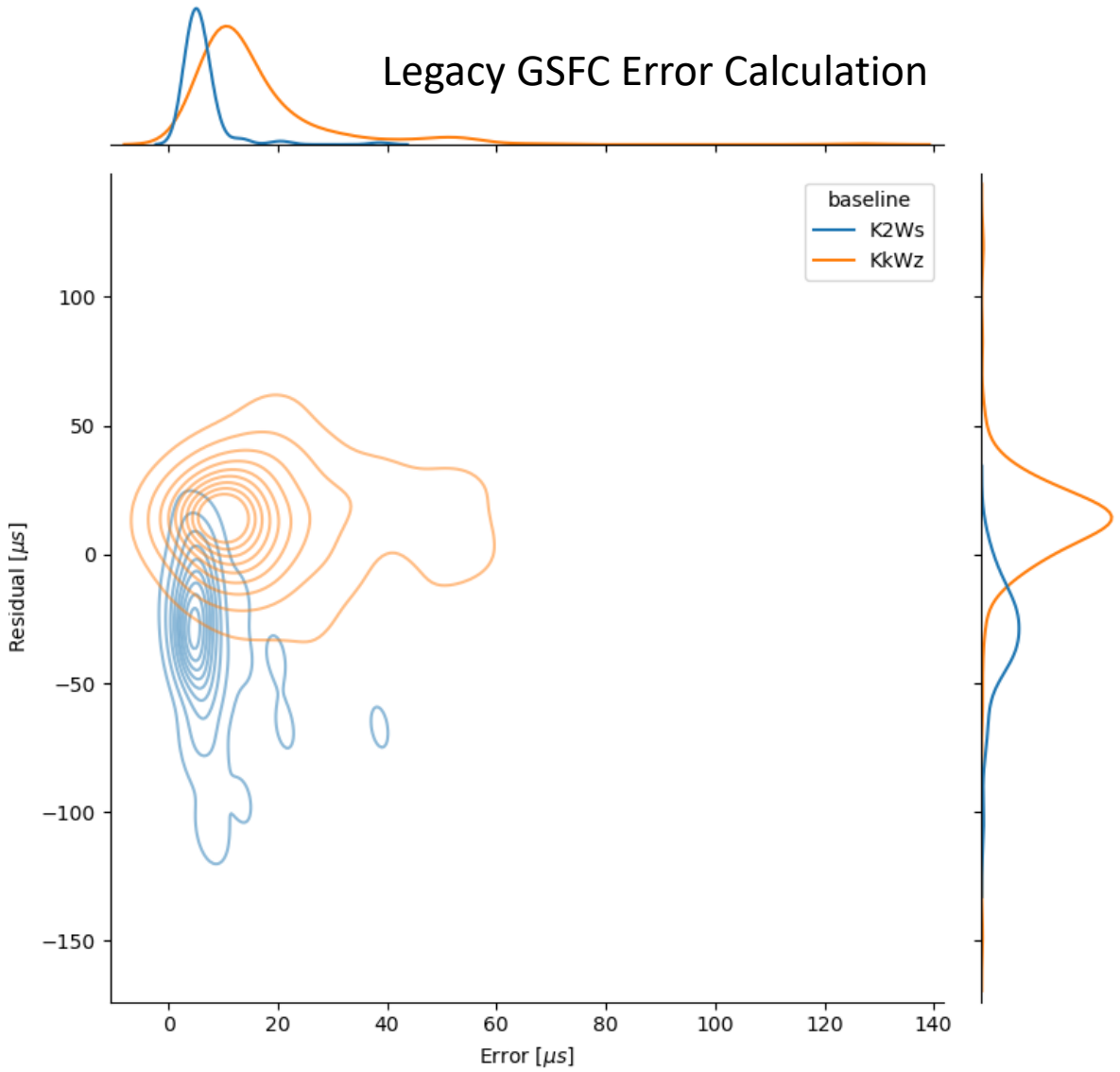
Observation Accuracy Reporting—UT1 Challenges

- UT1—UTC residual is order of magnitude smaller than PM.
  - *Residuals could be small because VLBI is the only technique that directly observes UT1.*
- Accuracy still appears to be grossly overestimated.
- Hope to begin addressing this problem with a new combination we are developing.
  - Can use LOD in the UT1-UTC combination.

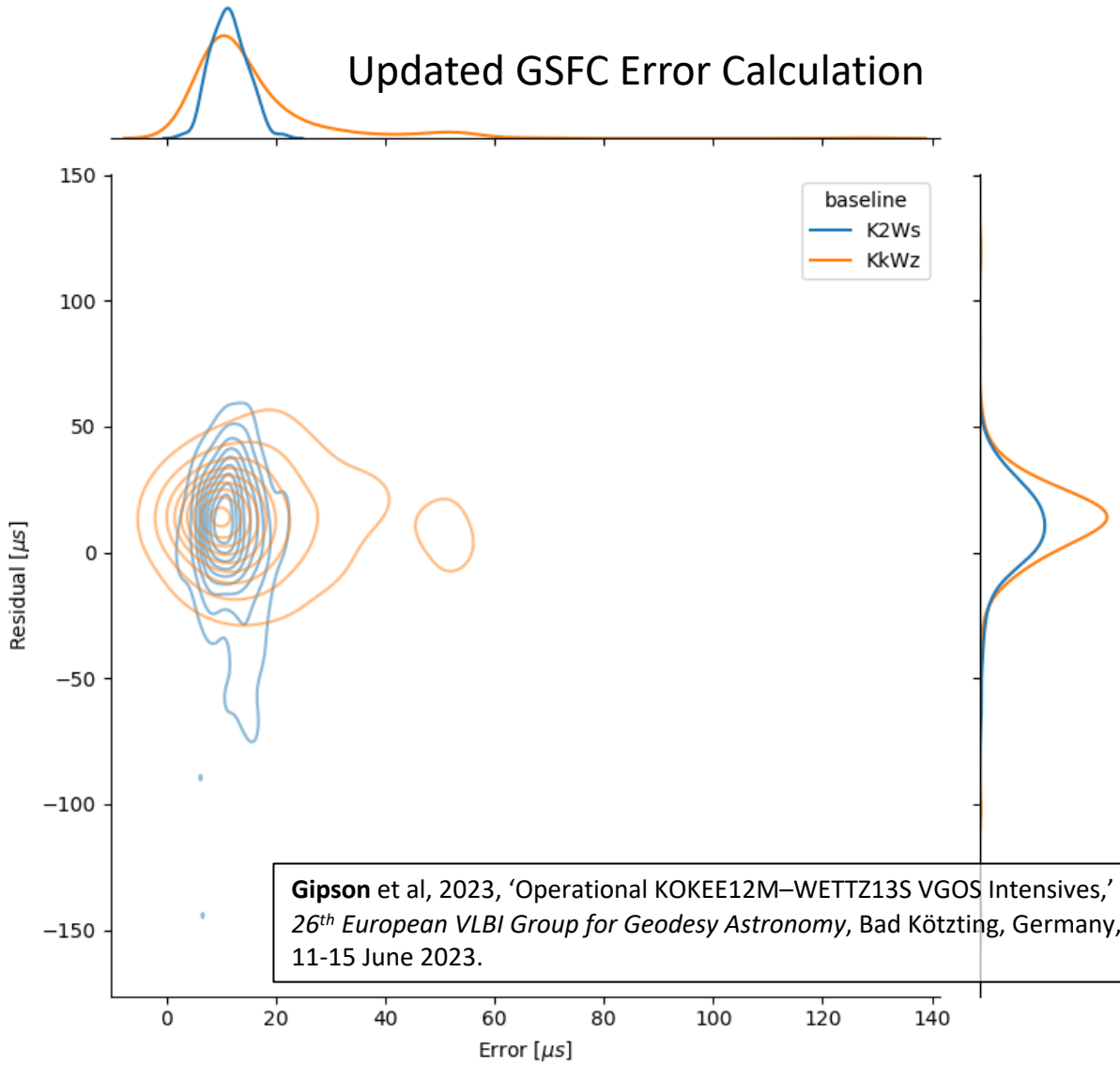


Accuracy Issue Partially Resolved for VGOS-INT-A

Legacy GSFC Error Calculation



Updated GSFC Error Calculation



Gipson et al, 2023, 'Operational KOKEE12M–WETTZ13S VGOS Intensives,' *26th European VLBI Group for Geodesy Astronomy*, Bad Kötzting, Germany, 11-15 June 2023.

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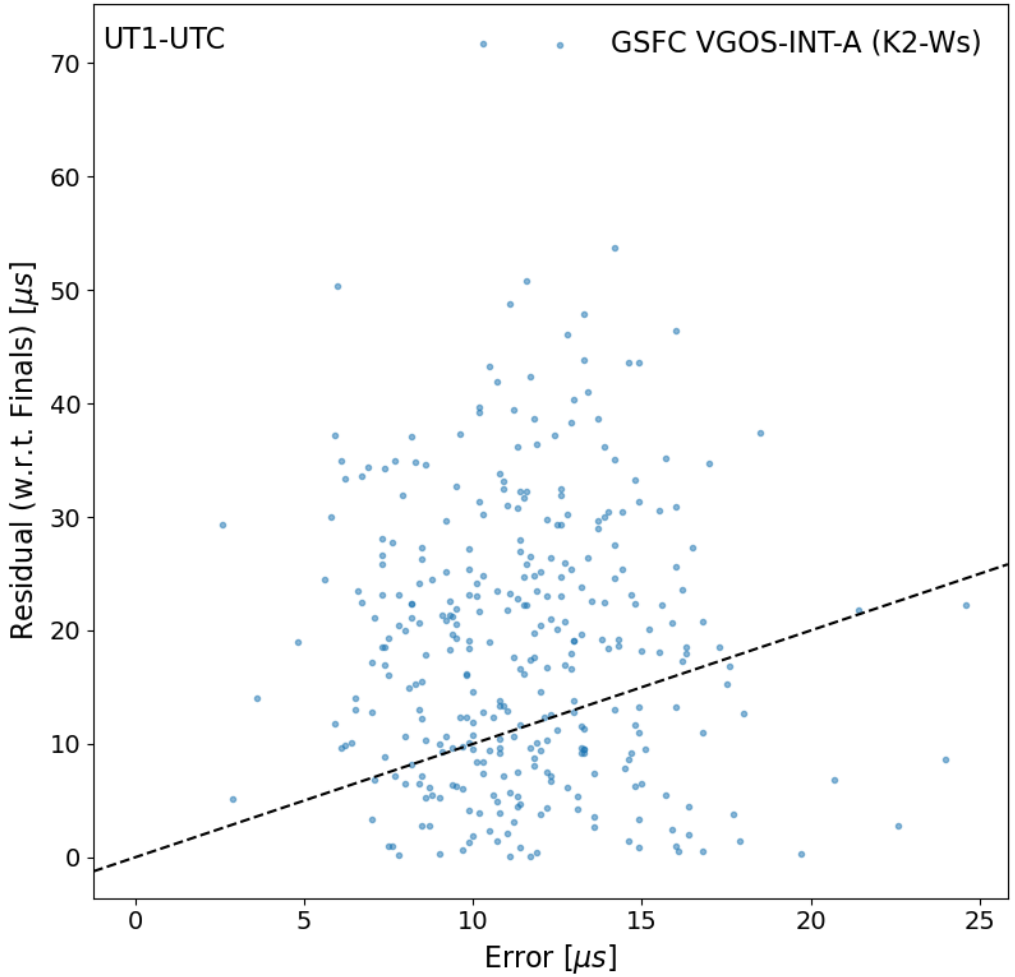

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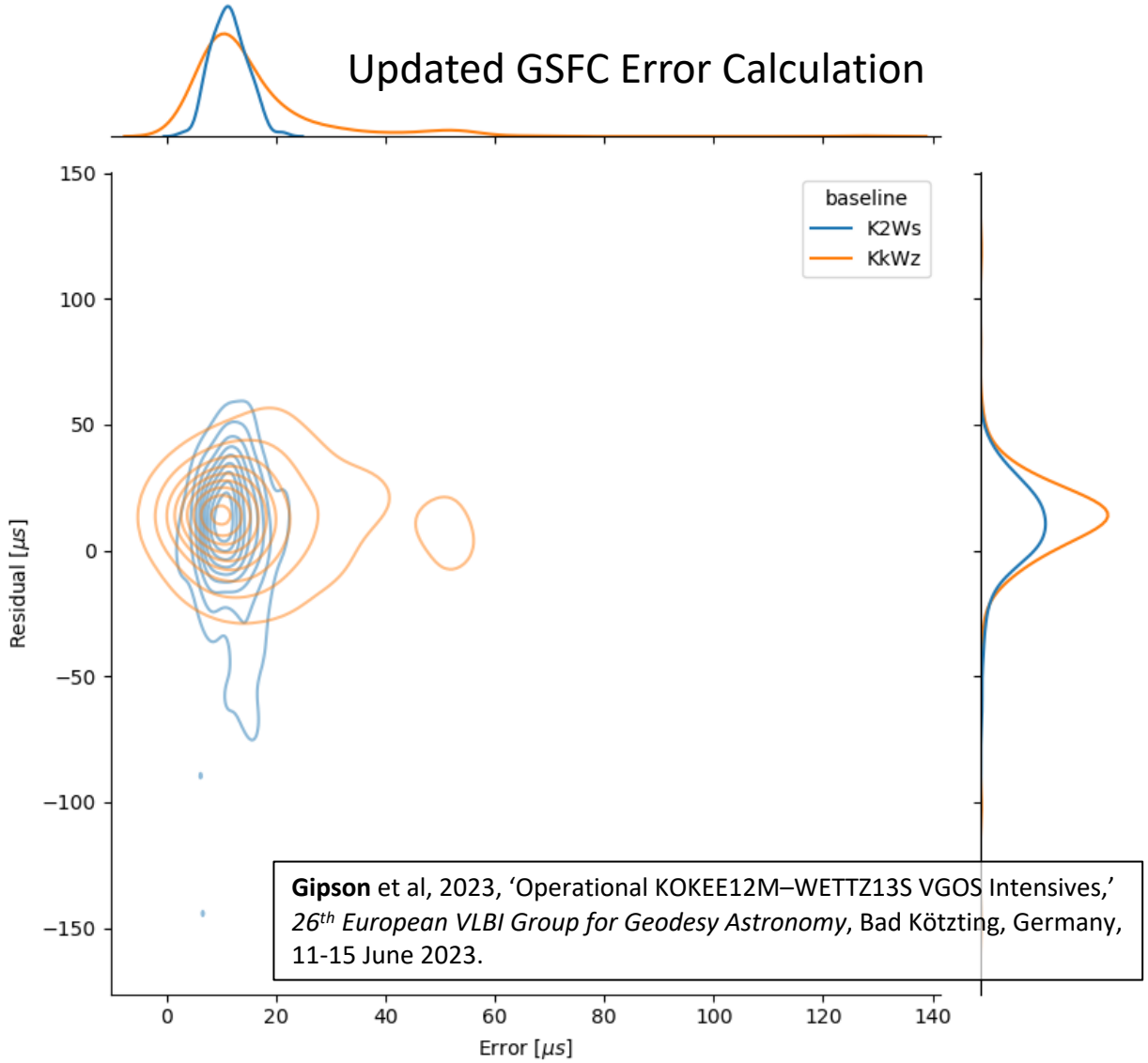

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Future Software Updates

- Developing new combination method
  - Allows us to use IGS/AAM LOD directly in UT1-UTC combination
  - Preliminary results suggest improvement to 0-day EOP values and 5-7 day predictions *(Stamatakos, et. al, AGU, 2023)*
- Re-development of AAM pre-processing
  - Preliminary analysis suggests improvements to UT1-UTC combination & prediction values
- Modernizing software
  - More dynamic, easier to maintain
  - Easier to integrate new contributors into combination
- Continue to improve on internal software/infrastructure robustness
  - Improves reliability of product

Data Addition Considerations

Data Product	Characteristics
Diversity in Intensive baselines/stations	- Redundancy in low-latency product - *Critical to generating high-quality UT1—UTC 0-day value* - Capture UT1—UTC from different hemisphere (*S. Hemisphere Intensive*)

VGOS Observations	- Intensives analyzed by multiple AC's
	- Robust alternative baseline to K2-Ws
	- Regular 24h observations as frequently as possible
	  - Volume of data currently a challenge for data-chain
	  - After establishing *observing frequencies* and *scheduling methodology*

Diversity in Analysis Centers	- Currently only using VLBI EOPs from USNO, GSFC, GSI, IAA, and IVS Combination - Analysis software other than Calc/Solve

RS/PC Products & Publishing Schedule

https://maia.usno.navy.mil/ser7

finals[2000A].all	2 Jan 1973 (MJD 41684) → <day$_{Bulletin\ A}$> + 373 days	
finals[2000A].data	1 Jan 1992 (MJD 48622) → < day$_{Bulletin\ A}$ > + 373 days	
Bulletin A (ser7.dat)	<day$_{Bulletin\ A}$> - 7 days & 365 days predictions (PM, UT1) - Latest updates to CPOs - Human readable + Announcements	Published Thursdays by 20:00 UTC (typically by 18:30 UTC)
2000A → dX/dY else → dψ/dε mark3.out	<day$_{Bulletin\ A}$> - 85 days → <day$_{Bulletin\ A}$> + 90 days - (Only PM-x, PM-y, and UT1)	
gpsrapid.out	1 May 1992 → <day$_{Bulletin\ A}$> + 15 days	
finals[2000A].daily.extended (NEW)	2 Jan 1973 (MJD 41684) → <today> + 373 days *- Began publishing in March 2021*	Published daily by 17:30 UTC
finals[2000A].daily	<today> – 90 days → <today> + 90 days	
gpsrapid.daily	<today> - 90 → <today> + 15 days	
deltat.data	deltaT values on 1st of each month since Feb 1973	Published quarterly
deltat.preds	deltaT predictions on beginning of quarter for 10 years	Published annually
historic_deltat.data	deltaT values every half year from 1657 to 1984.5	

Contact Us

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