US – EUSST Data Exchange for Improved Orbital Safety

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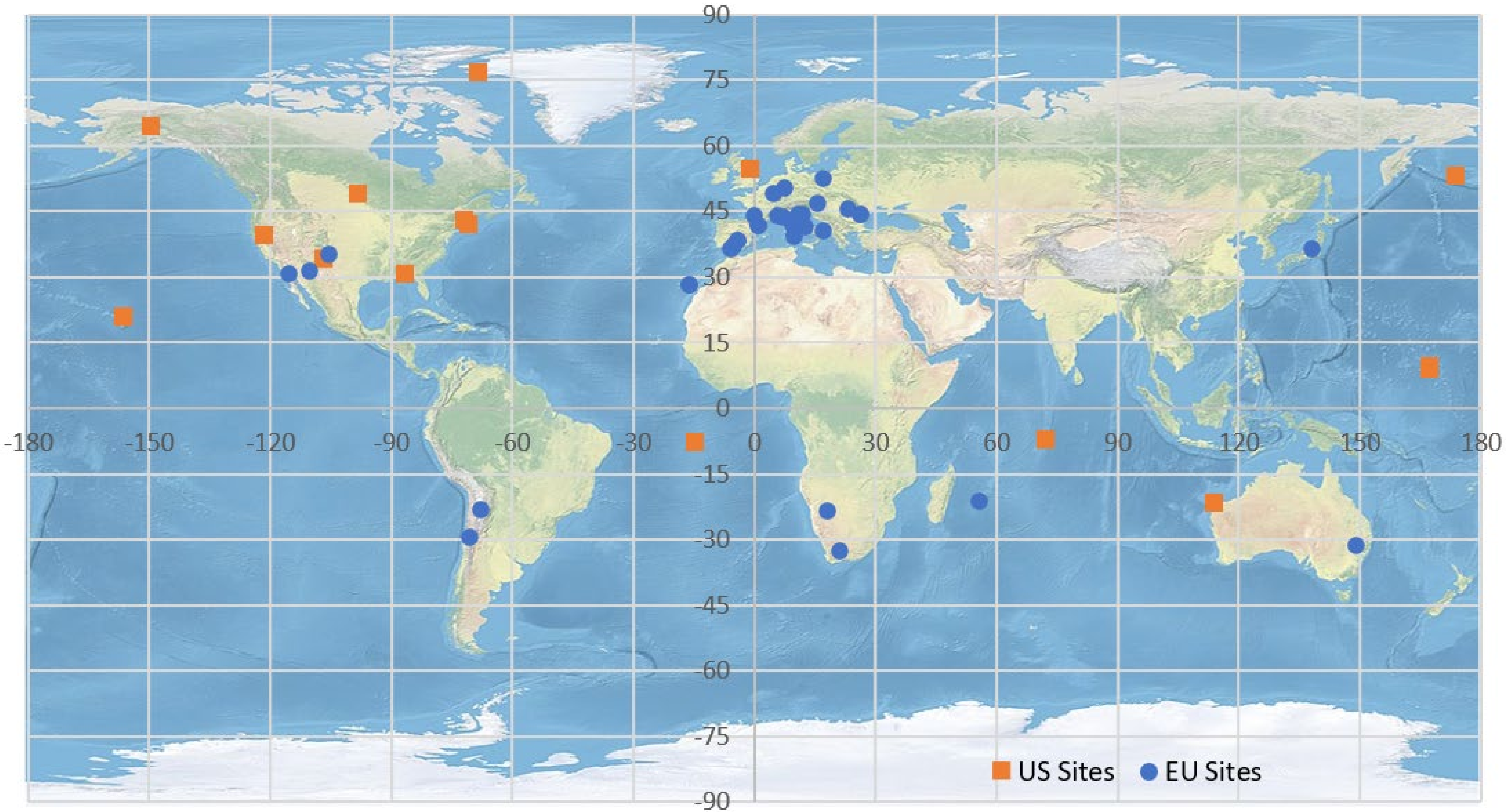
Background and Setting

BLUF

- 2018 meeting between EUSST consortium reps and US DOS, DoD, and NASA reps
  - *Articulated goal of cooperative collection and sharing of SSA data between EUSST and US entities*
- This goal took the form of joint agreement between DOC-EUSST in February 2021
  - *To execute experiment to undertake data sharing and understand its benefits*
- In early 2022, funding and structures in place for experiment
  - *Identify set of satellites for experiment and secure approvals for data exchange for these satellites*
    - A few with external truth orbits, and many others without
  - *Perform joint tracking of these satellites over a fixed period of interest (1 JUN - 31 JUL 2022)*
  - *Exchange observational data and supporting information (sensor locations, calibration, &c.)*
  - *Construct orbits on each side from the exchanged observational data*
    - US data only, EUSST data only, and both datasets combined
  - *Examine results set and draw conclusions*
    - Benefits of data sharing
    - Issues encountered with sharing observational data and recommendations for mitigation

US and EUSST Sensor Locations



Fills in gaps and improves southern hemisphere coverage

Study Satellites

Orbital Region, Satellite Identification, and Orbital Parameters

Ref orbit available (highlighted)

- GEO group
  - *2867 DODGE 1 – 33,264 km x 33,665 km, 1 deg incl* — *15 day fit span*
  - *7298 SMS 1 – 36,196 km x 36,321 km, 8 deg incl* — *15 day fit span*
  - *25673 EUTE 21A – 36,284 km x 36,341 km, 7 deg incl* — *15 day fit span*
- MEO/HEO group
  - *25847 MOLNIYA 3-50 – 518 km x 39,848 km, 63 deg incl* — *12 day fit span*
  - *29486 NAVSTAR 58 – 19,910 km x 20,459 km, 55 deg incl* — *12 day fit span*
  - *39173 BREEZE-M R/B – 2,664 km x 63,621 km, 28 deg incl* — *14 day fit span*
  - *43057 GALILEO 21 – 23,214 km x 23,233 km, 56 deg incl* — *15 day fit span*
  - *45359 FREGAT R/B – 19,388 km x 19,710 km, 65 deg incl* — *12 day fit span*
- LEO group
  - *17178 SL-14 R/B – 1,499 km x 1,505 km, 83 deg incl* — *10 day fit span*
  - *13590 SL-14 R/B – 1,496 km x 1,504 km, 83 deg incl* — *10 day fit span*
  - *15354 ERBS – 371 km x 386 km, 57 deg incl* — *5 day fit span*
  - *41335 SENTINEL 3A – 807 km x 808 km, 99 deg incl* — *10 day fit span*
    - Maneuvers on day 165 (09:30 Z) and day 203 (06:41 Z)

Largely inert satellites chosen, some with external reference orbits

Data Curation and Exchange Issues

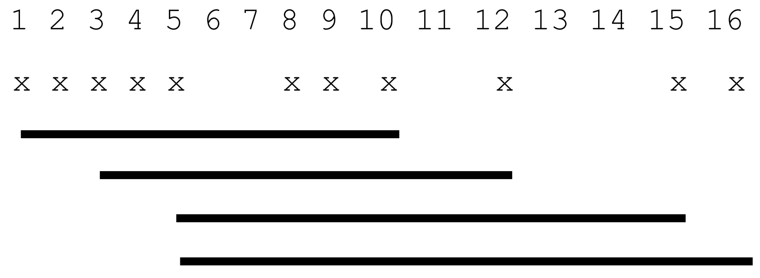
Lesson Learned: Allocate Plenty of Time/Effort for this Activity!

- Some sensor types may not be used by both entities, and software sets may not thus accommodate them
  - *Bistatic radars not used by US side; official software processing and tools not prepared to handle this*
- Different strategies for observation correction may be in use
  - *Require all corrections to be applied to obs before sending (bias removal, aberration and ionospheric corrections)*
- Different formats and coordinate systems may also be employed
  - *B3 vs CCSDS data formats; astronomical vs geodetic latitude/longitude*
- Sensor data rates may be substantially different, thus overweighting the higher-tempo submitters
  - *Track weighting or similar stratagem needed for compensation*
- Sensor locations and calibration information need to be exchanged/coordinated

Issues encountered with all of these—resolutions achieved, but sometimes after much labor

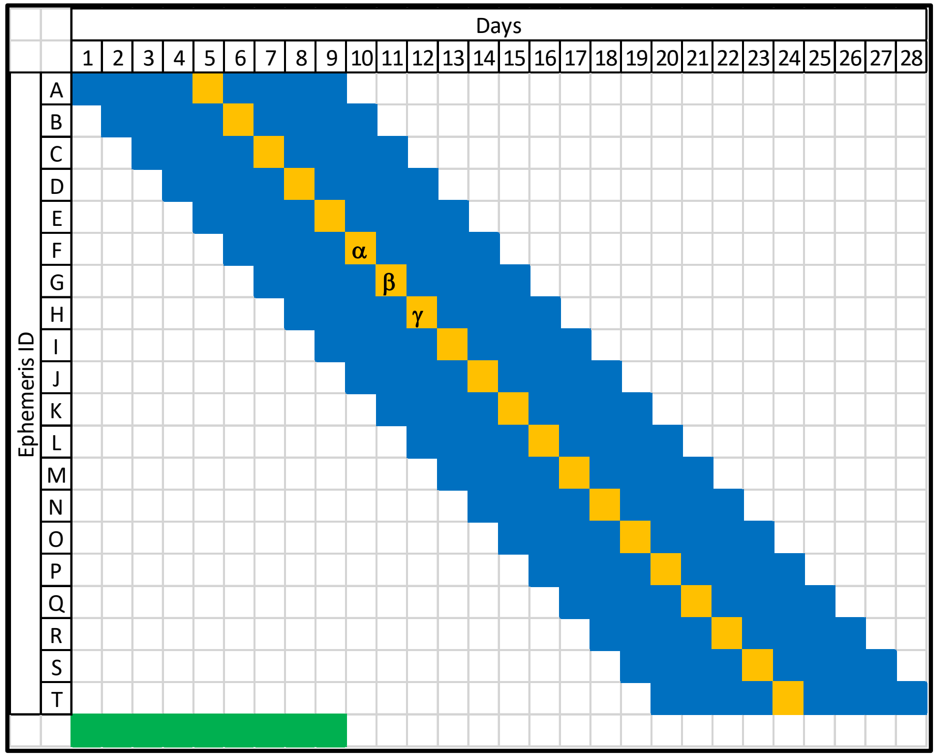
Orbit Determination and Prediction Approach for Experiment

- Data coherence test for each satellite
  - *Do a single least squares fit over all 60 days of observations from the other party; identifies presence of significant maneuvers and errors in sensor usage*
- Perform daily moving-window batch fits of the three strains of observation data (EUSST, US, both)
  - *Handling tracking data gaps*



Fit [1,10] pred 1, 2, 3
No fit [2,11] since no new data on 11, no preds
Fit [3,12] pred 1, 2, 3
No fit [4,13] since no new data on 13, no preds
No fit [5,14] since no new data on 14, no preds
Fit [5,15] pred 1, 2, 3
Fit [5,16] pred 1, 2, 3

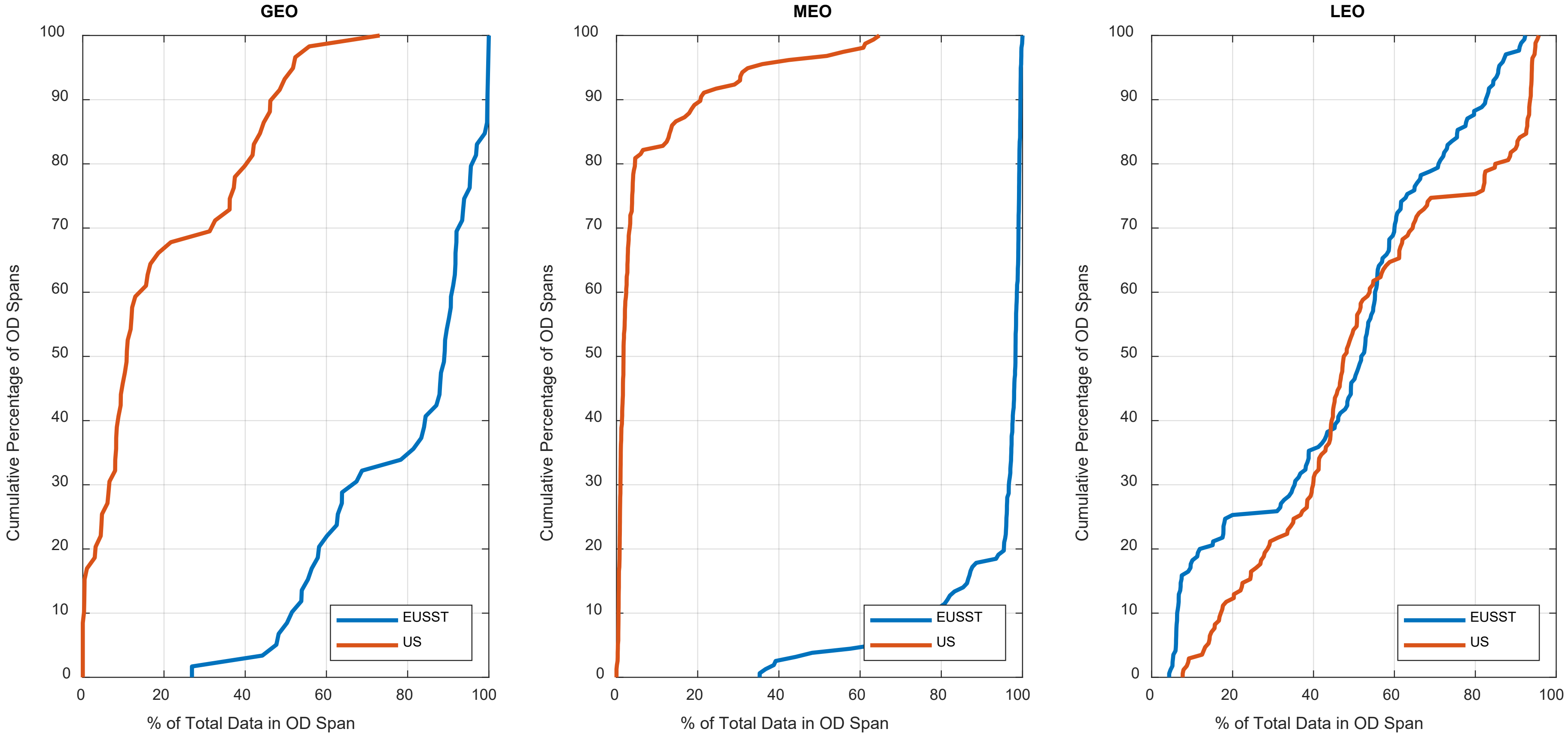
  - *Prediction assessment without reference orbits*



Improvement Metric: Quantity of Tracking

Based on observation count

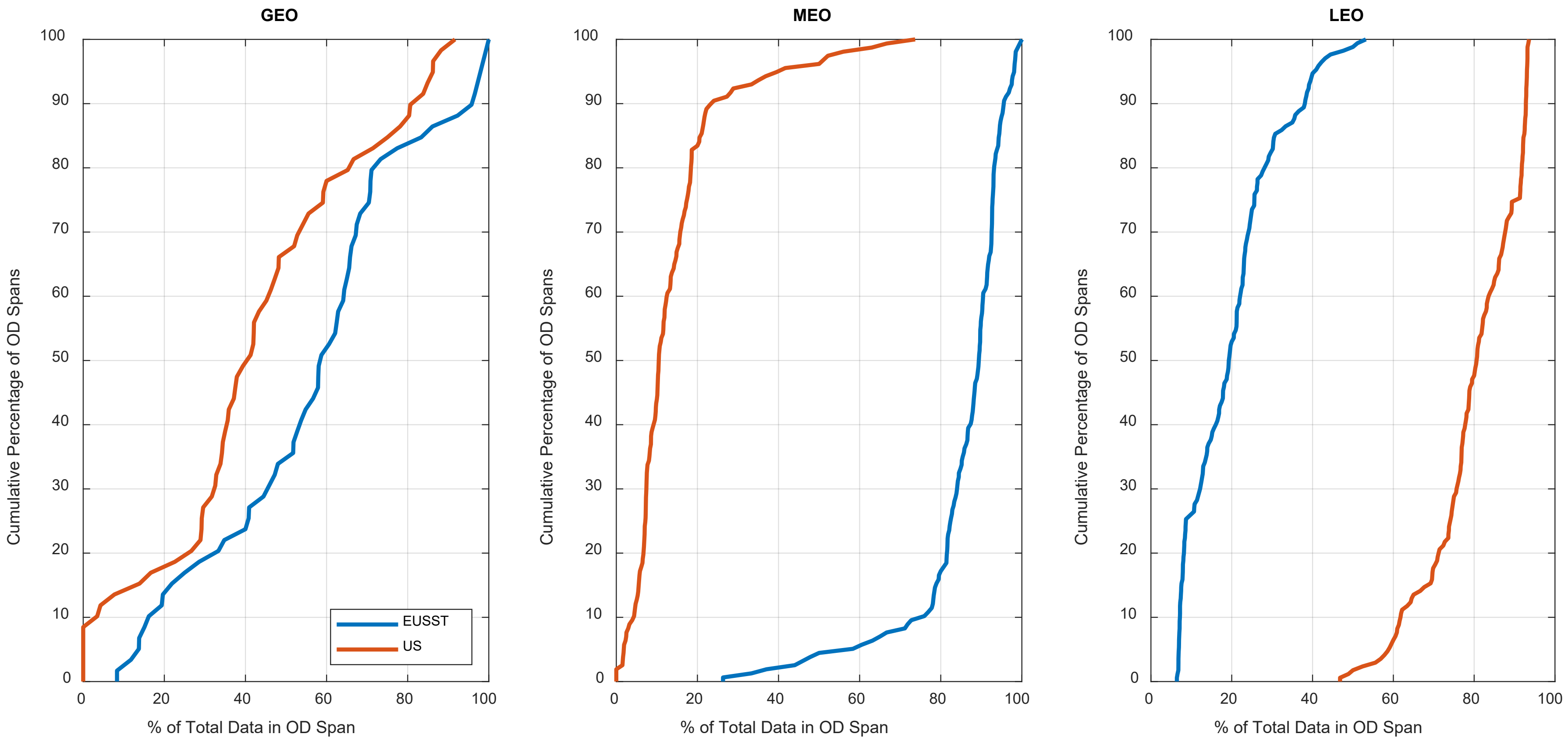
- Fresh tracking allows an OD update anchored on an actual measurement
  - *Reduces amount of prediction for CA (or other applications), thus improving accuracy*
- Metric: % of days in the 60-day data window for which fresh tracking was available



Improvement Metric: Quantity of Tracking

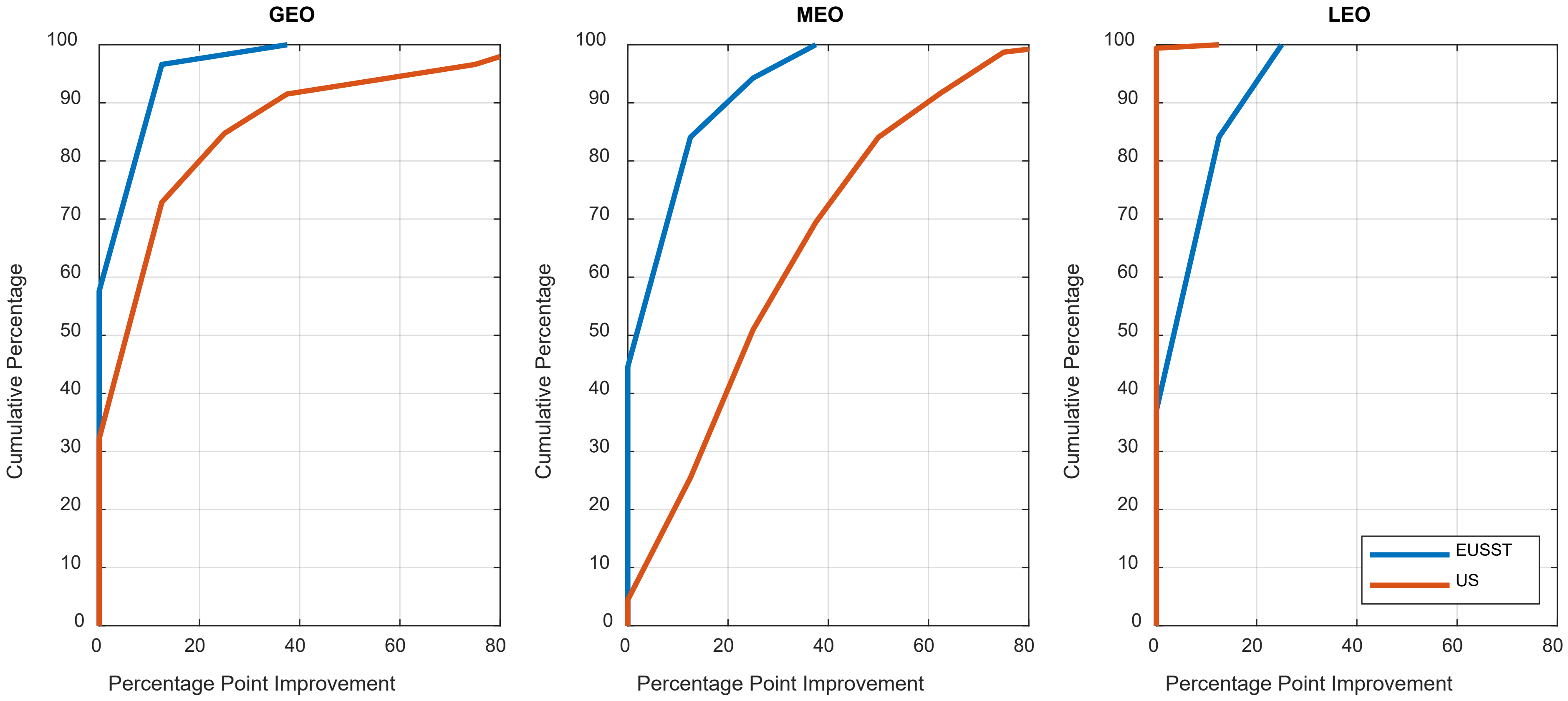
Based on track count

- Fresh tracking allows an OD update anchored on an actual measurement
  - *Reduces amount of prediction for CA (or other applications), thus improving accuracy*
- Metric: % of days in the 60-day data window for which fresh tracking was available



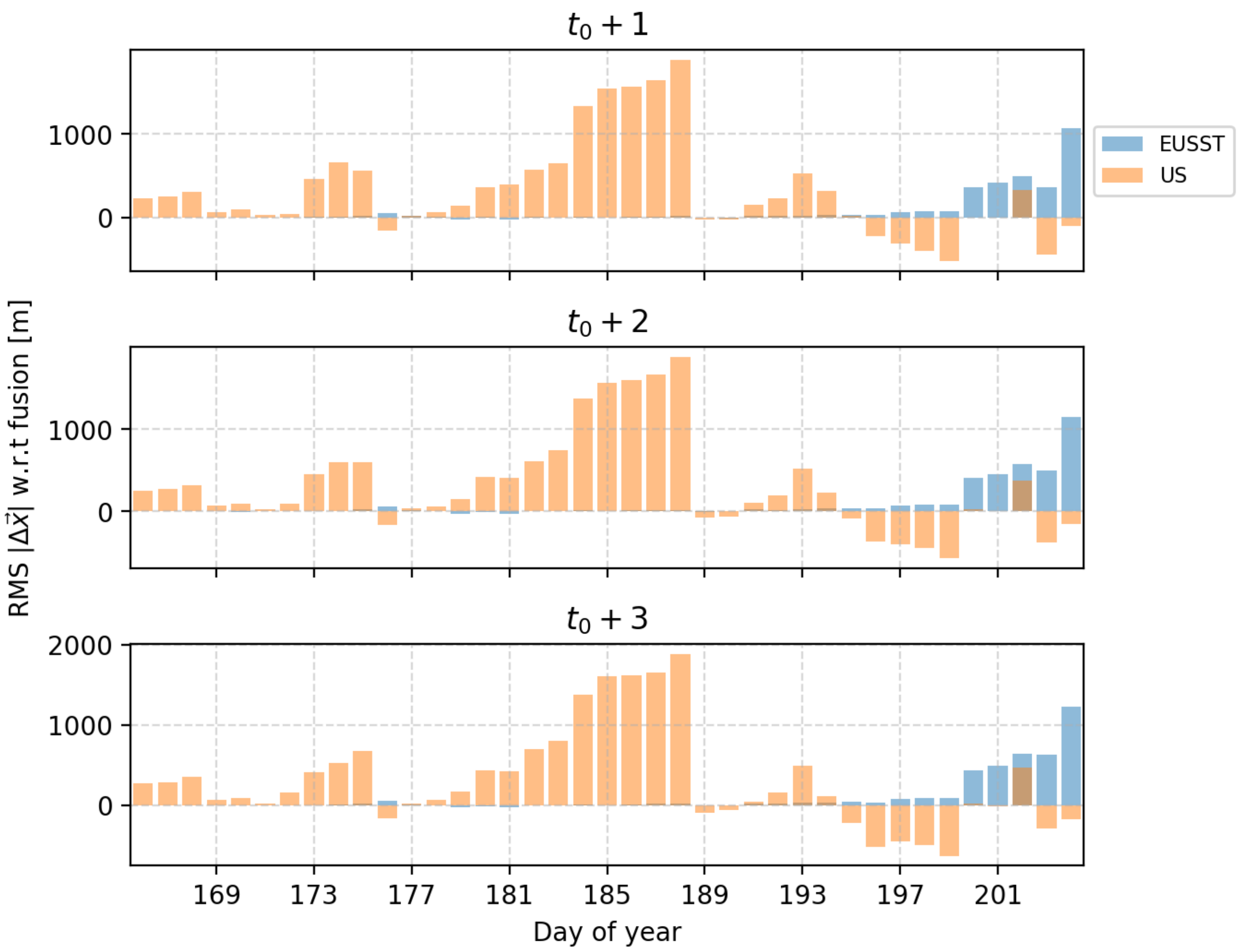
Improvement Metric: Orbit Dispersion of Tracking

- Favorable dispersion of tracking about the orbit improves overall fit and modeling throughout
  - *Especially helpful for CA, in which good modeling of orbit near TCA location important*
- Metric: % of argument of latitude bins populated for each satellite



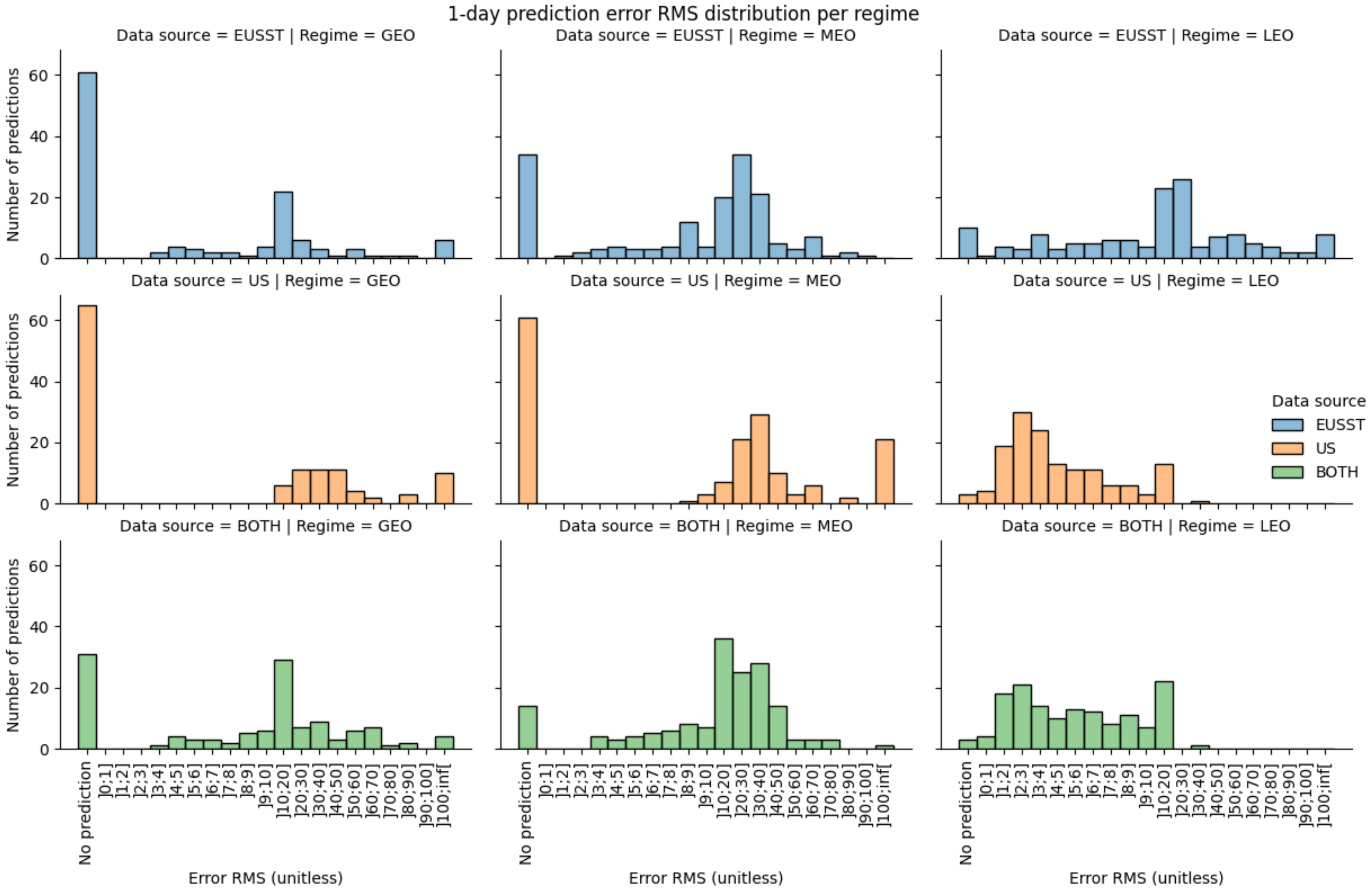
Comparison to Reference Orbit – Galileo 21

Relative improvement reveals tracking data gaps for each entity



Improvement Metric: Prediction Error Improvement (% at 1, 2 , 3 days)

- More plentiful and better distribution of tracking improves vector prediction error
  - *Because CA is always performed in prediction, reducing prediction error is important*



Conclusions

- The precision and robustness of orbit determination and propagation is improved when combining the data, solving data gaps, coverage, network availability issues and reducing the update intervals

- The benefits of data fusion are maximized when data scarcity comes into play

- In some situations, the combination is better than either of its parts

- In other cases, it is more of a one-sided approach, where one provider is filling in the data gaps of the other

- Overall, there are significant benefits to data sharing at the observation level both in temporal coverage and improved prediction accuracy.

Future Work

- Examine data sharing effect on the covariance accuracy and realism
- Real-time exchange for CA events of interest
- Comparison of observation level data fusion with ephemeris level data fusion

Sharing data at the observation level facilitates direct assessment of sharing benefits

Backup Slides

Results Summary

		EUSST		US	
		Temporal coverage	Prediction error	Temporal coverage	Prediction error
Combined	GEO	Significant improvement	Significant improvement	Significant improvement	Significant improvement
	MEO	Significant improvement	Inconclusive	Significant improvement	Significant improvement
	LEO	Slight improvement	Significant improvement	No improvement	Inconclusive