Ground and Inflight Calibrations of GPS Transmit Antennas

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DLR

Manufacturer Calibrations of GPS Transmit Antennas

Block	Gain, Phase	PCO
IIR	Marquis (2015)	NGA (2014, 2020)
IIR-M	Marquis (2015)	NGA (2014, 2020)
IIF	Igwe (2023)	NGA (2014, 2020)
III	Fisher (2022)	Lockheed Martin (2021), NGA (2020)

https://www.navcen.uscg.gov/gps-technical-references
https://earth-info.nga.mil/php/download.php?file=gnss-precise


The GPS Block IIR/IIR-M Antenna Panel Pattern

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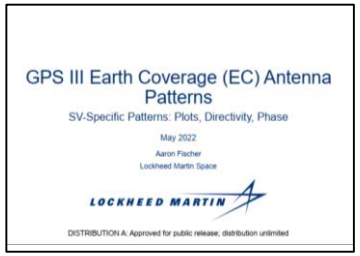
GPS III Earth Coverage (EC) Antenna Patterns

SV-Specific Patterns: Plots, Directivity, Phase

May 2022

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LOCKHEED MARTIN

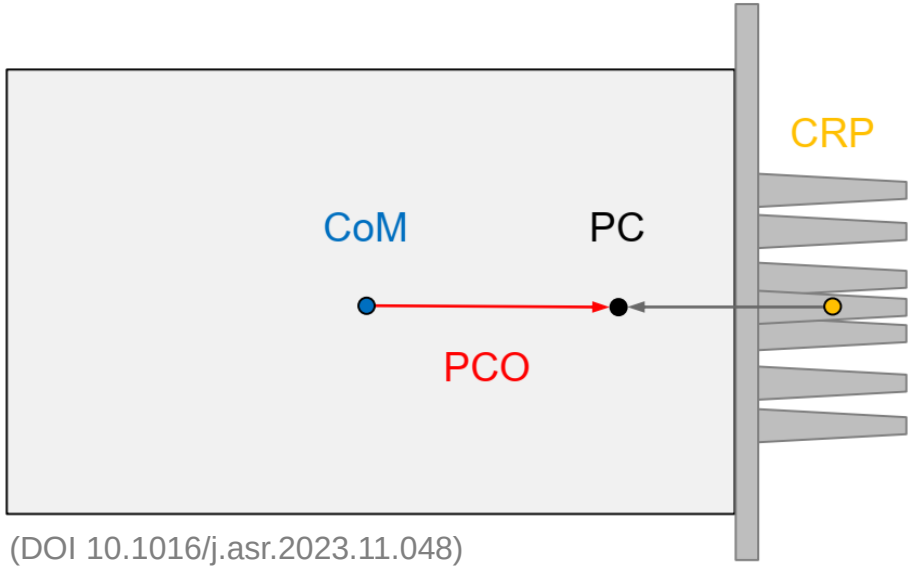
DISTRIBUTION A: Approved for public release, distribution unlimited

- Band-specific measurements for L1, L2, (L5)
- Focus on gain measurements (for space service volume)
- Phase calibrations lack proper documentation,
  raw data require extensive pre-processing (frame, wind-up, unwrapping)
- Phase patterns data refer to (unknown) calibration reference point
- NGA PCOs are (presumably) referred to L1

IIR-M panel (Hartman, ION GPS 2000)

Fundamentals

- Calibration Reference Point (CRP):
  reference point used for phase measurements in ground calibration
- Center-of-mass (CoM):
  reference point for IGS antenna model
- Phase Center (PC):
  center of sphere approximating* the wavefront
- Phase Variation (PV):
  line-of-sight dependent phase range relative to agreed-upon** reference point
- Phase Center Offset (PCO):
  Vector from reference point (mostly CoM) to PC

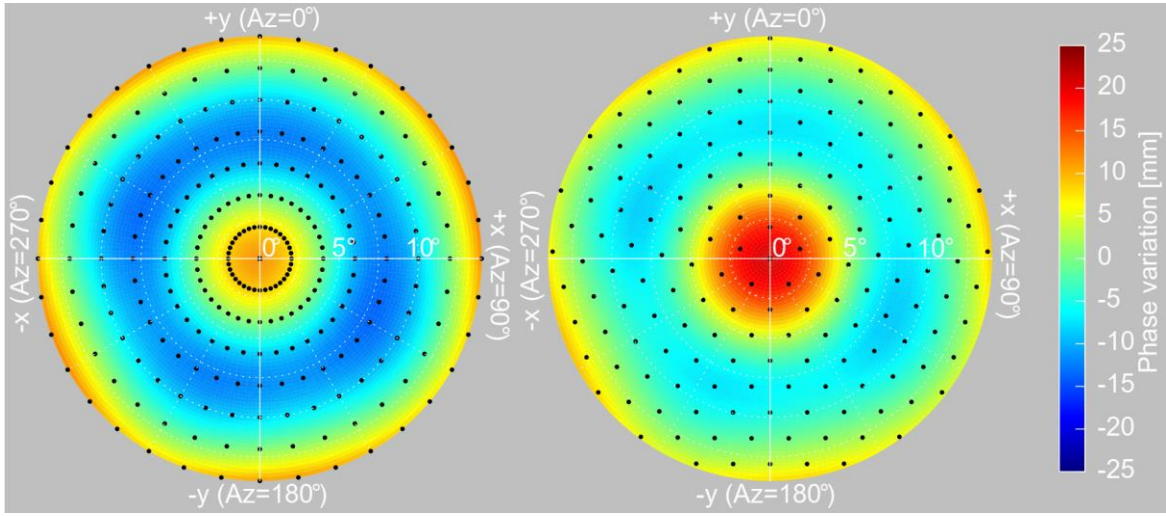


(DOI 10.1016/j.asr.2023.11.048)

Caveats:
* Depends on loss function for minimization of wavefront deviation from sphere
** Must ensure consistency of PC and PV

Phase Center Definition

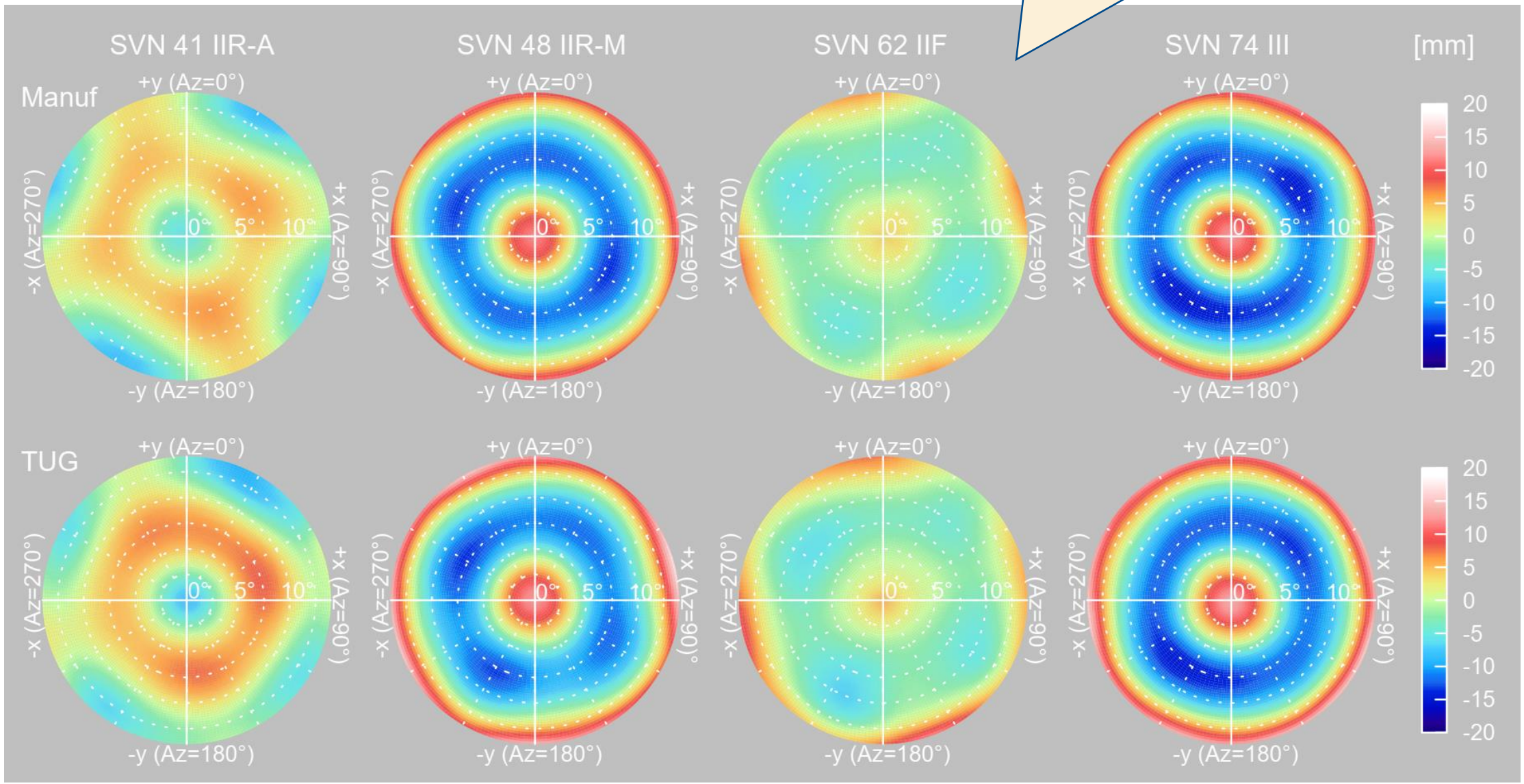
- PC depends on grid and weights used for “flattening” PV
- Inspection of GPS III calibrations suggests that manufacturer uses (Az,θ) grid with equal weight (and Δθ, ΔAz=2°)
- This
  - suppresses the “red nose”
  - is roughly compatible with azimuth-averaged IGS patterns
  - but does not reflect the natural distribution of GNSS observations nor elevation weighting in PPP/POD



Block IIR-M pattern after minimization on equidistant Az,θ grid (left) and isotropic grid (right)

GPS Phase Patterns

Good match of manufacturer calibrated patterns with estimated patterns of TUG after harmonizing the phase center concept (flattening condition)

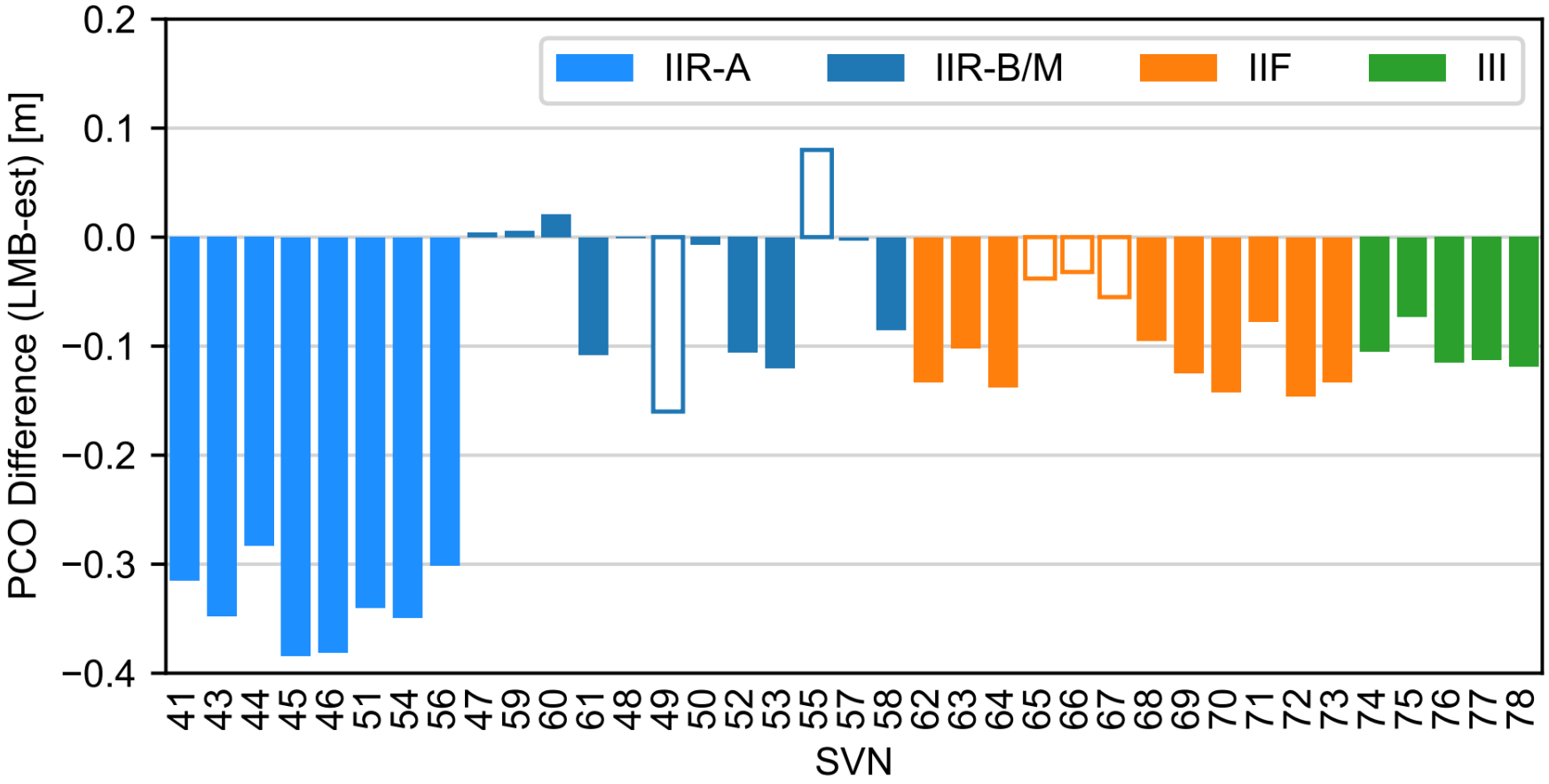


GPS PCOs

A bit of black magic and empiricism

- Manufacturer phase calibrations refer to unknown CRP
- NGA has published PCOs of unknown nature (for use in GPS ground segment)
- Comparison of NGA with LM PCOs for GPS III
  suggests that NGA provides L1 PCOs (relative to CoM)
- Phase center (relative to CRP) can be derived by minimizing difference of measured phase from sphere around PC on agreed upon grid (see slide 4)
- CRP to CoM offset from comparison with NGA L1 PCOs

Z-PCO Comparison with igs20.atx



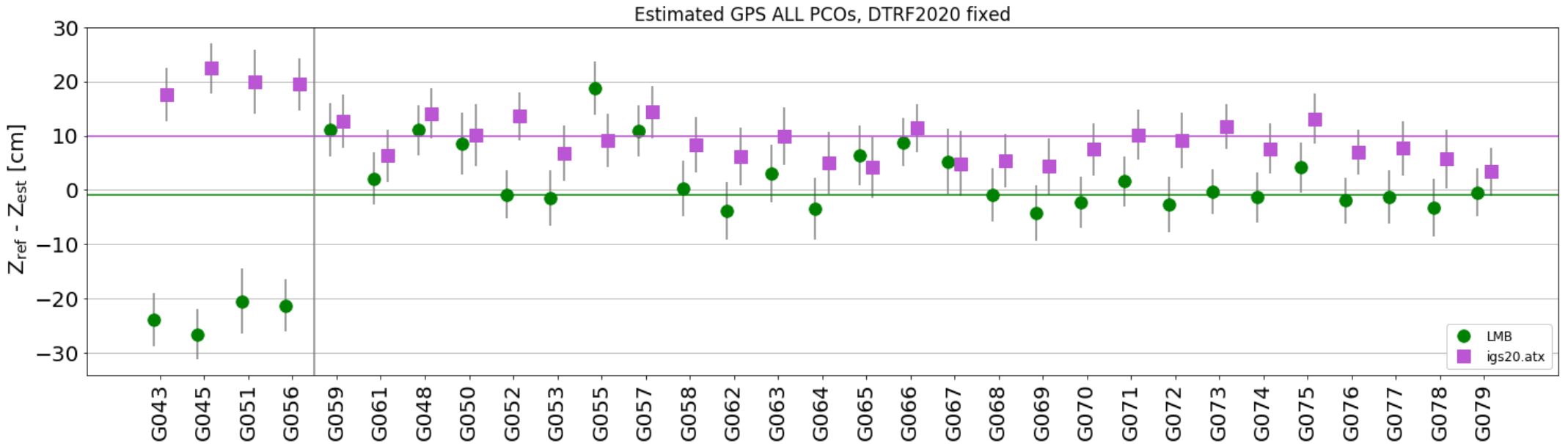
- ~ –12 cm offset for GPS III, IIF, and (partly IIR-B/M)
- Large discrepancy for IIR-A (different calibration chamber)

lmb20.atx

- Frequency-specific phase patterns from manufacturer
  - 2-dimensional
  - up to 20° (to support LEOs)
- Frequency-specific manufacturer PCOs plus common correction to align L1/L2 with IGS20 frame
  - Block-specific offsets estimated for GPS III and IIF
  - Satellite-specific offsets estimated for GPS IIR, IIR-M
- Publicly available for community testing (electronic supplement of DOI 10.1007/s00190-023-01809-y)

Scale Contribution

- Scale offset between manufacturer calibrations of GPS III, IIF, IIR-B/M and IGS20 is close to that of Galileo manufacturer calibrations (12 cm PC shift @ GPS corresponds to 15 cm @ Galileo)
- Good consistency of GPS III, IIF, IIR-B/M manufacturer PCOs with estimated PCOs aligned to DTRF2000 (which inherits repro3/Galileo scale)



Summary

- Comprehensive set of manufacturer calibrations made available for all current GPS satellites
- Trustworthy phase patterns (2D, available up to 20° and up)
- Missing info on calibration reference point replaced by “creativity”
- Prepared igs20.atx compatible “lmb20.atx” antenna model
- GNSS TRF scale implied by manufacturer calibrations of GPS III, IIF, IIR-B/M and Galileo appear largely consistent