# GPS III radiation force modeling

F. Dilssner, T. Springer, E. Schönemann, W. Enderle

28/06/2022

# Background

- No pre-launch engineering information from manufacturer available to build solar/thermal force models needed for GPS Block III spacecraft precise orbit determination (POD)
  - Need to determine Block III radiative force model from flight data
- Technique/parametrization similar to JPL's GSPM approach (Bar-Sever and Kuang, 2004)
  - Dynamical long (9-day) arc fitting to precise orbit data
  - Radiation force represented as a truncated Fourier expansion about Earth-Satellite-Sun angle
  - Iterative adjustment of Fourier coefficients together with orbit state, Y-bias and along-track CPR parameters
  - Combination on normal equation level to form robust set of satellite-/satellite-group-specific force models
- Advantageous in several aspects over physics-based models such as "box-wing"
  - Reflects actual in-orbit properties
  - Does not require spacecraft surface dimensions or any optical/thermal properties
  - Straightforward to implement into existing POD software

# Sensitivity to solar radiation pressure (SRP)

- Dimensions of Block III SVs substantially different to previous Block II
  - 2161 kg on-orbit mass, about 500 to 1200 kg heavier than predecessors
  - SV body much more cuboid, X face almost twice as large as Z face
- Estimate effect the varying cross section of SV body has on SRP
  - Difference maximum minus minimum radiated area divided by mass
  - Sensitivity factor among GPS satellite family is highest for Block III, indicates strong need for a-priori background model

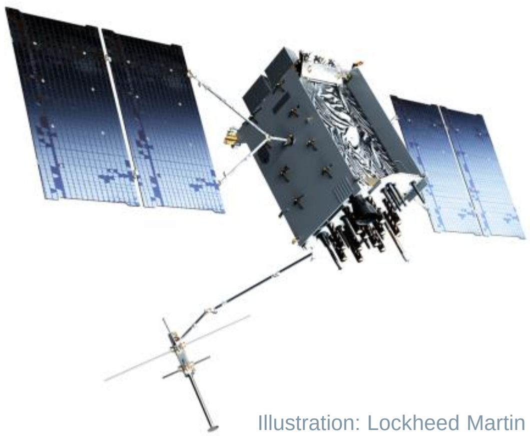
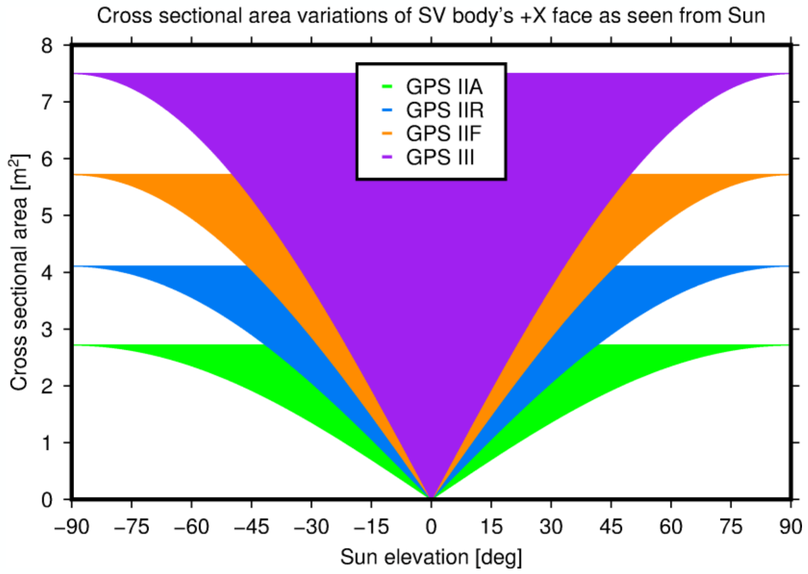


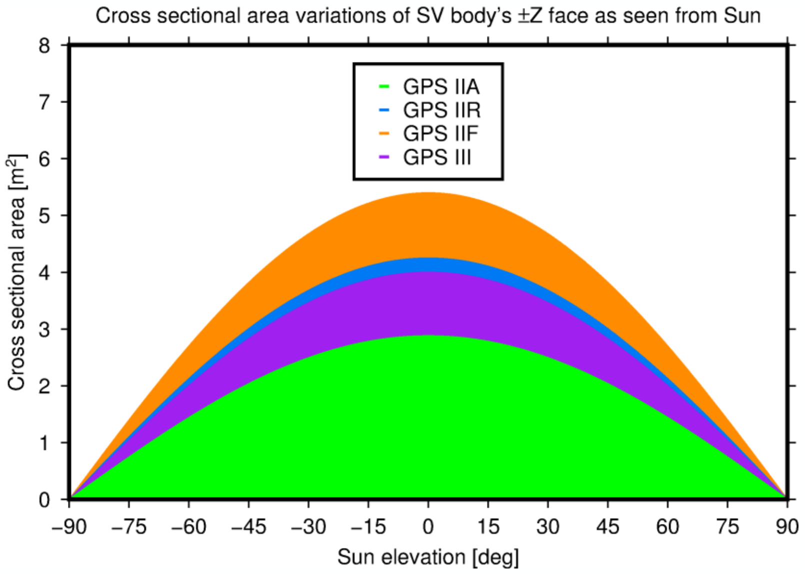
Illustration: Lockheed Martin

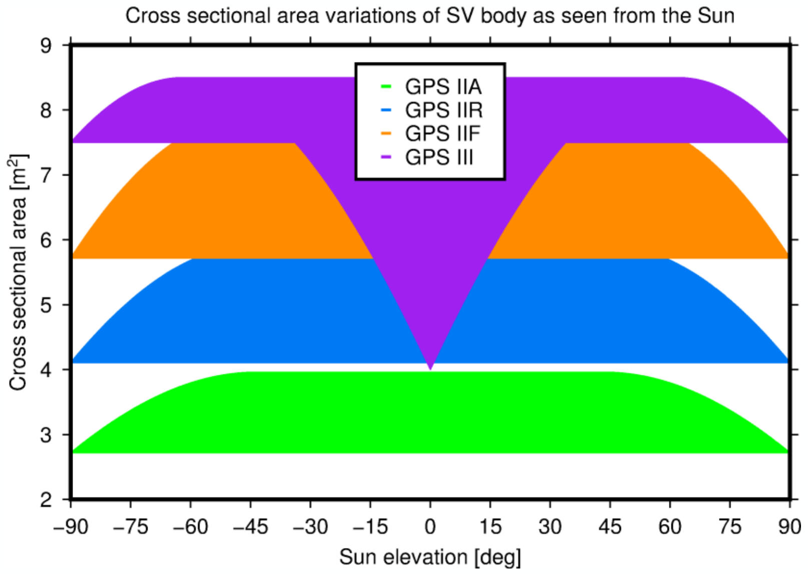
| GNSS SV | x-panel [m²] | z-panel [m²] | $A_{max} - A_{min}$ [m²] | m [kg] | ΔA/m [m²/kg] |
|---|---|---|---|---|---|
| Galileo FOC | 1.32 | 3.04 | 1.99 | 700 | 0.0028 |
| GPS III | 7.50 | 4.00 | 4.50 | 2161 | 0.0021 |
| GPS IIR | 4.11 | 4.25 | 1.80 | 1080 | 0.0017 |
| GPS IIF | 5.72 | 5.40 | 2.47 | 1633 | 0.0015 |
| GPS IIA | 2.72 | 2.88 | 1.24 | 930 | 0.0013 |

# Sensitivity to solar radiation pressure (SRP)

- Plotting of the satellite body's cross sectional area (A) exposed to sunlight as function of the Sun elevation angle ("beta prime")
- Variation of A over the arc depends on beta prime and so does the sensitivity against SRP
  - The lower the Sun, the larger the variability of A and of the force acting on A
- Increasing sensitivity for Block III SVs when going below 34º beta angle



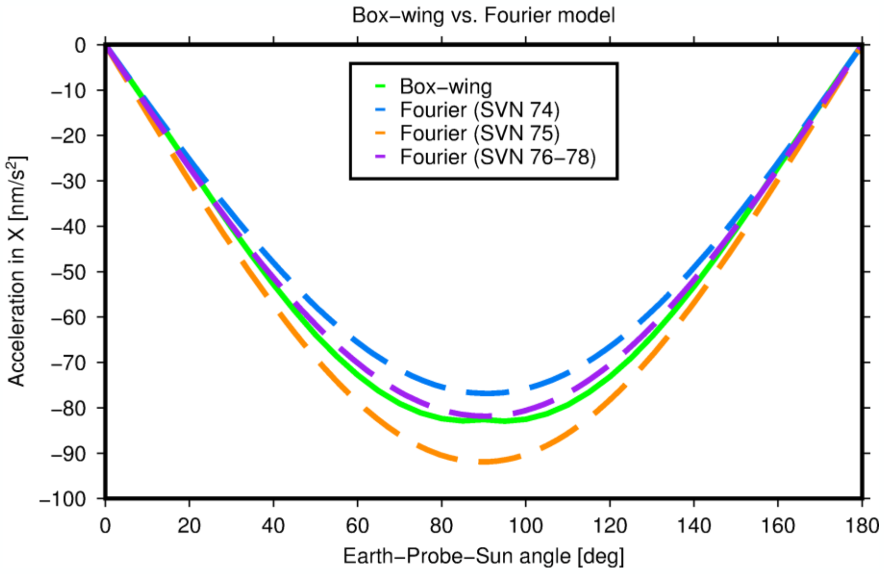



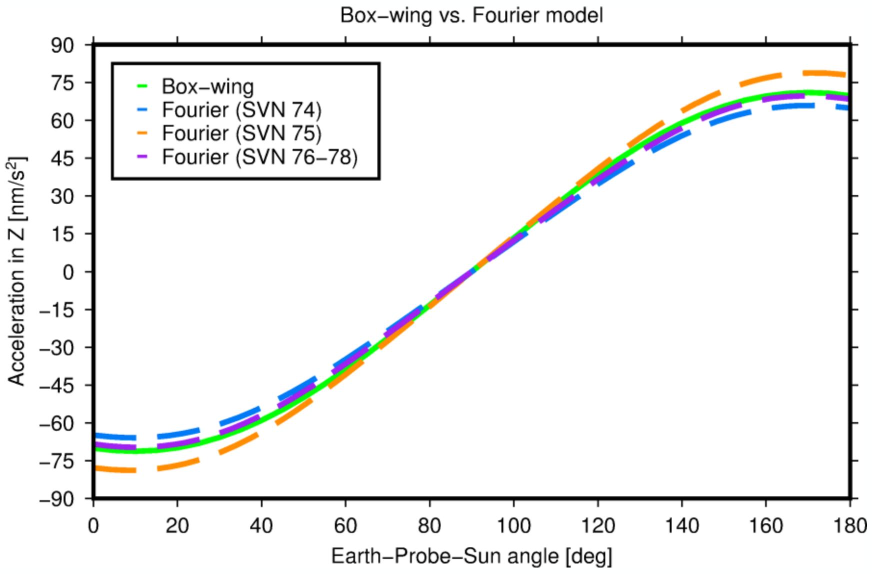
# Empirically-derived radiation force models

- Models developed based upon up to 2.5 years of daily GPS orbits from ESOC's MGNSS Final processing and the following low-order Fourier series in body-frame XZ plane:

$$\boxed{\begin{aligned} X &= XS1\sin(\epsilon) + XS2\sin(2\epsilon) + XS3\sin(3\epsilon) \\ Z &= ZC1\cos(\epsilon) + ZS2\sin(2\epsilon) + ZS4\sin(4\epsilon) \end{aligned}}$$

- SVN 74-75 showing different response to radiation pressure compared to SVN 76-78
  - Requires creation of separate, satellite-specific models for SVN 74 and 75
  - Fourier models for SVN 76-78 fairly consistent and similar to box-wing



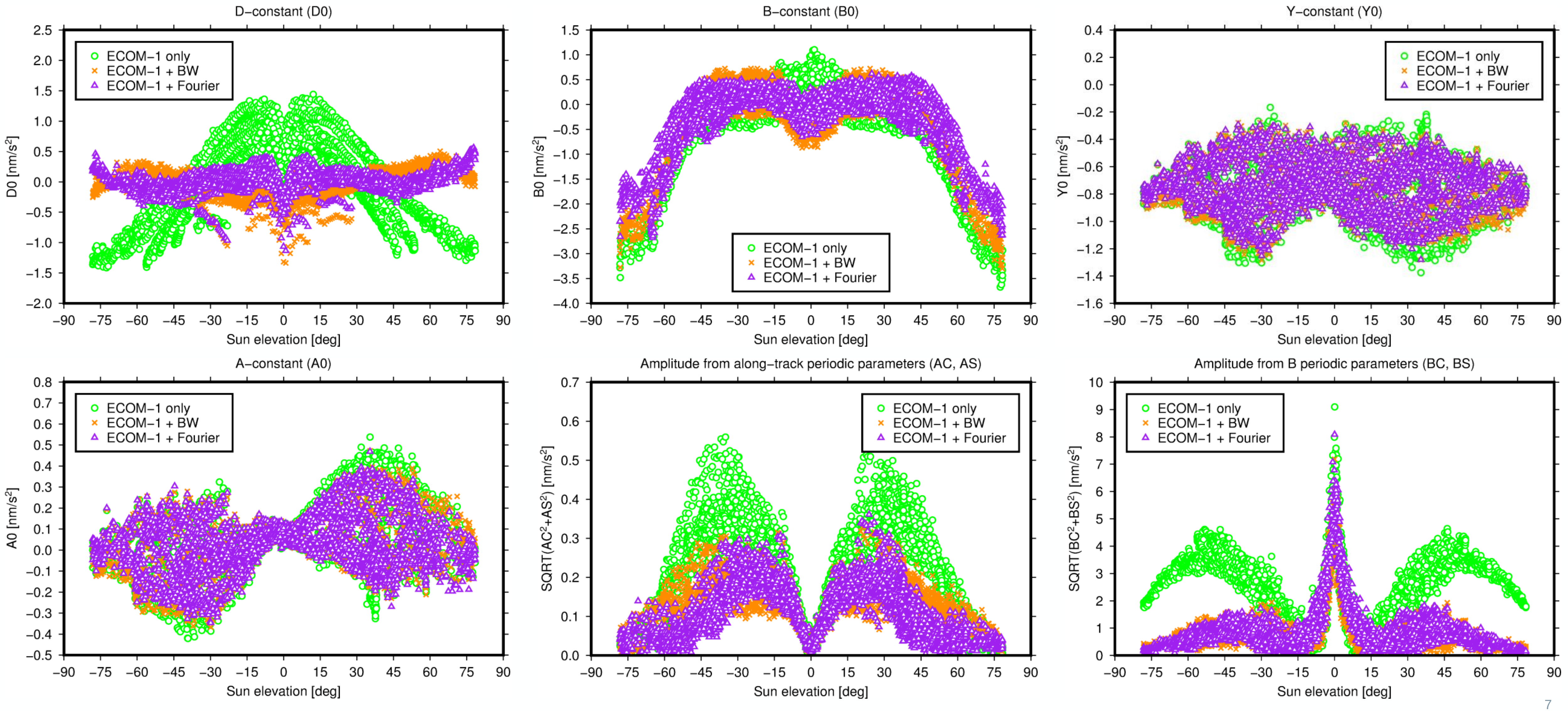
# Model evaluation

- Generate 24-hour arc test solutions spanning January 2020 to May 2022
  - 150 station global network
  - Five solutions based on identical data, the only difference being the force model applied (see below)

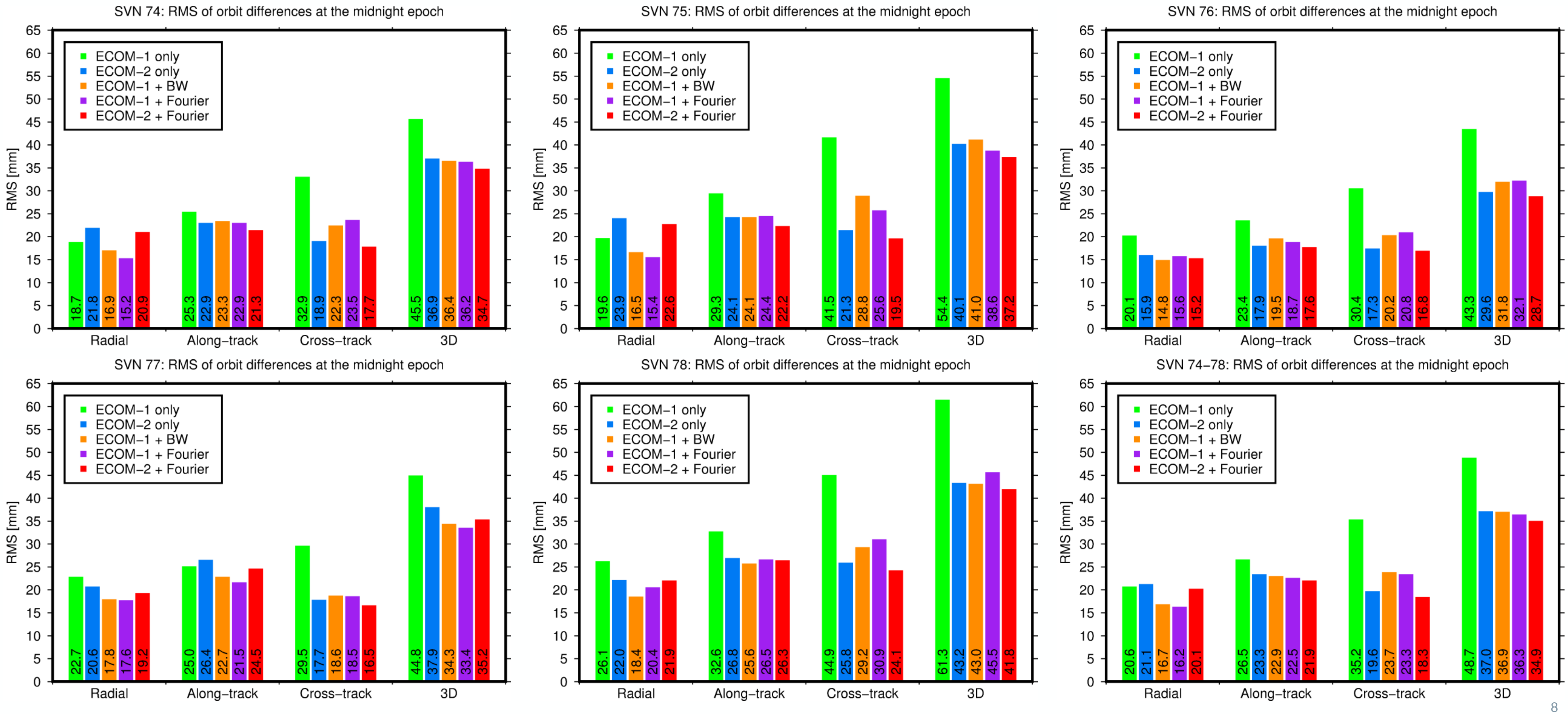
| Force model | Parameterization |
| --- | --- |
| ECOM-1 only | Five-parameter ECOM (D0, Y0, B0, BC, BS) plus three tightly constrained along-track CPRs (A0, AC, AS) and no a-priori model |
| ECOM-2 only | Same as strategy 1 but with additional twice-per-revolution terms (D2C, D2S) in satellite-Sun direction |
| ECOM-1 + BW | Same as strategy 1 but with a-priori box-wing model (Steigenberger et al. 2020) |
| ECOM-1 + Fourier | Same as strategy 1 but with a-priori Fourier model |
| ECOM-2 + Fourier | Same as strategy 2 but with a-priori Fourier model |

- Check radiation pressure estimates and variability over beta angle
- Compute "overlaps" at midnight epoch as "worst case" estimate of the satellite orbit quality

# ECOM & CPR estimates



# Overlap results



# Summary & Conclusions

- GPS Block III spacecraft more sensitive to SRP force as its Block II predecessors
- Low-order Fourier models to account for combined radiation forces acting on first five SVs developed
- Fourier approach valuable tool when spacecraft surface properties are missing
- Use of Fourier models along with ECOM-1 leading to 25 percent reduction in 3D orbit overlap RMS over solution with ECOM-1 only
  - Orbit component benefiting most from advanced modelling is across-track
  - Results as good as or even better than those with box-wing or seven-parameter ECOM-2
- Remaining systematics in some of the ECOM estimates, especially “BC” (see p. 7)
- More work needed to
  - identify optimal set of Fourier terms and
  - derive models for other GNSS satellites (e.g. BeiDou)