Impact of a-priori SRP models and ECOM models on GNSS precise orbit determination

Xiao Chang[1,2], Benjamin Männel[2], Harald Schuh[1,2], and Roman Galas[1]

1 Technische Universität Berlin, Institute for Geodesy and Geoinformation Technology, Berlin, Germany

2 GFZ German Research Centre for Geoscience, Geodesy, Potsdam, Germany

Contents

- 1.Motivation
- 2.Data and Methodology
- 3.Results and Analysis
- 4.Summary

CC BY

Contents

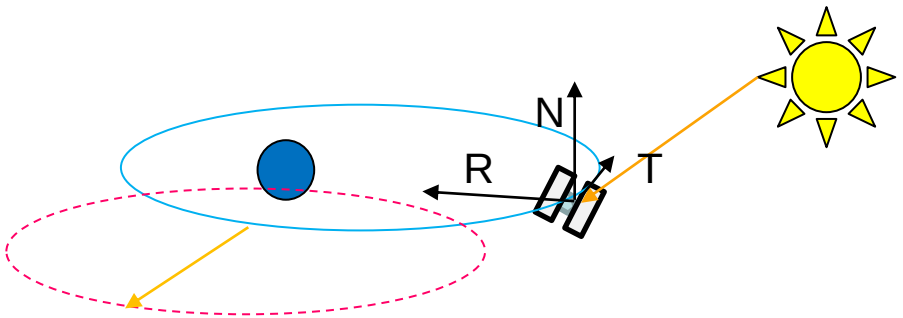
CC BY

- **Solar radiation pressure (SRP)**

Solar radiation is the most important perturbation after the oblateness J2, the sun and the moon (Fliegel et al.1996)

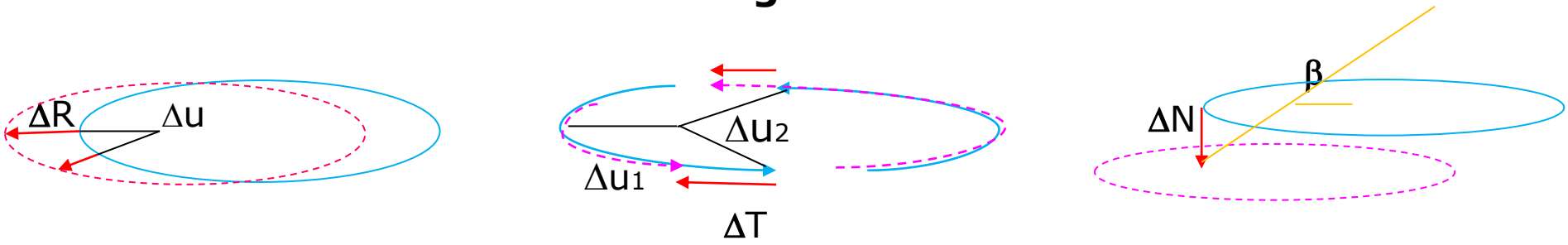
Table 1 Typical perturbations on a GPS SV after one revolution (12 h)

Perturbation	Magnitude, m
J2	15,600
Moon	880
Sun (gravitation)	420
Solar radiation	130
C (2,2), S (2,2)	120
C (3, m), S (3, m)(all m)	20



- **How SRP affect the orbit of GNSS satellites**

Radial **Tangential** **Normal**



- Inappropriate modeling of SRP leads to a Δu-related error for radial and tangential direction and β-related error for normal direction

CC BY

- **Solar radiation pressure models**

  Empirical Model: ECOM, GSPM
  Analytical Model: ROCK, Box-wing
  hybrid empirical-physical model: Adjustable Box-wing

- **How analytical and empirical model affect the GNSS precise orbit determination (POD)**

  ✓ The difference of POD based on different empirical models and to what extent the analytical model affect the POD of GNSS (The focus of this presentation)

  ✓ For different GNSS systems or types, if the existing models are enough to describe the SRP

  ✓ What is the “best” model or model combination strategy for current GNSS systems

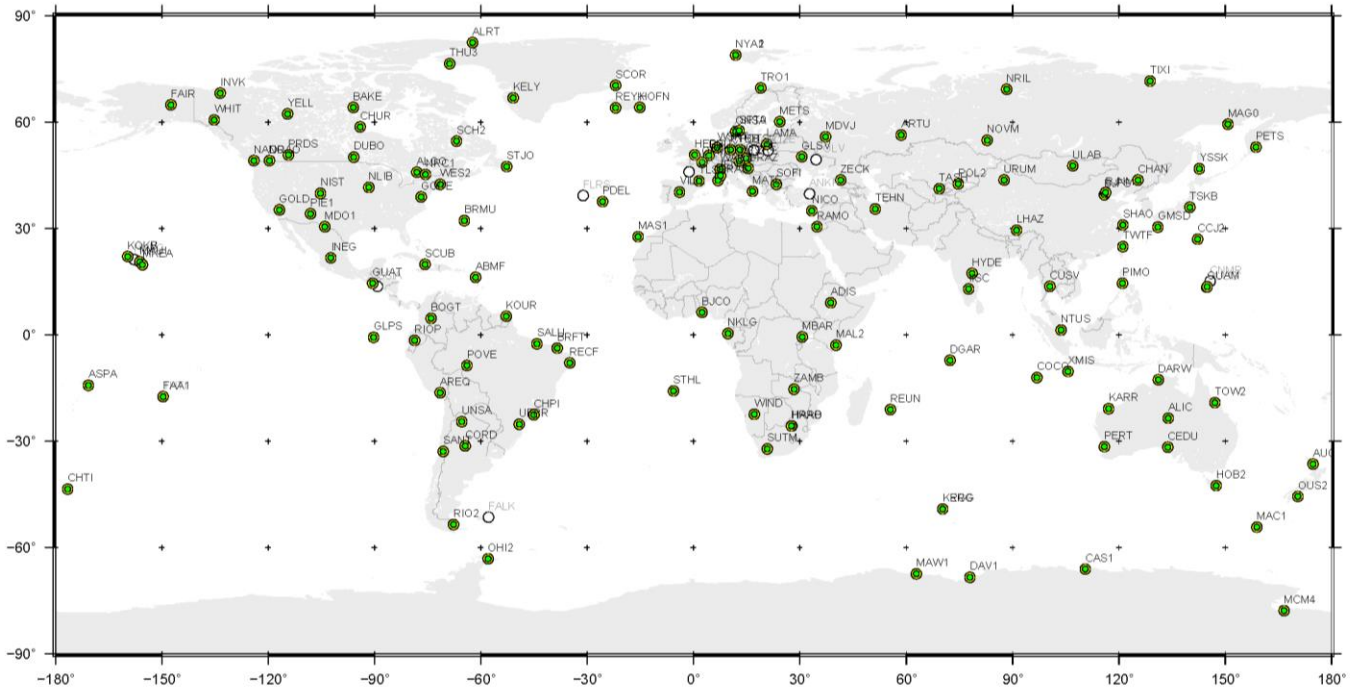
CC BY

Contents

CC BY

2.1 Data

- **Station Networks**



In this presentation, GPS is covered based on one year data (Y2018) of 143 stations

CC BY

2.2 Methodology

- **Models tested**

  - Analytical models: ROCK model (Fliegel et al.1992,1996.) and Box-wing model (Rodriguez-Solano et al. 2013)

  - Empirical models: 5-parameters' ECOM (Springer et al. 1999a) and new ECOM (Arnold et al. 2015)

ECOM1

$$\begin{cases} D(\Delta u) = D_0 \\ Y(\Delta u) = Y_0 \\ B(\Delta u) = B_0 + B_C \cos \Delta u + B_S \sin \Delta u \end{cases}.$$

ECOM2

$$\begin{cases} D(\Delta u) = D_0 + D_{2,C} \cos 2\Delta u + D_{2,S} \sin 2\Delta u + D_{4,C} \cos 4\Delta u + D_{4,S} \sin 4\Delta u \\ Y(\Delta u) = Y_0 \\ B(\Delta u) = B_0 + B_{1,C} \cos \Delta u + B_{1,S} \sin \Delta u \end{cases}.$$

CC BY

2.2 Methodology

- **Comparison strategy**

Scenario#	ECOM Parameterization	A-priori model
S1	ECOM1	/
S2	ECOM2	/
S3	ECOM1	Box-wing
S4	ECOM1	ROCK
S5	ECOM2	Box-wing
S6	ECOM2	ROCK

- Comparing S1 with S2: the difference of these two parameterization method on POD
- Comparing S1 with S3/S4: how a-priori model affect the POD on top of ECOM1 parameterization
- Comparing S2 with S5/S6: how a-priori model affect the POD on top of ECOM2 parameterization

CC BY

Contents

CC BY

3.1 ECOM

1. Orbit difference shows systematic change related to the Argument of Latitude w.r.t that of the midnight

2. Orbit difference of IIR and IIF differs in terms of the amplitude

- **Daily arc comparison of orbits based on two parameterization methods of ECOM**

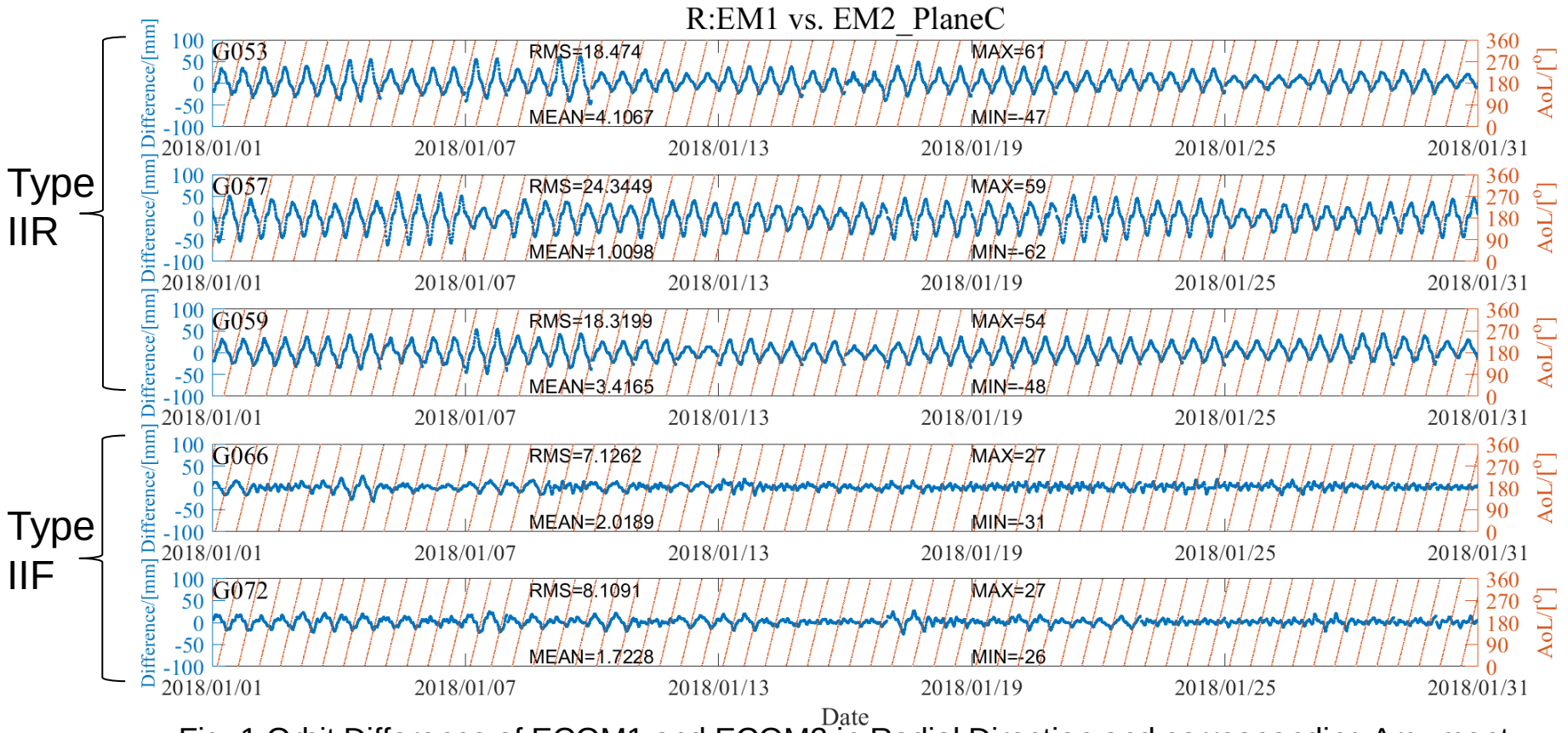


Fig. 1 Orbit Difference of ECOM1 and ECOM2 in Radial Direction and corresponding Argument of Latitude w.r.t that of the midnight (AoL) (Unit: mm/degree)

3.1 ECOM

1. Orbit difference shows systematic change related to the Argument of Latitude w.r.t that of the midnight

2. Orbit difference of IIR and IIF shows different peaks per revolution

- **Daily arc comparison of orbits based on two parameterization methods of ECOM**

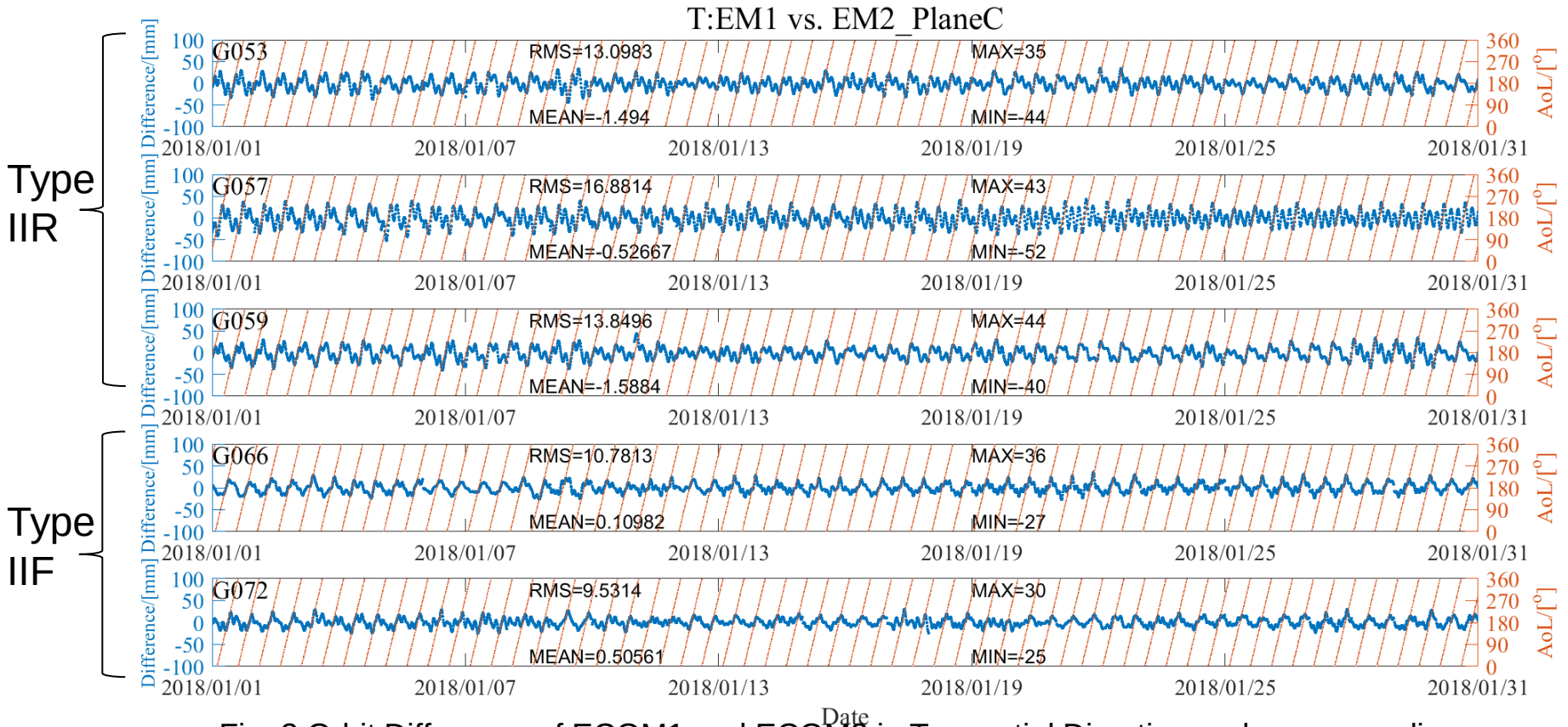


Fig. 2 Orbit Difference of ECOM1 and ECOM2 in Tangential Direction and corresponding Argument of Latitude w.r.t that of the midnight (AoL) (Unit: mm/degree)

CC BY

3.1 ECOM

1. Orbit difference of IIR show systematic change related to the Argument of Latitude w.r.t that of the midnight

2. The MEAN of orbit difference for IIR shows an obvious shift

- **Daily arc comparison of orbits based on two parameterization methods of ECOM**

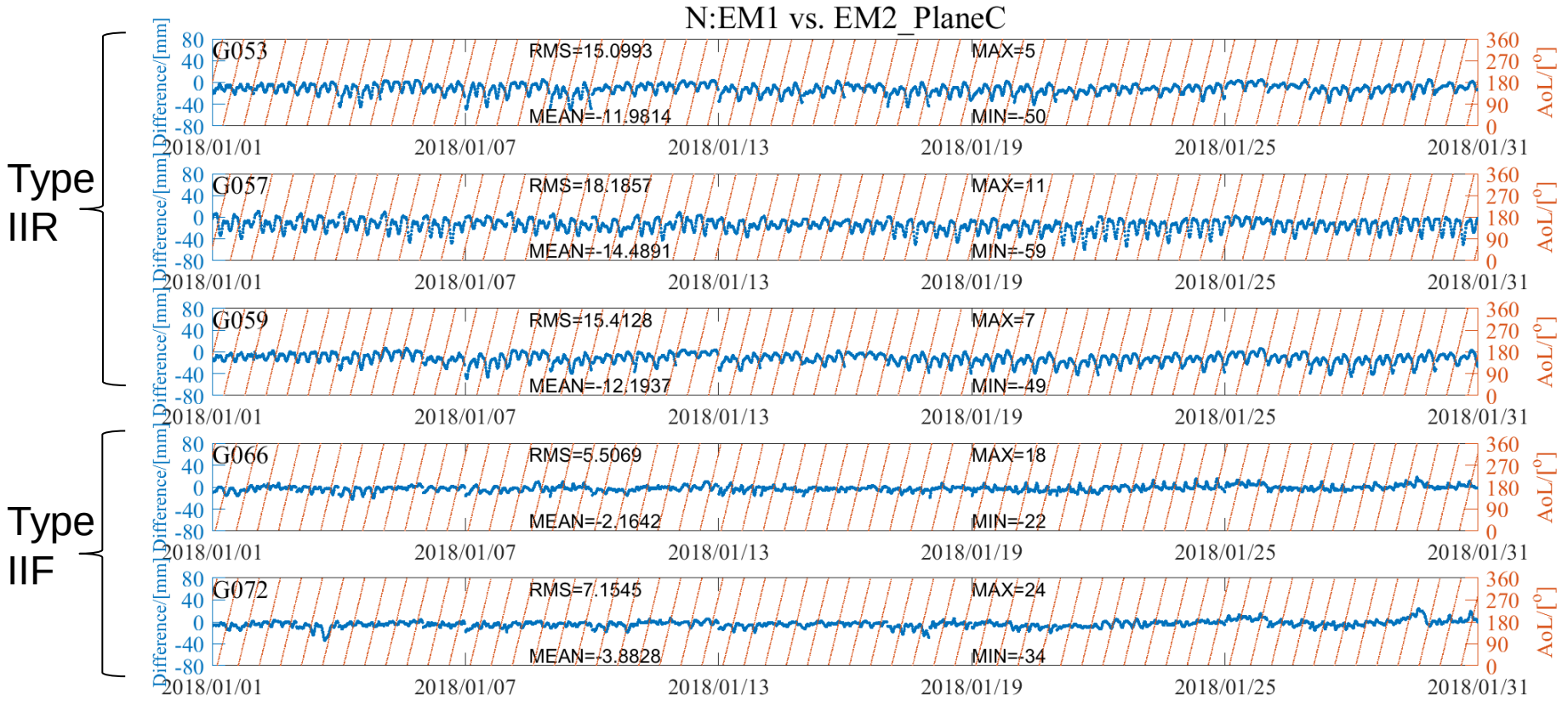


Fig. 3 Orbit Difference of ECOM1 and ECOM2 in Normal Direction and corresponding Argument of Latitude w.r.t that of the midnight (AoL) (Unit: mm/degree)

CC BY

3.1 ECOM

- **Orbit difference vs. Argument of Latitude w.r.t the midnight (AoL) and beta angel (β)**

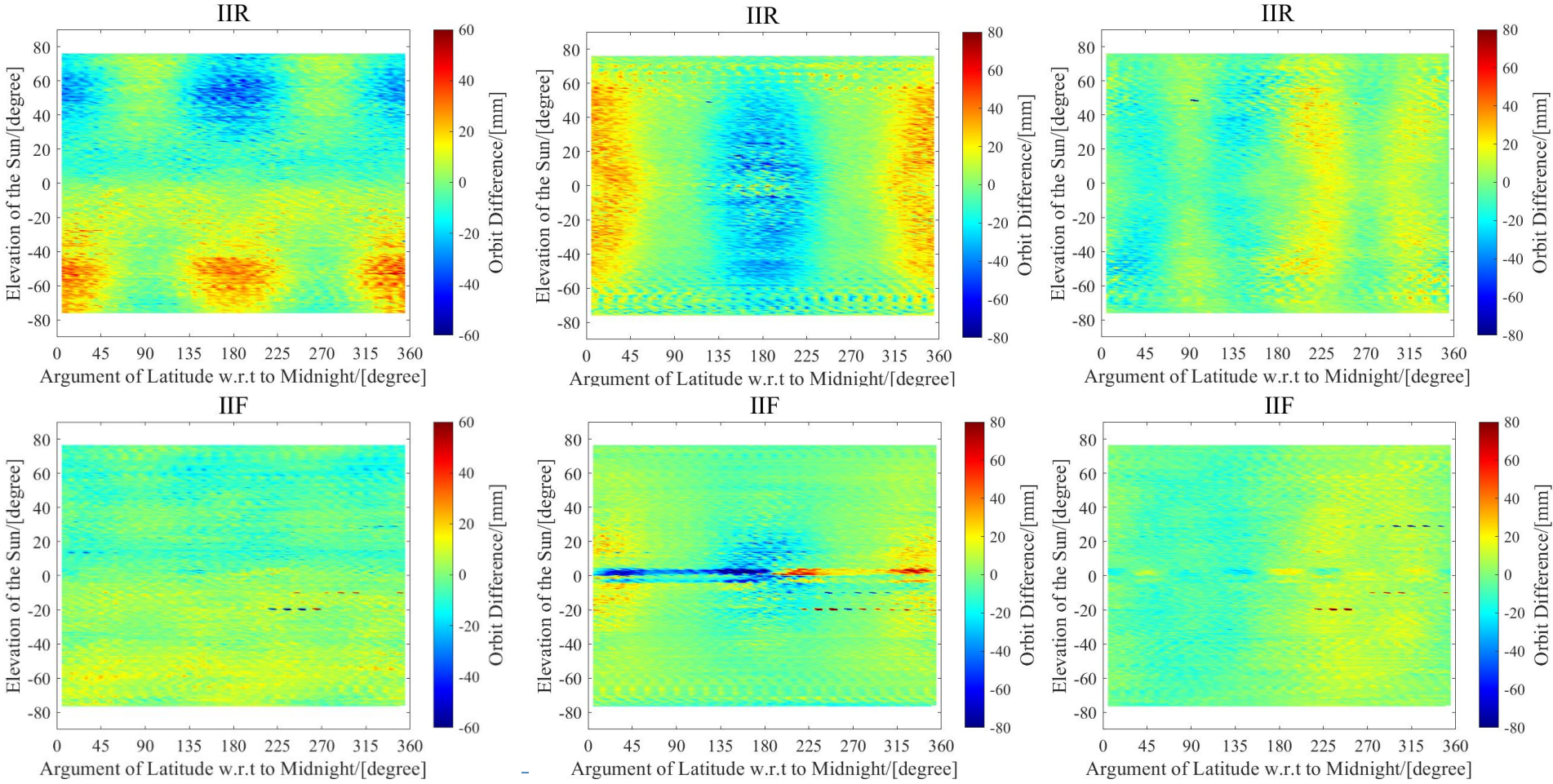


Fig. 4 Orbit Difference of ECOM1 and ECOM2 vs. AoL and β in N, R and T (Unit: mm)

3.1 ECOM

- **Orbit difference vs. Argument of Latitude w.r.t the midnight (AoL) and beta angel (β)**

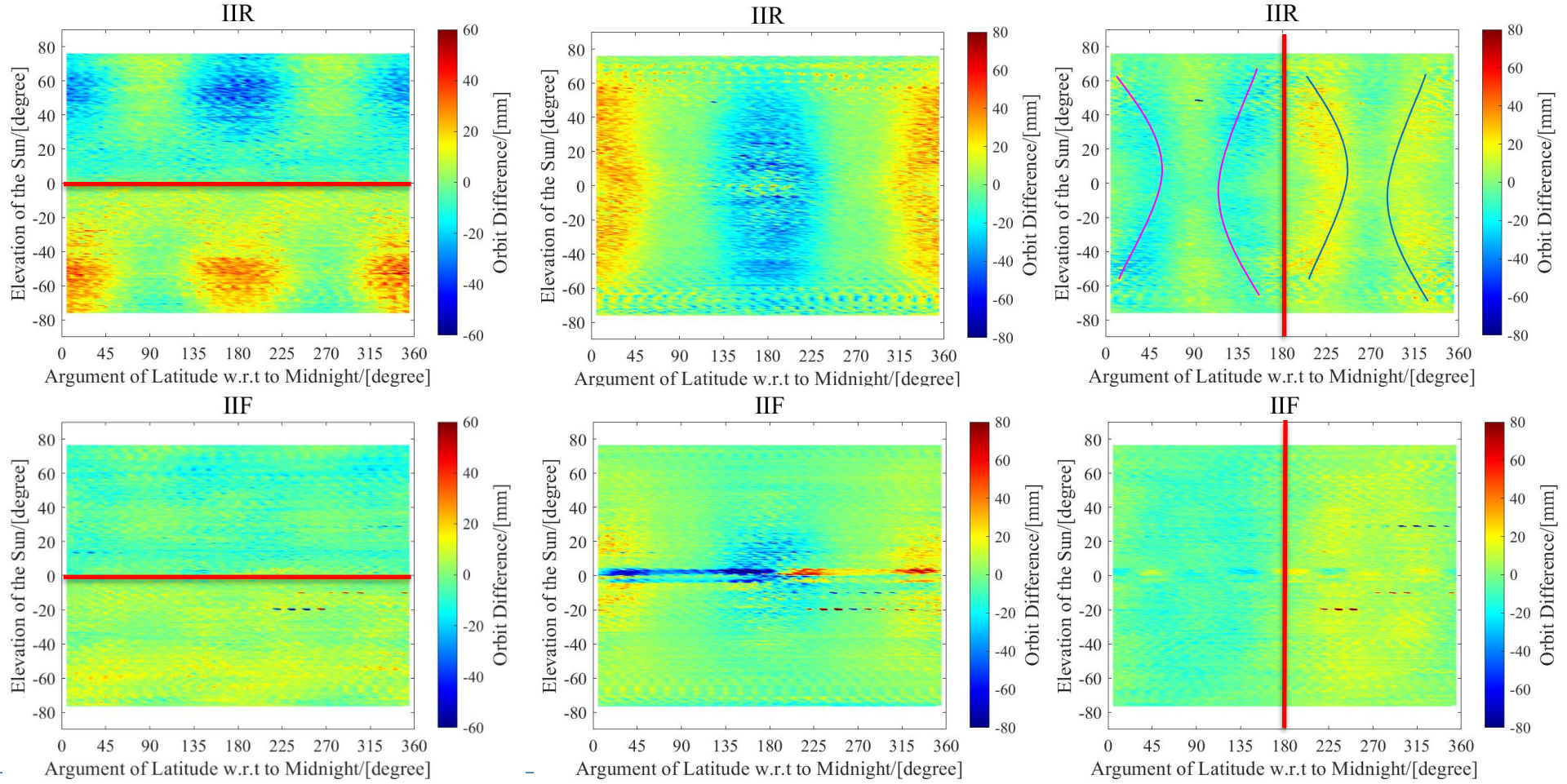


Fig. 4 Orbit Difference of ECOM1 and ECOM2 vs. AoL and β in N, R and T (Unit: mm)

3.1 ECOM

- **Commons for IIR and IIF satellites**
  - β-related change of orbit difference in N
  - AoL-related change of orbit difference in R and T
- **Difference for IIR and IIF satellites**
  - β-related change of orbit difference in R for IIF satellites
  - AoL-related change of orbit difference in N for IIR satellites when absolute β larger than 40°
  - “Double X” pattern of orbit difference in T for IIR satellites

CC BY

3.1 ECOM

- **Different pattern of IIR**

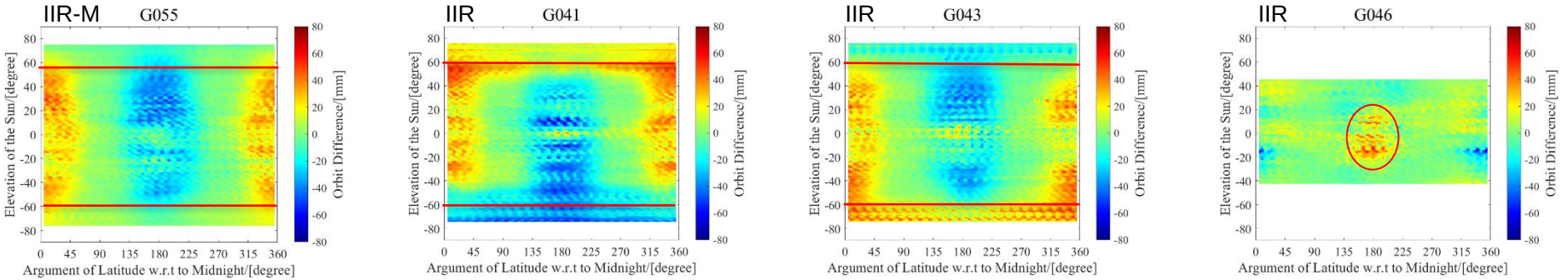
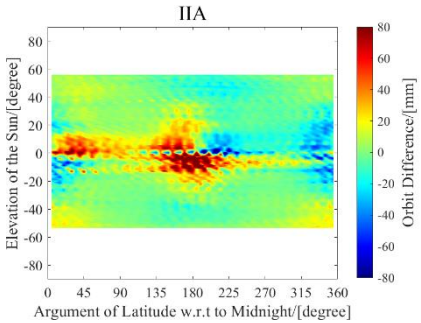


Fig. 5 Orbit Difference of Various IIR Satellites in R direction (Unit: mm)



Pattern	IIR	IIR-M[1]
Normal Peanut	2	2
Helmet(up or down)	3	0
IIA-like	1	0
Unclear*	5	5

Sub-group of IIR?

- Normally, the orbit difference of IIR in R direction shows a “peanut” pattern when AoL is around 0° or 180° and absolute β is lower than 60°
- Some IIR satellites show different patterns: (1) “helmet” pattern when absolute β is higher than 60°, (2) reverse orbit difference when absolute β is around 0°, similar to that of IIA satellite

1 https://www.navcen.uscg.gov/?Do=constellationStatus

* Owing to the inclination of orbit plane, the maximum β of the satellites in special plane could not reach 60° and the pattern of these looks just like part of the “peanut” and it is hard to say they are “peanut” or “helmet”

CC BY

3.1 ECOM

- **Points**

  - Orbit difference shows that ECOM1 and ECOM2 influence POD differently in every directions for various satellite types.

  - The orbit of IIR satellites differs a lot when using different ECOM parameterization in three directions while the orbit difference of two ECOM parameterization show obvious pattern in R direction for IIF satellites and one IIA satellite.

  - For IIR satellites, there are some none-IIR-M satellites, which might belong to a sub-group of IIR satellites, showing special pattern in terms of the orbit difference in R direction.

CC BY

3.3 ECOM1+a-priori model

- **Orbit difference of ECOM1 and ECOM1 + a-priori model for IIR satellites**

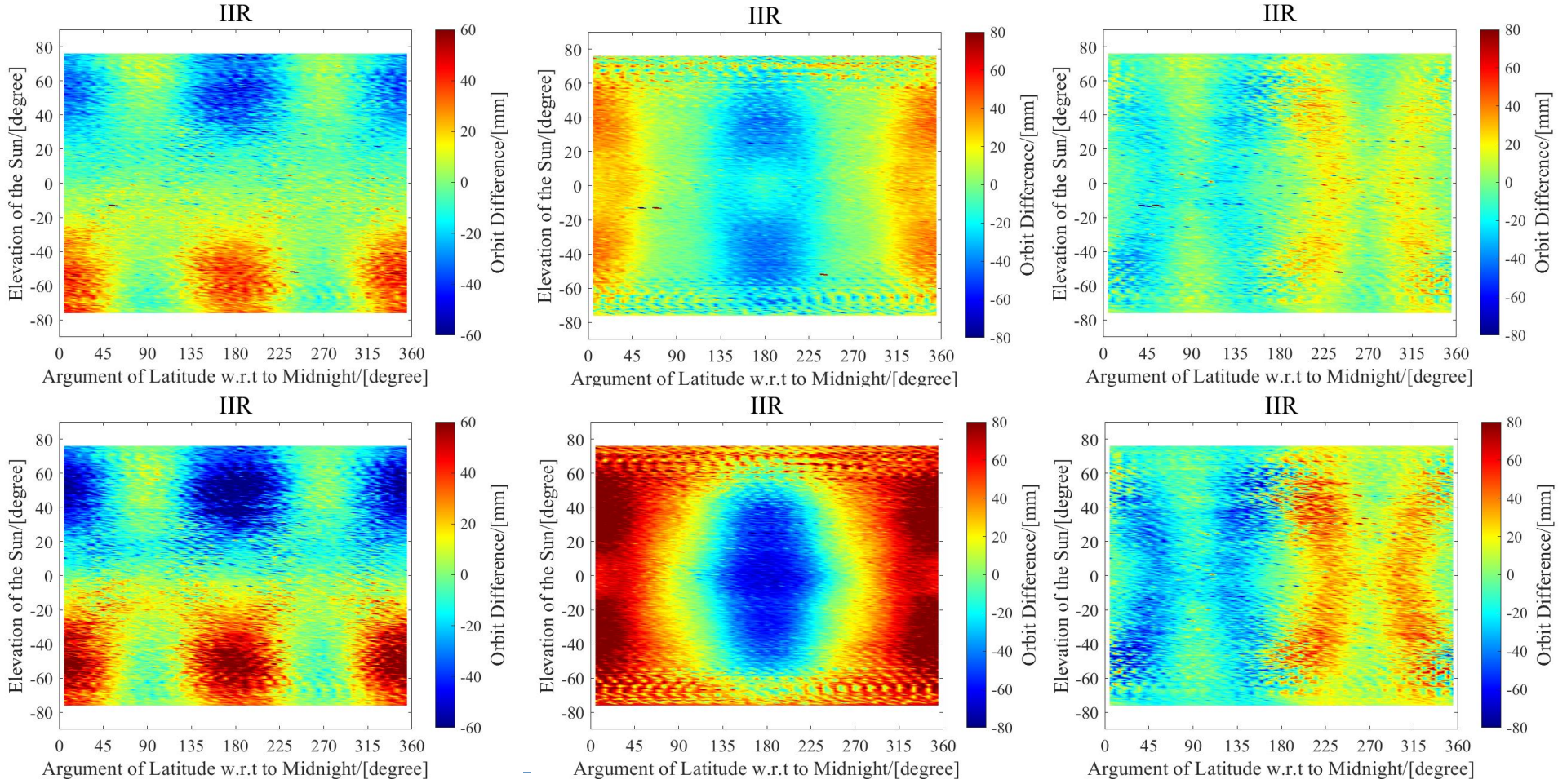


Fig. 6 IIR orbit difference of ECOM1 and ECOM1 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

1. The orbit difference of ECOM1 and ECOM1 plus Box-wing model shows similar pattern as that of ECOM1 and ECOM2

2. The orbit difference of ECOM1 and ECOM1 plus ROCK model shows similar pattern as that of ECOM1 and ECOM1 plus Box-wing in N and T direction, but with larger difference. While in R direction, an "eye" pattern could be recognized

- **Orbit difference of ECOM1 and ECOM1 + a-priori model for IIR satellites**

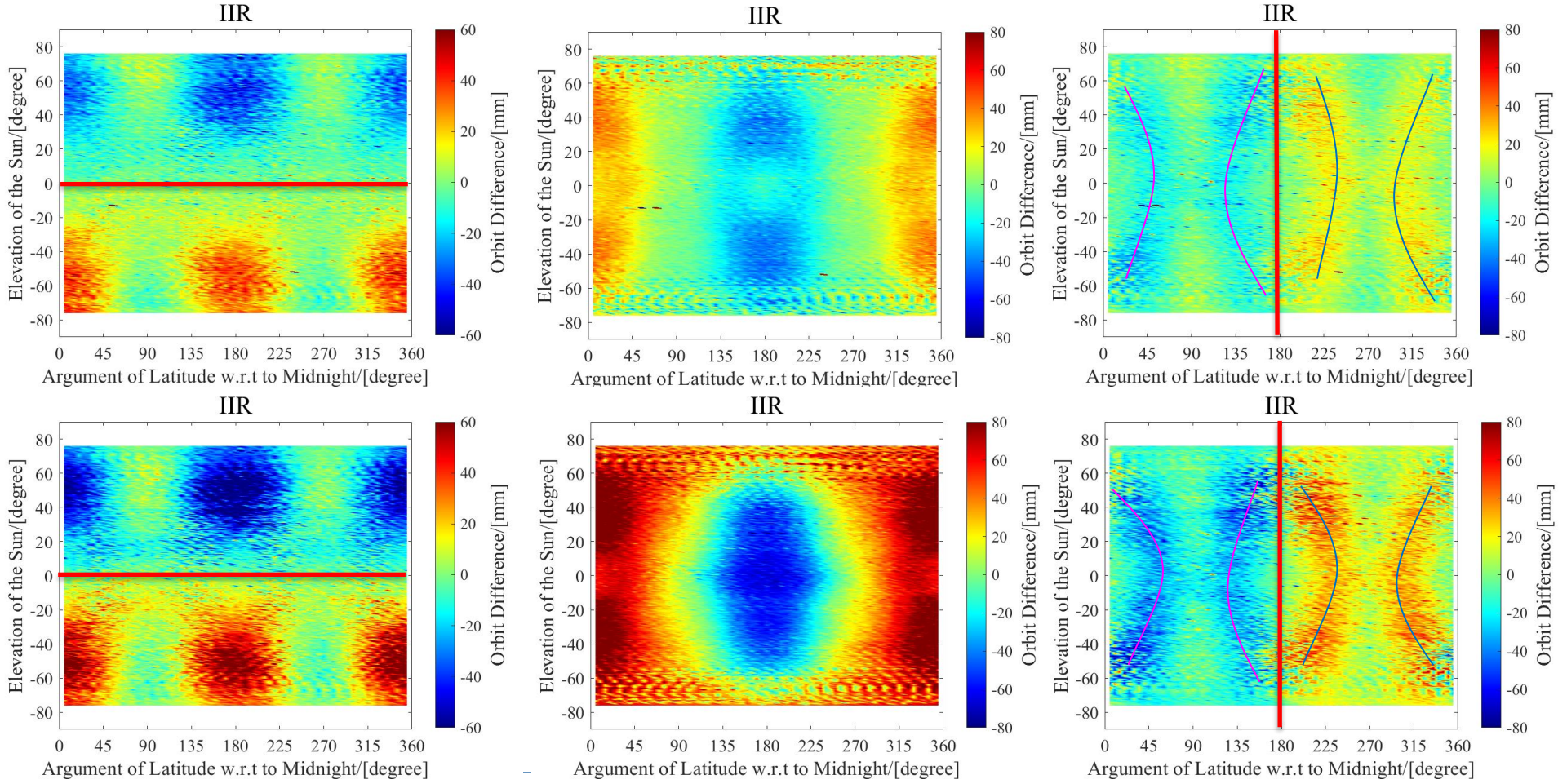


Fig. 6 IIR orbit difference of ECOM1 and ECOM1 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

3.3 ECOM1+a-priori model

- **Orbit difference of ECOM1 and ECOM1 + a-priori model for IIF satellites**

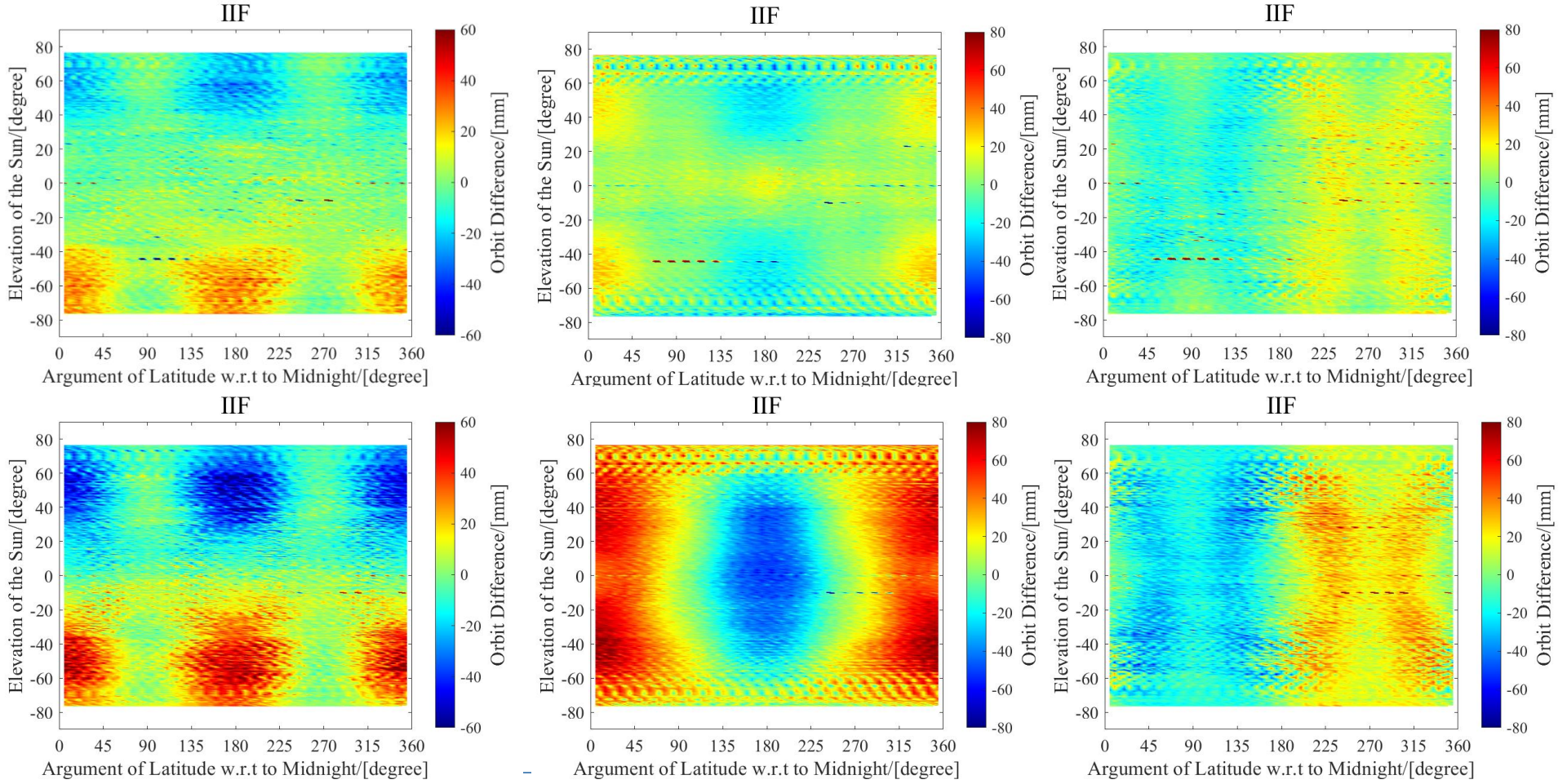


Fig. 7 IIF orbit difference of ECOM1 and ECOM1 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

1. Different from that of ECOM1 and ECOM2, the IIF orbit difference of ECOM1 and ECOM1 plus Box-wing model indicate a AoL-related change in N direction when absolute β is more than 40° and different pattern in R and T direction

2. The orbit difference of ECOM1 and ECOM1 plus ROCK model shows similar pattern as that of ECOM1 and ECOM1 plus Box-wing in N and T direction, but with larger difference while in R direction, an "eye" pattern could be recognized for the former and a different pattern for the latter

- **Orbit difference of ECOM1 and ECOM1 + a-priori model for IIF satellites**

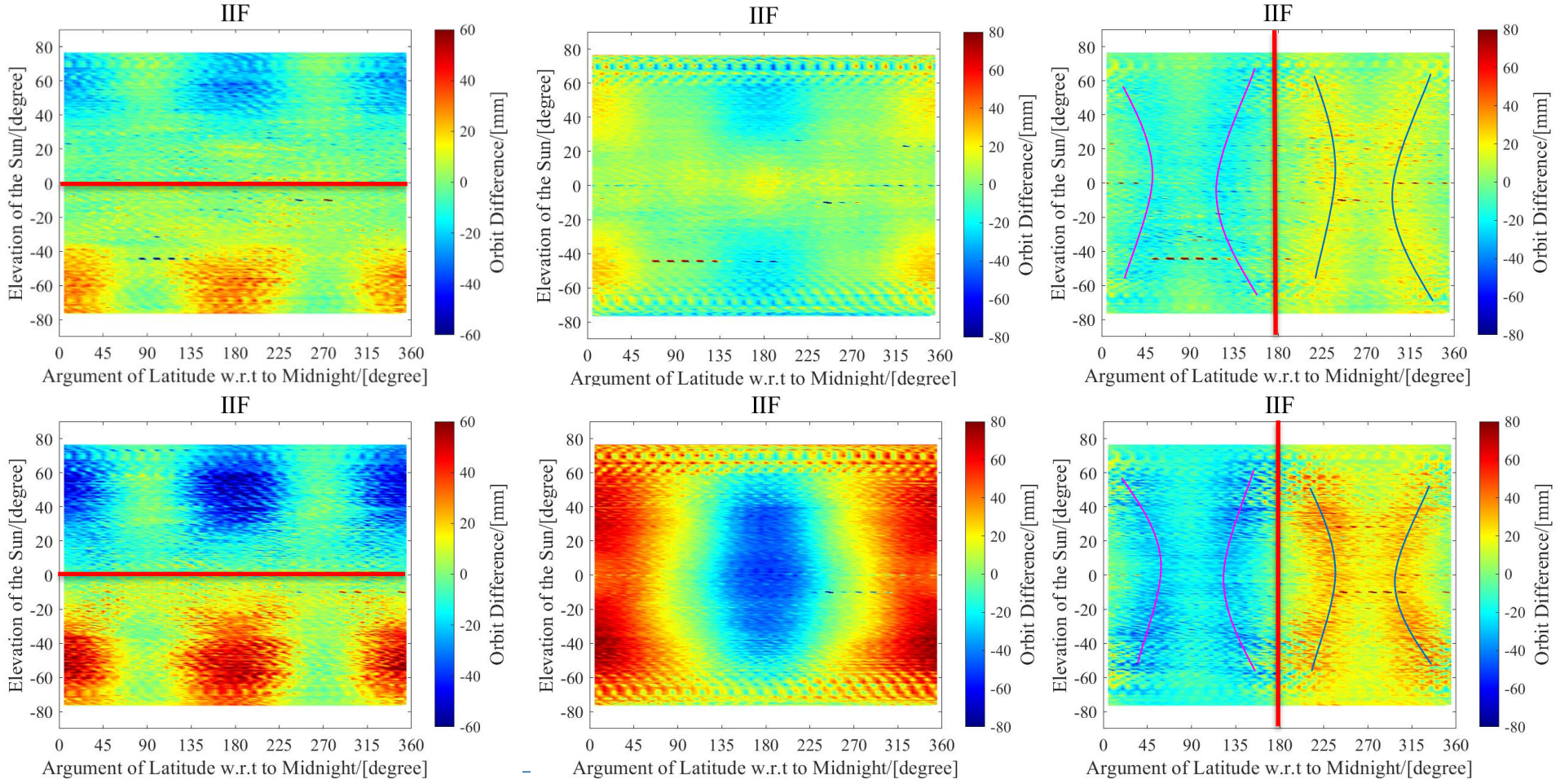


Fig. 7 IIF orbit difference of ECOM1 and ECOM1 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

3.3 ECOM1+a-priori model

- **Satellites with special pattern in R direciton**

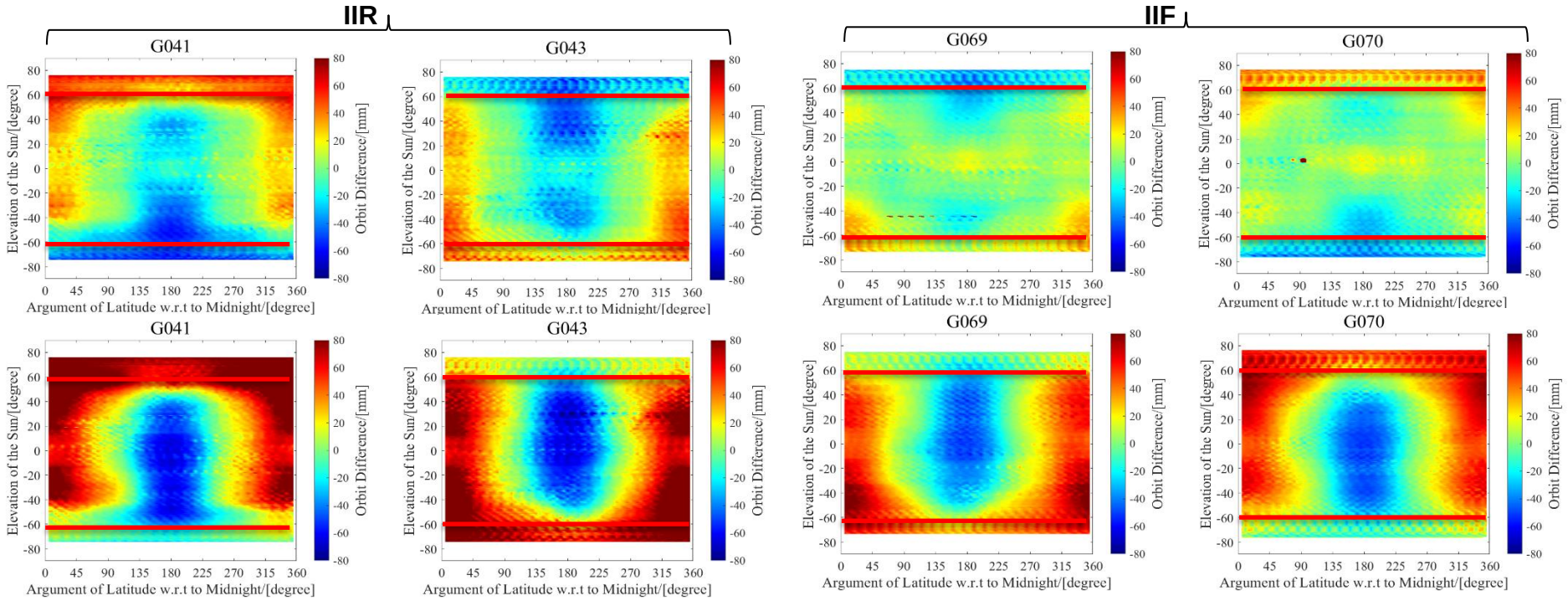


Fig. 8 Special orbit pattern of ECOM1 and ECOM1 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in R direction (Unit: mm)

For some IIR and IIF satellites, the POD with ECOM1 on top of priori models show an asymmetrical pattern when compared with POD with only ECOM1. This might indicate the asymmetrical satellite bus of these satellites.

CC BY

3.3 ECOM1+a-priori model

- **Points**

  - When ECOM1 is used as the parameterization method, with and without a-priori model show obvious difference, the β-related orbit difference change in N direction and AoL-related orbit difference change reveal that ECOM1 is not compatible with the two a-priori models in terms of the SRP modeling in three directions.

  - For both IIR and IIF satellites, with two a-priori models show similar orbit difference in N and T directions while the orbit difference pattern differs in R direction when ECOM1 is used as the parameterization method.

  - For IIR satellites, ECOM2 has similar effect as ECOM1 plus Box-wing model on POD according to the orbit difference compared with ECOM1.

  - When a-priori models are used, some satellites showing asymmetrical orbit difference pattern might indicate their asymmetrical satellite bus.

CC BY

3.3 ECOM2+a-priori model

1. ECOM2 is consistent with Box-wing model for POD except for a slight difference near the noon point when β is around 0°
2. ECOM2 is highly consistent with ROCK model in N and T while for orbit difference in R direction, a systematic shift when absolute β is larger than 40° and AoL-related change when β is between - 20° and 20° could be recognized

- **Orbit difference of ECOM2 and ECOM2 + a-priori model for IIR satellites**

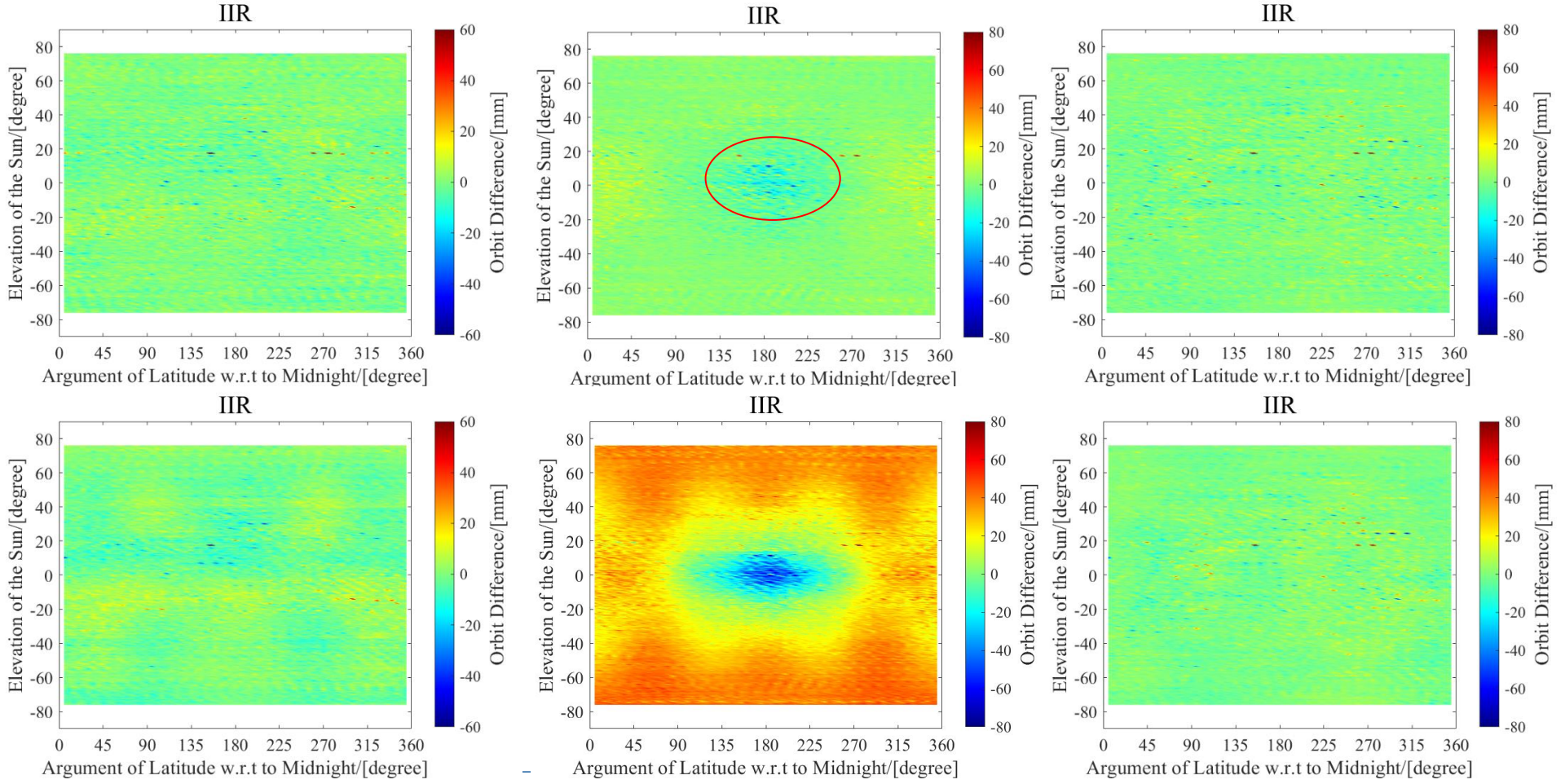


Fig. 9 IIR orbit difference of ECOM2 and ECOM2 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

3.3 ECOM2+a-priori model

1. ECOM2 is highly consistent with Box-wing model for POD except for an AoL-related difference when β is around 0°
2. ECOM2 is highly consistent with ROCK model in N and T while for orbit difference in R direction, a systematic shift when absolute β is larger than 40° and AoL-related change when β is between - 20° and 20° could be recognized

- **Orbit difference of ECOM2 and ECOM2 + a-priori model for IIF satellites**

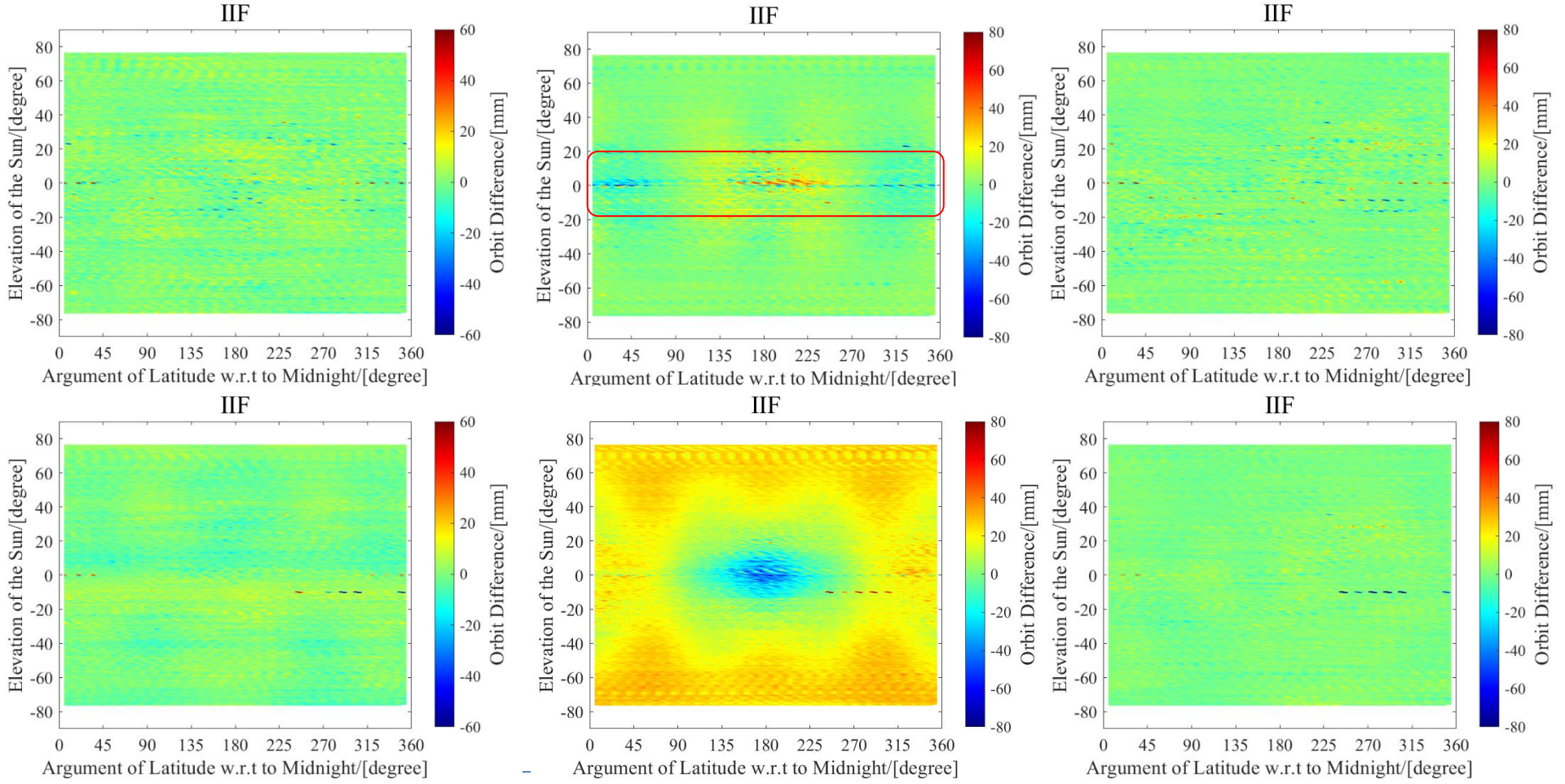


Fig. 9 IIF orbit difference of ECOM2 and ECOM2 plus a-priori model (Box-wing model (upper) / ROCK (lower)) vs. AoL and β in N, R and T direction (Unit: mm)

3.3 ECOM2+a-priori model

- **Points**

  - When ECOM2 is used as the parameterization method, with and without Box-wing model show high consistency in terms of orbit in three directions except for a not significant difference when β is around 0°.

  - When ECOM2 is used as the parameterization method, with and without ROCK model show high consistency in terms of orbit in N and T directions. The orbit difference shift when absolute β is above 40° and the AoL-related orbit difference change when β is between - 20° and 20° indicate that ECOM2 is not compatible with ROCK models in terms of the SRP modeling in R direction.

CC BY

Contents

CC BY

3.3 Summary

- ECOM1 and ECOM2 affect the POD differently, especially for IIF satellites in R direction and IIR satellites in all directions.
- When ECOM1 is used as the parameterization method, with and without a-priori model differ significantly for both types of satellites.
- When ECOM2 is used as the parameterization method, with and without Box-wing model show high consistency; with and without ROCK model differ a lot in R direction but is consistent with each other in other two directions in terms of orbit difference.
- The possible asymmetrical satellite bus may cause the non-symmetrical orbit difference pattern in R direction when compare ECOM2, ECOM1+Box-wing/ROCK respectively with ECOM1.

CC BY