Response to comments from Lars Kaleschke

I am pleased to see that the ASI method is being used successfully on the Chinese satellites FengYun-3B, 3C and 3D. To my knowledge this is the first sea ice product from a Chinese satellite series that covers a long time period. Therefore, I consider this work potentially relevant for the ESSD journal. I'd like to give only general comments and questions because the information provided with the manuscript does not allow further review in particular with respect to the source data and validation.

A code repository is missing, see https://essd.copernicus.org/articles/10/2275/2018/

Reply:

Thanks for your comment. We have provided the processing steps of our MWRI-ASI SIC product in the supplement file, including the flow chart, steps, codes, and procedure outcomes.

For the introduction of the near 90 GHz method please also refer to the prior work of Svendsen et al. (1987) which forms the basics of the algorithm. Svendsen, E., Matzler c., and Grenfell, TC. (1987). "A Model for Retrieving Total Sea Ice Concentration from a Spaceborne Dual-Polarized Passive Microwave Instrument Operating Near 90 GHz", International Journal 0/ Remote Sensing, Vol. 8, No. 10, pp. 1479-1487.

Reply:

Thanks for your advice. We have added this reference.

Page 6, Line 158-159, we wrote:

More details about the dynamic tie points ASI algorithm were given in Zhao et al. (2022), and the details about the ASI algorithm can be referred to Svendsen et al., (1987), Kaleschke et al. (2001) and Spreen et al. (2008).

I can not judge the quality of the brightness temperature because it is not yet published: The recently re-calibrated brightness temperature (TB) of the MWRI sensors provided by NSMC (Wu et al., 2022) were used in this study. Because ESSD is a journal for "open data" (isn't it?), I also would like to know a bit more about the availability of the source data. Table 1: TB characteristics missing. What about uncertainties? Grid resolution is different from field of view. Table 1 in Zhao et al. (2021) states across scan resolution of 89 GHz is 9x15 km^2. With a grid spacing of 12.5 km there is significant undersampling in one direction. Why not use a 6 km grid for the sake of Nyquist-Shannon?

Reply:

Thanks for your comments and questions. We have removed the reference "Wu et al., 2022", which is still under review. Once it is published, we will add it again. We added the website for the re-calibrated MWRI TB data. We also added the inter-comparison among the MWRI TB, SSMI TB, and AMSR TB in Section 4.1 to illustrate the quality and uncertainties of the re-calibrated MWRI TB. The grid resolution is determined based on time integration, and the distance between two points is 10 km, which is closer to the 12.5-km grid than the 6.25-km grid. Therefore, we projected the re-calibrated MWRI TB on the 12.5-km polar stereographic grid.

Page 3, Line 91-93, we wrote:

Therefore, the MWRI TB data was re-calibrated using the operational algorithm, which focused on the hot load, antenna, and receiver calibration, reducing the TB deviations of different MWRI sensors.

Page 3, Line 94-95, we wrote:

This study used the re-calibrated level 1 swath MWRI TB data from the FY-3B, FY-3C, and FY-3D satellites, provided by the NSMC, which is available at http://www.richceos.cn (Table 1).

Page 4, Line 103-110, we wrote:

To evaluate the uncertainties of the re-calibrated MWRI TB in the polar regions, we chose two daily TB products, i.e., the SSMI TB (version 6, Meier et al., 2021) and AMSR TB (AMSR-E version 3, Cavalieri et al., 2014; AMSR2 version 1, Meier et al., 2018), which are both available from the National Snow and Ice Data Center (NSIDC). This SSMI TB product is projected on 12.5-km and 25-km polar stereographic grids at high and low frequencies, respectively. All the frequencies of the AMSR TB products are projected on a 12.5-km polar stereographic grid. The time coverages of the two daily TB products are corresponding to that of the MWRI TB. To conduct a comparison among these three TB products, the swath MWRI TB was gridded to daily MWRI TB and the low frequencies of SSMI TB were resampled to the 12.5-km polar stereographic grid. The TB differences were calculated in the PIZ, MIZ, and open water.

Page 18-19, Line 371-383, we wrote:

For the frequencies used for the ASI algorithm, i.e., at 89 GHz with V- and H-polarization and differences between them (defined as polarization differences), the MWRI TB is closer to the AMSR TB than the SSMI TB (Table 6). In the PIZ, the MADs of polarization difference at 89 GHz between the MWRI TB and SSMI TB are smaller with values of 1.5 and 1.7 K in the Arctic and Antarctic, respectively, compared to those (4.6 and 4.4 K; 7.6 and 7.6 K) in the MIZ and over open water, where the atmospheric influence is more intense. Overall, the polarization difference at 89 GHz of the MWRI sensor is lightly higher than that of the SSMI sensor with a mean positive bias of 0.9 K and lightly lower than that of the AMSR sensor with a mean negative bias of -1.1 K. It illustrates that the re-calibrated MWRI TB is comparable to the SSMI and AMSR TB, which can be well applied to the ASI algorithm.

The TB differences between the MWRI and SSMI sensor are smaller than those between MWRI and AMSR sensor at low frequencies used for the weather filters. The overall biases between MWRI TB and SSMI TB are -1.2, -0.7, and 0.1 K at 18.7, 23.8, and 36.5 GHz with V-polarization, respectively. Compared to the AMSR TB, the MWRI TB is lower with mean biases of -5.3, -5.4, and -3.9 K at 18.7, 23.8, and 36.5 GHz with V-polarization, respectively. In general, the low frequencies of MWRI sensor can filter the weather effects, which is similar to those of the SSMI and AMSR sensors.

Table 6. MADs between the MWRI TB and other two TBs from 2010 to 2019 in the PIZ, MIZ, and open water. "A / B": A present the MADs between the MWRI TB and SSMI TB, and B present the MADs between the MWRI TB and AMSR TB.

	Arctic			Antarctic		
	PIZ	MIZ	Open water	PIZ	MIZ	Open water
18 V	1.7 / 4.0	4.8 / 7.2	7.4 / 11.4	2.4 / 4.5	3.6 / 6.6	4.8 / 9.5
23 V	2.0 / 4.1	4.5 / 6.2	7.0 / 11.4	2.3 / 4.7	3.5 / 6.5	4.3 / 9.1
36 V	2.5 / 2.8	4.1 / 4.7	6.3 / 9.2	2.5 / 3.0	3.4 / 4.9	4.2 / 6.3
89 V	3.9 / 3.5	4.6 / 3.4	13.8 / 7.1	4.1 / 3.3	4.2 / 3.6	8.1 / 4.0
89 H	4.3 / 3.8	7.4 / 5.5	18.1 / 10.7	4.9 / 3.8	7.1 / 5.4	14.1 / 8.3
89 V – 89 H	1.5 / 1.3	4.6 / 4.1	7.6 / 6.0	1.7 / 1.5	4.4 / 3.8	7.6 / 5.7

Page 19, Line 394-396, we wrote:

To obtain a more consistent SIC product, the re-calibrated MWRI TB were adopted as input source TB, because the differences among the re-calibrated MWRI TB from different satellites were low with mean of 2.8 and 1.0 K in the Arctic and Antarctic, respectively.

I have not fully understood the concept of the preliminary dynamic tie points. This could be outlined in more detail.

Reply:

Thanks for your suggestion. The "preliminary dynamic tie points" presented in the Abstract is the ASI algorithm in Zhao et al. (2022): Zhao, X., Chen, Y., Kern, S., Qu, M., Ji, Q., Fan, P., and Liu, Y.: Sea Ice Concentration Derived from FY-3D MWRI and Its Accuracy Assessment, IEEE Trans. Geosci. Remote Sens., 60, https://doi.org/10.1109/TGRS.2021.3063272, 2022, which is our previous study. In this study, we modified the ASI algorithm of Zhao et al. (2022), presented in Section 2.4. To better understand this sentence, we rewrote it. Meanwhile, we have showed procedures of the initial tie points and dynamic tie points in more detail in the supplement file (S1.2 and S1.4).

Page 1, Line 17-18, we wrote:

We modified the previous Arctic Radiation and Turbulence Interaction Study Sea Ice (ASI) dynamic tie points algorithm mainly by changing input brightness temperature and initial tie points.

Page 6, Line 161-162, we wrote:

The detailed procedures for retrieving this MWRI-ASI SIC product can be seen in the supplement file.

Page 7, Line 176-177, we wrote:

The steps for generating the initial points are given in more details in Section S1.2 of the supplement file.

Page 7, Line 182-183, we wrote:

The Section S1.4 of the supplement file illustrates detailed procedures of generating the dynamic tie points.

Page 19, Line 389-391, we wrote:

The MWRI-ASI v1 SIC has small differences against AMSR-ASI SIC, but the time series of AMSR-ASI is shorter than the SSMI-ASI SIC. To obtain longer-term SIC products, this study modified the previous algorithm and adopted the SSMI-ASI SIC as referential SIC to update and extend the MWRI-ASI SIC.

My main concern is insufficient scientific motivation: "In order to promote the application of MWRI sensors, especially to back up the existing sea ice products". Why is there the need for a backup for the existing data? Well, I could understand the argument for the future. This could be further elaborated. However, I think the main advantage of having such a data set is the true independence which potentially allows the application of techniques like triple collocation between different satellite data records. How would you judge the "risk of breaking". For example, we expect the AMSR3 launch in 2023 or 24.

Reply:

Thanks for your suggestion. We have reconsidered the motivation of our studies and pointed out that our MWRI-ASI SIC product can be as independent SIC dataset to monitor the changes of sea ice and serve as reliable data to evaluate the future sensors. Meanwhile, the "risk of breaking" was not highlighted, and we rewrote the motivation.

Page 2, Line 35-49, we wrote:

Due to the long-term services of spaceborne sensors, the PM sea ice measurements can continuously track the response of sea ice to climate change and support the applications for climate models or multidisciplinary studies in the polar regions. The currently operating Special Sensor Microwave Imager Sounder (SSMIS) and Advanced Microwave Scanning Radiometer 2 (AMSR2) sensors have been used for many years beyond their design lifetime (Gerland et al., 2019). The new missions for successors of these two sensors or the launch plans for other instruments, e.g., the Copernicus Imaging Microwave Radiometer (Jiménez et al., 2021) and Weather Satellite Follow–On–Microwave (Newell et al., 2020), are in the preparation stage and will be achieved in the next several years. The Chinese instruments, the Microwave Radiation Imager (MWRI) sensors onboard the FengYun-3 (FY-3) series satellites, i.e., FY-3A, FY-3B, FY-3C, and FY-3D (Zhang et al., 2018, 2019; Xian et al., 2021), are promisingly used to independently provide long-term SIC (Chen et al., 2021; Zhao et al., 2022). However, the inconsistency of different sensors and the drift of the sensor itself with increased operation time can increase the uncertainties of SIC (Eisenman et al., 2014). Thus, enriching data resources are beneficial to achieve the triple collocation between different satellites. For example, the SSMIS data has been used as a bridge to compare and connect the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) and AMSR2 estimates, which have a data gap from 2011 to 2012 (Meier and Ivanoff, 2017). Besides, a new SIC product from the MWRI sensors after systematic assessment can also provide an option to verify the SIC products of new launched PM sensors in the future.

Page 3, Line 78-79, we wrote:
In order to promote the application of MWRI sensors, this study extends the work of Zhao et al. (2022) and generates a new polar SIC product from November 2010 to December 2019.

Page 3, Line 81-84, we wrote:
Moreover, the MWRI-ASI SIC is compared to the existing ASI SIC products and assessed systematically using ship-based SIC observation to identify its uncertainty in various regions and seasons. We also derive SIE from the MWRI-ASI SIC and compare it to the existing SIE products to test its ability to independently monitor sea ice changes.

Page 5-6, Line 149-150, we wrote:
Moreover, to test the capability of the MWRI-ASI SIE as an independent indicator for climate changes, we performed an analysis of combined SIE trends.

Page 22, Line 462-465, we wrote:
To test the ability of the MWRI-ASI as an independent PM SIC dataset, the MWRI-ASI SIC is compared to the existing ASI SIC products of SSMI-ASI and AMSR-ASI, and the MWRI-ASI SIE is compared to the existing SIE products of SSMI-BST, SSMI-NT, OSI-SAF, and Sea Ice Index. The accuracy of the MWRI-ASI SIC is also validated using the ship-based observed SIC.

Page 23, Line 475-476, we wrote:
It suggests the MWRI-ASI SIC product can independently monitor changes of sea ice and serve as reliable data to evaluate the future sensors.

What is meant with "qualified to be integrated into long-term sea ice records" and "The MWRI-ASI SIE can be better integrated into the Sea Ice Index SIE in the Arctic and the OSI-SAF SIE in the Antarctic compared to other products."

Reply:

Thanks for your questions. Because our motivation was changed, these two sentences have been rewritten. Moreover, the similar descriptions were also changed.

Page 1, Line 24-25, we wrote:
Therefore, the MWRI-ASI SIC is comparable with other SIC products and can be applied independently.

Page 22, Line 469, we wrote:
Therefore, the MWRI-ASI SIC is closer to the SSMI-ASI SIC.

Page 22, Line 470-471, we wrote:

The sensitivity of MWRI-ASI SIC to sea ice melting surface is higher than the SSMI-ASI, which suggests the MWRI-ASI SIC product may have better identification ability for the melting surface.

Page 22, Line 472-473, we wrote:
The MWRI-ASI SIE has smaller differences against the Sea Ice Index SIE in the Arctic and the OSI-SAF SIE in the Antarctic compared to other products.

The ICDC ASI-SSMI version is probably the 5-day median-filtered version? The single day data are available from IFREMER. Both data sets are different in their characteristics. Probably not too much but this should be considered. This is important also for the discussion of the land spillover because the temporal filter has a strong effect. For potential further improvement. I refer to Maaß et al. (2010). Nina Maaß & Lars Kaleschke (2010) Improving passive microwave sea ice concentration algorithms for coastal areas: applications to the Baltic Sea, Tellus A: Dynamic Meteorology and Oceanography, 62:4, 393-410, DOI: 10.1111/j.1600-0870.2009.00452.x

Reply:
Thanks for your question and advice. We have obtained the single-day SSMI-ASI SIC product from IFREMER and compared it to our MWRI-ASI SIC product in Section 4.2. We divided the regions into two parts, one is the region within 50 km away from the coast, and other is the region beyond 50 km away from the coast. Our MWRI-ASI SIC was compared to the single-day SSMI-ASI SIC, five-day SSMI-ASI SIC, AMSR-ASI SIC in these two parts. We also have discussed the land spillover in more details and added this reference.

Page 19-20, Line 403-410, we wrote:
Although some methods have been proposed to solve the land spillover, such as expanding the land mask (Maslanik et al., 1996), subtracting the summer minimum SIC from original images (Cavalieri et al., 1996), and estimating the fraction of land emissivity in the TB (Maaß and Kaleschke, 2010), the SIC differences are still higher in the near-coast regions than in the regions far away from the coast. The SIC MADs between the MWRI-ASI and SSMI-ASI within 50 km away from the coast are larger with values of 6.2% in the Arctic and of 6.7% in the Antarctic, compared to those (3.5% and 5%) beyond 50 km away from the coast. The MADs within 50 km away from the coast between MWRI-ASI SIC and AMSR-ASI SIC are 8.2 % in the Arctic and 8.8% in the Antarctic, which are higher than those (5.5% and 6.5%) beyond 50 km away from the coast.

Page 20, Line 414-415 we wrote:
Due to larger uncertainties of our MWRI-ASI SIC in the near-coast region, it is recommended that the grids extended outward from the coast by 50 km can be removed when using it.

Page 20, Line 416-422 we wrote:
To analyze the influence of temporal filter on land spillover, we acquired the single-day SSMI-ASI SIC product (Single-day SSMI-ASI) from the French Research Institute for Exploitation of the Sea via the Centre d'Exploitation et de Recherche SATellitaire (Ifremer/CERSAT) (Girard-Ardhuin et al., 2008). The SSMI-ASI SIC produced by Hamburg Uni were filtered by a five-day median filter (Five-day SSMI-ASI). In the region within 50 km away from the coast, the SIC MADs between MWRI-ASI and Single-day SSMI-ASI are 5.8% in the Arctic and 6.3% in the Antarctic, which are slightly smaller than those between MWRI-ASI and Five-day SSMI-ASI by 0.4%. It indicates that the SIC uncertainties in the near-coast regions is slightly increased after temporal filter.

Response to comments from Vishnu Nandan

In this manuscript, the authors use FengYun satellite series and derived sea ice concentration from 2010-19, which is interesting and valuable to the sea ice community and adds valuable information to the existing SIC climatology from other PMW satellite data. Therefore, I suggest potential publication to ESSD journal. However, I have few major comments that needs to be addressed before publication. Since I am a radar remote sensing scientist with expertise in sea ice (and snow) geophysics, for this round of review, I focus more on the geophysical uncertainty aspect that needs some attention. I am happy to review the revised manuscript and then would give a comprehensive review with more technical and specific comments. Below are my major comments.

a) My main concern with your paper is that you have not provided any information on how SNOW as a critical geophysical parameter affects brightness temperature and SIC estimates and its UNCERTAINTY from your datasets. In a warming Arctic and a fluctuating Antarctic, how does shift in sea ice types from MYI to FYI affect snow properties and that in turn affects your SIC estimates? Can you provide a uncertainty range in your derived SICs based on the snow cover and its spatiotemporal variability? For example, FYI cover is characterized by saline snow covers while thicker snow on thinner ice (especially in the Antarctic) is severely affected by flooding, slush and refrozen snow-ice formations. They severely affect the emitting layer correct? I think authors, since they are showing a brand new dataset, its worth and necessary to show the geophysical uncertainties as a quanity. I am a bit disappointed that snow is completely neglected (I should say) in your data product.
b) I am really surprised to see almost NO regional variabiity in Antarctic SIC (see Figure 3 (g) to (i)), from your products, when even recent studies (for example: https://essd.copernicus.org/articles/14/619/2022/essd-14-619-2022.html just to quote one) from the same time period as yours have shown large variability in snow depth (that heavily influences SIC) across multiple Antarctic sea ice sectors. This points to my previous comment about accounting for snow depth and its variability in your calculations. I think its a good idea to revisit PMW-derived snow depth data (not that its completely accurate) or any other snow models that can be used to quantify the SIC uncertainty, and combinely use them to figure out the regional SIC variaiblity atleast in the Antarctic. I am sure readers would appreciate that !

Reply:

Thanks for your questions and comments. We have used the PMW-derived snow depth data to estimate overall effects of snow depth on SIC uncertainties in the Arctic and Antarctic. Meanwhile, the effects of snow depth on TB differences were also analyzed. We added the example days in winter and summer for the Antarctic to quantity the SIC uncertainties in more details. In Fig. 3, the spatial distribution of SIC differences do not show the obvious variability with the snow depth, because the SIC differences were calculated from the SIC products all using the ASI algorithm, which have the consistent sensitivity to snow depth.

Page 5, Line 128-132, we wrote:

To quantify the effects of snow depth on SIC uncertainties, we obtained the snow depth on sea ice for the Arctic and Antarctic from the NSIDC (Table 1, AMSR-E version 3, Cavalieri et al., 2014; AMSR2 version 1, Meier et al., 2018). This data is derived from the AMSR TB using the AMSR-E snow-depth-on-sea-ice algorithms and projected on a 12.5-km polar stereographic grid. It is notes that this data is averaged by a five-day running window and only includes the depth of dry snow. Besides, this data provides snow depth for the entire Antarctic, but only for the first-year ice in the Arctic.

Page 12, Line 275-283, we wrote:

When the snow depth is lower than 10 cm, the SIC differences are largest with overall MADs of 6.3% between the MWRI-ASI and SSMI-ASI and of 8.4% between the MWRI-ASI and AMSR-ASI, which are about three times of those (2.2% and 3.2%) when the snow depth is higher than 40 cm. One of the reasons is that the TB differences are also largest when the snow depth is lower than 10 cm, about twice as much as when the snow depth is higher than 10 cm. The spatial distribution of SIC differences do not show the obvious variability with the snow depth (Fig. 3), because all the SIC products are retrieved by the ASI algorithm, which have the consistent sensitivity to snow depth. In the Antarctic (Fig. 5), when the snow depth is lower than 10 cm, the MAD between MWRI-ASI SIC and SSMI-ASI SIC is 10% on the example day in summer, which are larger than those in winter by 3.5%. Overall, the snow over sea ice has an effect on the SIC uncertainties, which is greater at lower snow depth, especially in summer.

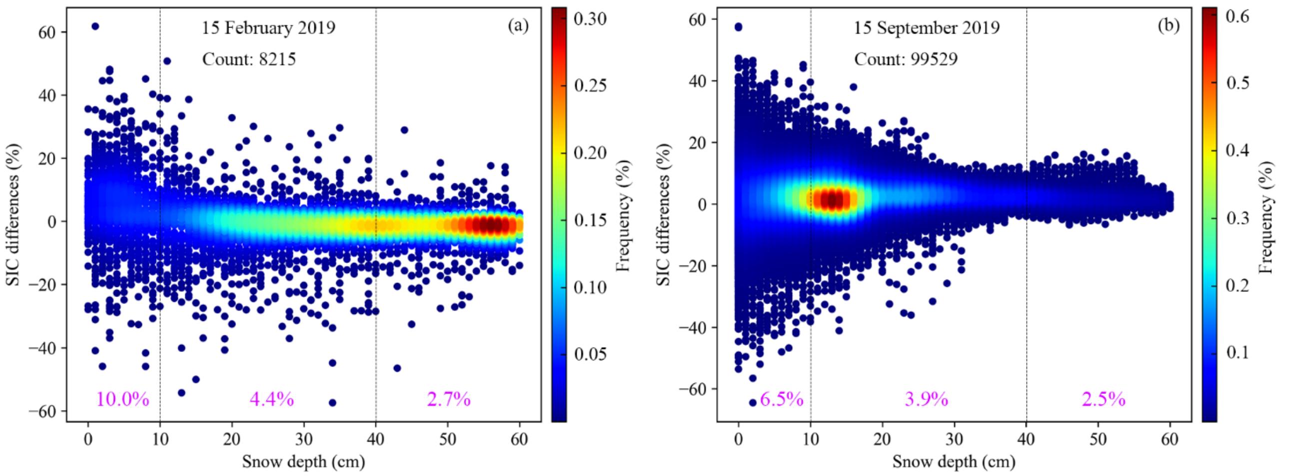

Figure 5: Frequency of SIC differences between the MWRI-ASI and SSMI-ASI with different snow depths in the Antarctic on 15 February (a) and 15 September (b) 2019. The purple numbers present the MADs in SIC between the MWRI-ASI and SSMI-ASI with the snow depth of 0-10 cm, 10-40 cm, and 40-60 cm.

Page 22, Line 469-470, we wrote:
Besides, shallower snow depth over sea ice could produce larger SIC uncertainties.

c) Like reviewer 1 mentioned, the introduction with your rationale is missing or maybe scattered/lost/cluttered within the intro material. I think refining the introduction will help the readability of the paper. Also, just a minor comment. I was curious to know the incidence angle used for the data acquisition. For now I refrain to providing these major comments above. In your revised version, I will provide comprehensive comments on the write up.

Reply:

Thanks for your advice. We have rewritten the introduction. The procedures of our MWRI-ASI SIC product can be seen in the supplement file, including the flow chart, steps, codes, and procedure outcomes. The incidence angle of MWRI sensors is 53, and theirs' characteristics are shown in the following table referring to our previous study: Zhao, X., Chen, Y., Kern, S., Qu, M., Ji, Q., Fan, P., and Liu, Y.: Sea Ice Concentration Derived from FY-3D MWRI and Its Accuracy Assessment, IEEE Trans. Geosci. Remote Sens., 60, https://doi.org/10.1109/TGRS.2021.3063272, 2022,

TABLE I

MAIN CHARACTERISTICS OF MWRI, AMSR2, AND SSMIS

Sensor	MWRI	AMSR2	SSMIS
Satellite	FY-3D	GCOM-W1	DMSP F-18
Altitude (km)	836	700	850
Incidence Angle (°)	53	55	53
Equator Crossing Time (Local Time Zone)	A: 14:00 D: 02:00	A: 13:30 D: 01:30	A: 18:03 D: 07:08
Swath Width (km)	1400	1450	1707
Scan Period (s)	1.8	1.5	1.9
Number of Scans	266	243 / 486	256
Antenna Size (m)	0.977×0.897	2	0.61
Center Frequency (GHz) Polarization	10.65 V/H	10.65 V/H	- -
	18.7 V/H	18.7 V/H	19.35 V/H
	23.8 V/H	23.8 V/H	22.235 V
	36.5 V/H	36.5 V/H	37 V/H
	89 V/H	89 V/H	91.655 V/H
Footprint Size Along Scan × Across Scan (km^2) Sampling Interval Along Scan × Across Scan (km^2)	51×85 / 6×12	24×42 / 10×10	- -
	30×50 / 6×12	14×22 / 10×10	42×70 / 25×25
	27×45 / 6×12	11×10 / 10×10	42×70 / 25×25
	18×30 / 6×12	7×12 / 10×10	28×45 / 25×25
	9×15 / 6×12	3×5 / 5×5	13×15 / 12.5×12.5

"A" is ascending orbit and "D" is descending.