Annual summary of the Second Earth Orientation Parameters Prediction Comparison Campaign (2nd EOP PCC)

Tomasz Kur[1], Justyna Śliwińska[1], Jolanta Nastula[1], Henryk Dobslaw[2], Małgorzata Wińska[3], Aleksander Partyka[1]

[1]Centrum Badań Kosmicznych Polskiej Akademii Nauk, Warsaw, Poland
[2]GFZ German Research Centre for Geosciences, Potsdam, Germany
[3]Warsaw University of Technology, Faculty of Civil Engineering, Warsaw, Poland

eoppcc@cbk.waw.pl

eoppcc.cbk.waw.pl/

REFAG 2022 Reference Frames For Applications in Geosciences, 17 – 20 October 2022, Thessaloniki, Greece

Second EOP Prediction Comparison Campaign (2nd EOP PCC)

- In the light of the progress made in recent years in the field of improved geodetic data processing, reduced VLBI latency, and routine availability of model-based forecasts of effective angular momentum functions, a re-assessment of the various Earth Orientation Parameters (EOP) prediction capabilities is now pursued in the frame of the **Second Earth Orientation Parameters Prediction Comparison Campaign (2nd EOP PCC)**.
- The aim of the 2nd EOP PCC is re-assessing various EOP prediction capabilities. In particular:
  - collecting and comparing EOP predictions from different institutions over a representative period of time,
  - evaluating the accuracy of final estimates of EOP,
  - identifying both accurate and robust prediction methodologies,
  - assessing the inherent uncertainties in present-day EOP predictions,
  - analysing the impact of various factors (input data used, method applied, reference data, length of prediction etc.) on prediction accuracy.
- The campaign is carried out under the auspices of the IERS within the Working Group on the 2nd EOP PCC.
- The operational phase of the 2nd EOP PCC began on **September 1, 2021** and will last until **the end of 2022.**
- The EOP PCC Office at CBK PAN is responsible for data collecting, routine visualization and final evaluation of all submitted predictions.

Outline

- Submission statistics
- Results
  I. Evolution of the prediction's accuracy
  II. Selection of predictions with β-parameter
- Conclusions and future plans

Submission statistics

Participants and file statistics

Table 1 Details on the 1st and 2nd EOP PCC participants and methods

	1st EOP PCC	2nd EOP PCC
Number of registered participants	13	22
Number of institutes	10	28
Number of countries of participants origin	7	9
Total number of all teams' members	No data	66
Number of registered prediction methods (IDs)	20 (+1 combined prediction series)	57
Number of active participants	11	18

Table 2 Number of predictions submitted to the with respect to the number of participants and the number of IDs on 21.08.2022

	x pole	y pole	UT1–UTC	LOD	dPsi	dEpsilon	dX	dY	Total
Number of predictions	1244	1244	1047	876	90	90	357	357	**5305**
Number of participants	18	18	16	11	2	2	6	6	**22**
Number of methods (IDs)	32	32	26	23	2	2	9	9	**57**

Length of predictions

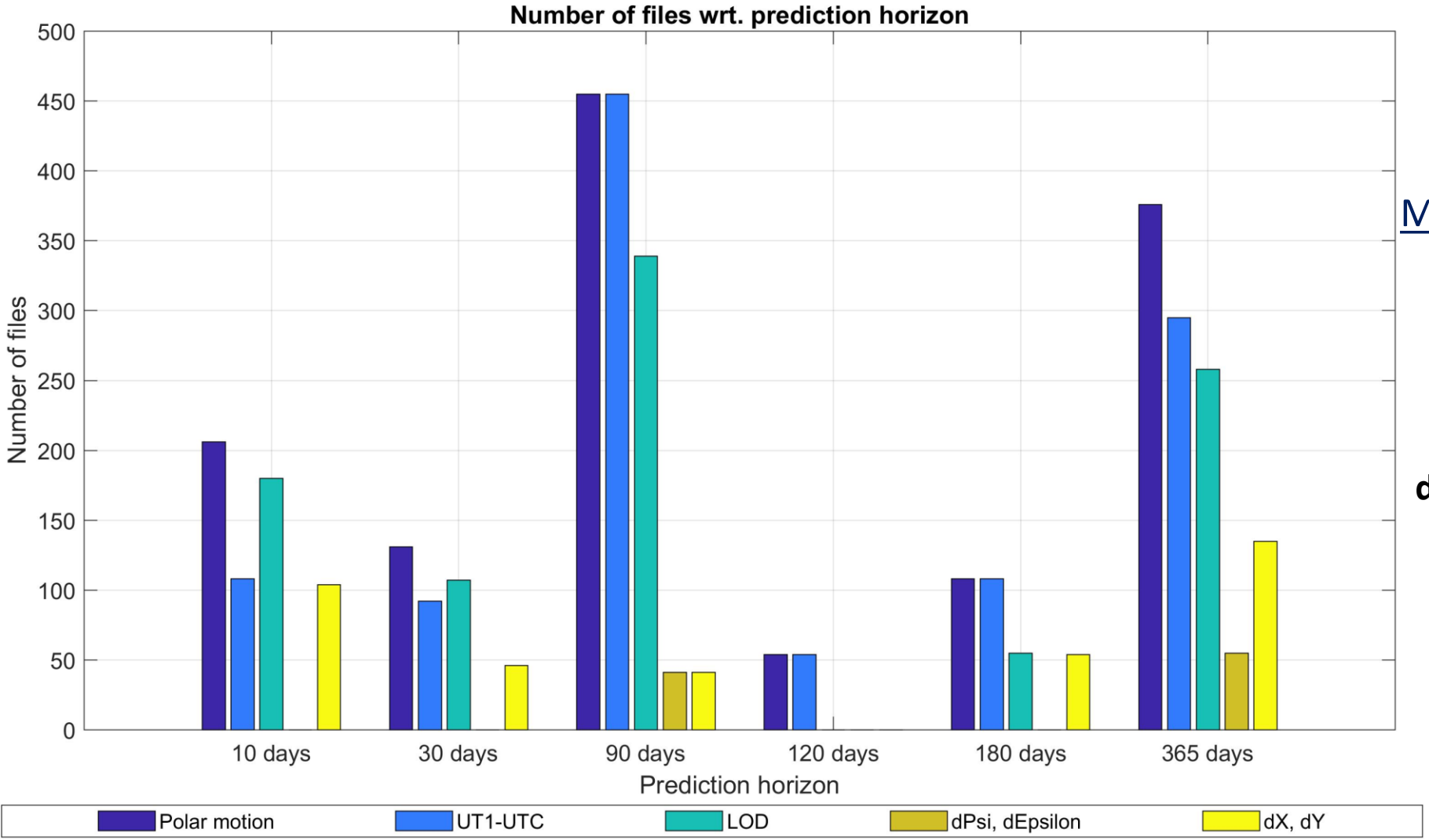


Figure 1 Number of prediction files for each EOP with reference to prediction horizon.

Most common prediction horizon:

PM → 90 and 365 days

UT1-UTC → 90 and 365 days

LOD → 90 and 365 days

dPsi and **dEpsilon** → 90 and 365 days

dX and **dY** → 10 and 365 days

Results

I. Evolution of the prediction's accuracy

Reference data

Reference EOP	First day of comparison	Last day of comparison
IERS C04**	MJD: **59458** 1.09.2021 (start of the EOP PCC)	MJD: **59812** 21.08.2022 (last final EOP solution used in computation)

Due to the limited time, we will particularly focus just on **x pole** and **UT1-UTC**. Y pole, LOD, dX, dY, dPsi and dEpsilon can be found in the end of the presentation in Appendix.

** https://datacenter.iers.org/products/eop/long-term/c04_14/iau2000/csv/
https://datacenter.iers.org/products/eop/long-term/c04_14/iau1980/csv/

Mean Absolute Error – MAE

$$MAE_i = \frac{1}{n_p}\sum_{j=1}^{n_p}\left|\varepsilon_{i,j}\right|$$

$$\varepsilon_{i,j} = x_i^{obs} - x_{i,j}^{pred}$$

Where:

$\varepsilon_{i,j}$ - differences between the observed EOP data x_i^{obs} and their ith point of jth prediction $x_{i,j}^{pred}$

n_p - number of predictions related to the same ID and the same parameter

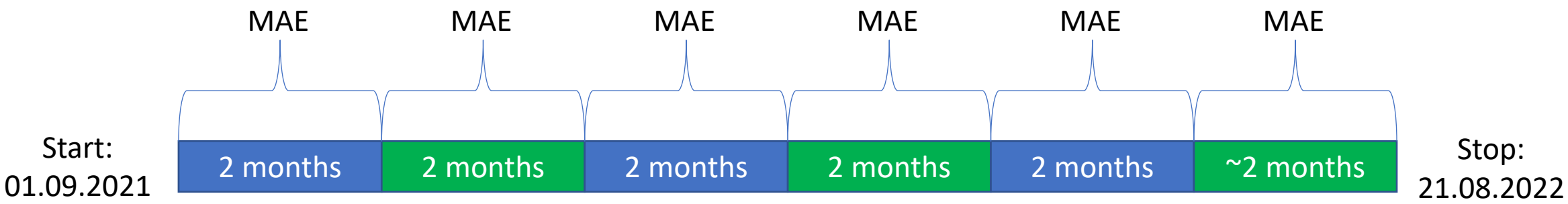
$i = 1,2, \dots, I$

I - length of prediction

(*Kalarus et al., 2010*)

Evolution of the accuracy

Predictions were analyzed in six groups:



Percentage Change - PCh

$$PCh = mean\left(\frac{MAE_i(n) - MAE_i(n+1)}{MAE_i(n)}\right) * 100\%$$

Where:

MAE_i is value for i[th] point of prediction computed for n^{th} group

$PCh > 0$ – next group has lower MAE -> predictions are better

$PCh < 0$ – next group has higher MAE -> predictions are worse

MAE10 for x pole (1.09.2021 – 21.08.2022)

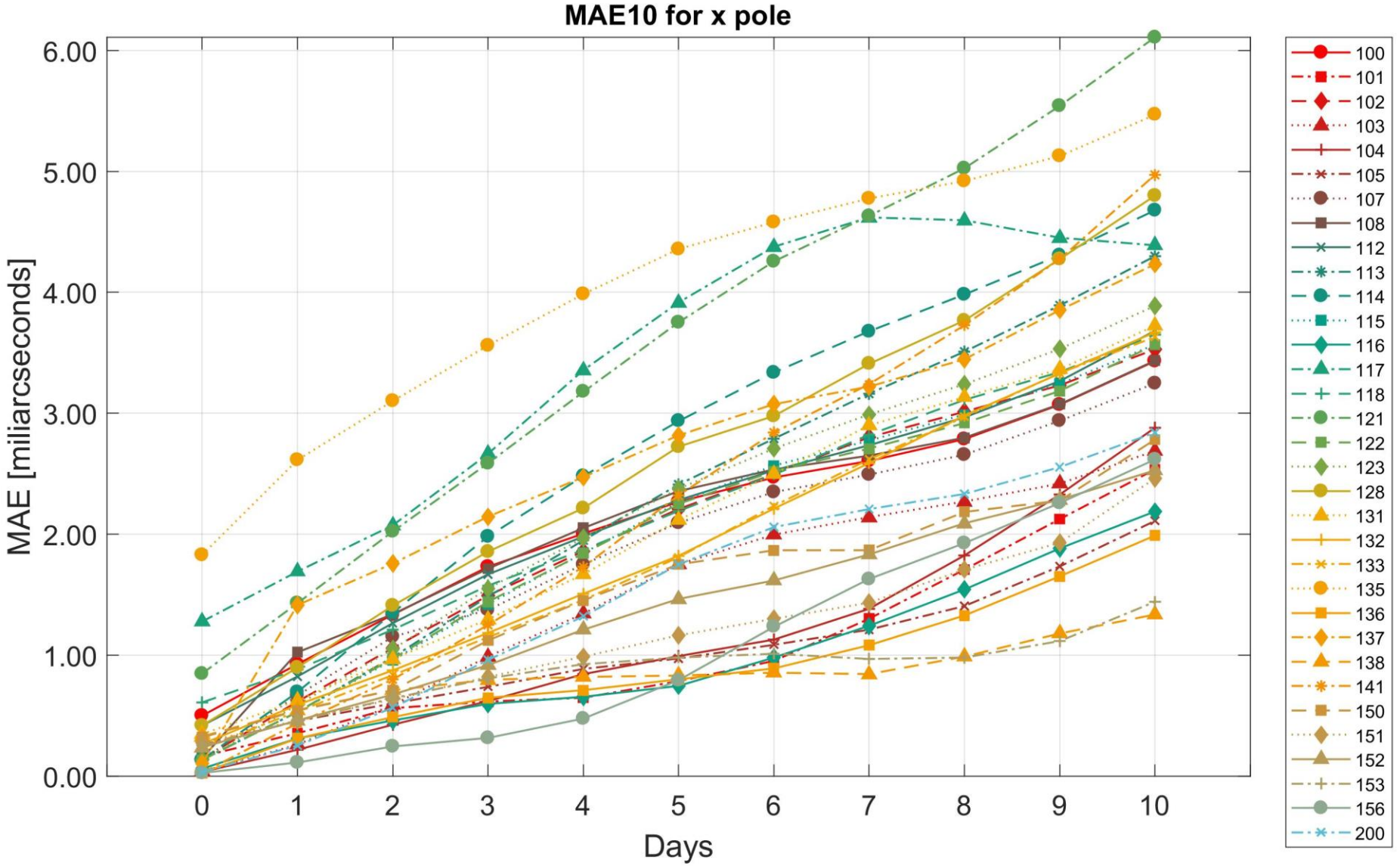


Figure 2 MAE for x pole for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – x pole

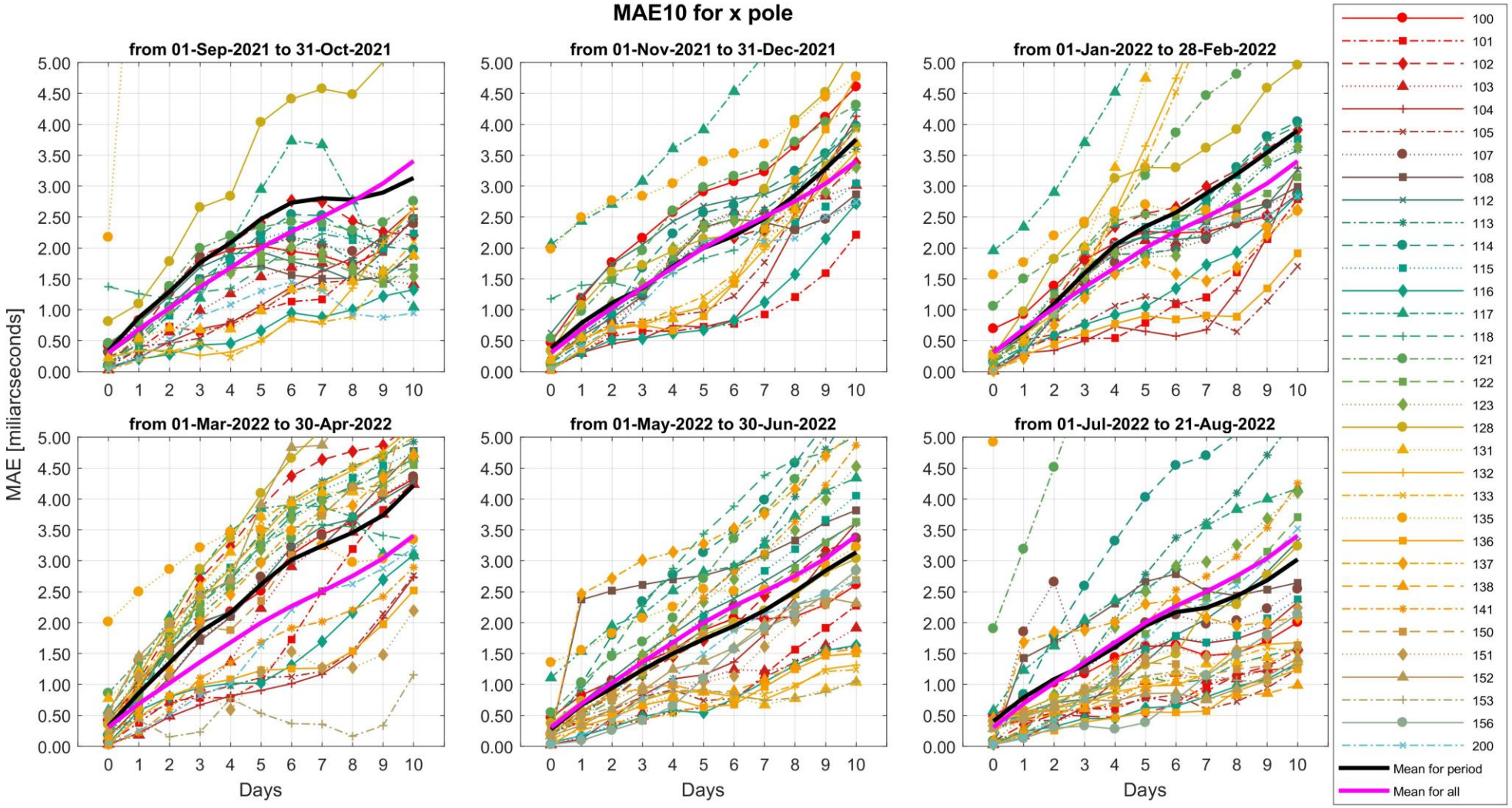


Table 3 Statistics of Percentage Change (PCh)

Mean PCh	-17%
Min PCh	-362.8%
Max PCh	77.2%
Median PCh	-5.9%
#(PCh > 0)	61
#(PCh < 0)	78

Figure 3 Change of MAE for x pole during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for UT1-UTC (1.09.2021 – 21.08.2022)

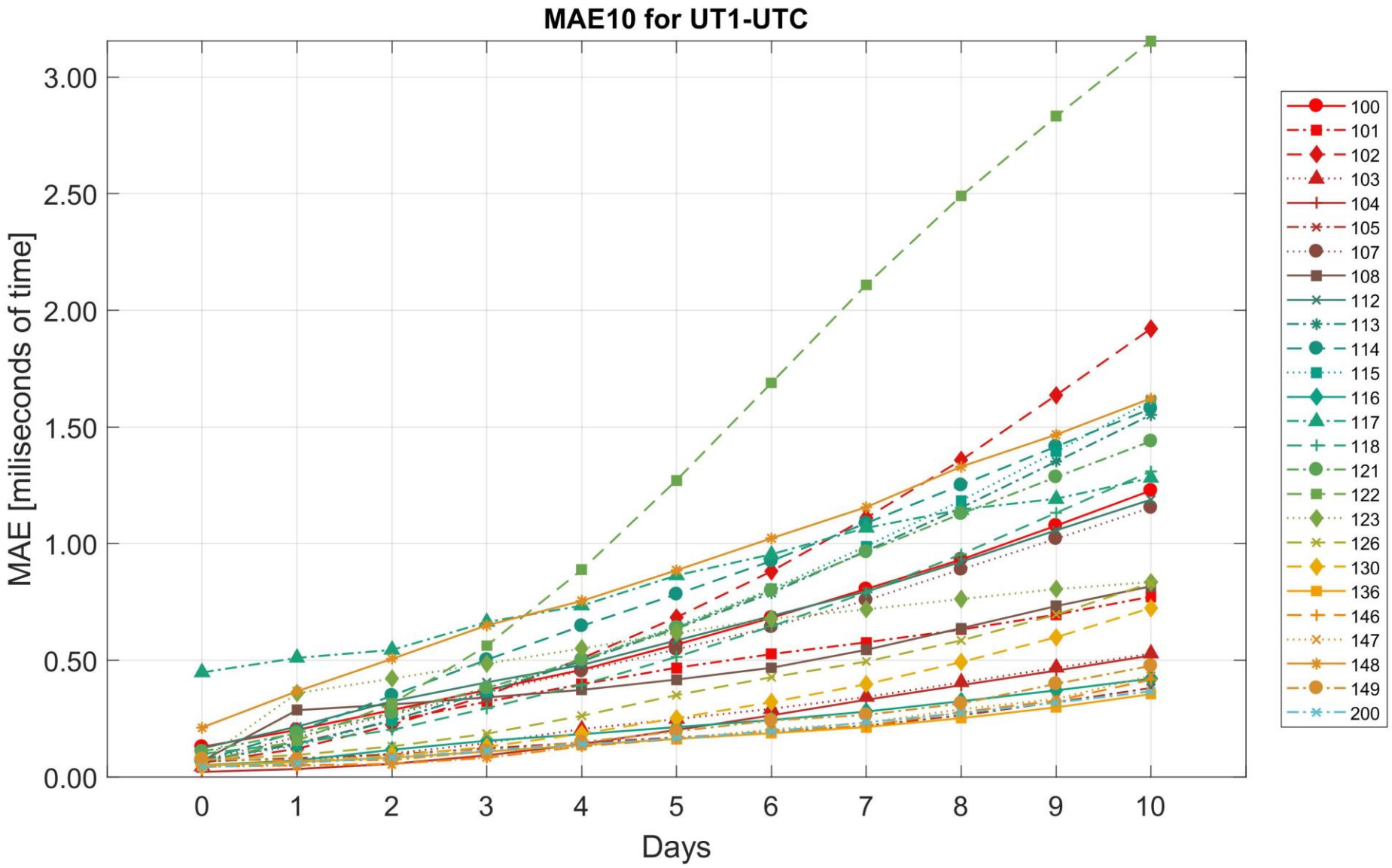


Figure 4 MAE for UT1-UTC for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – UT1-UTC

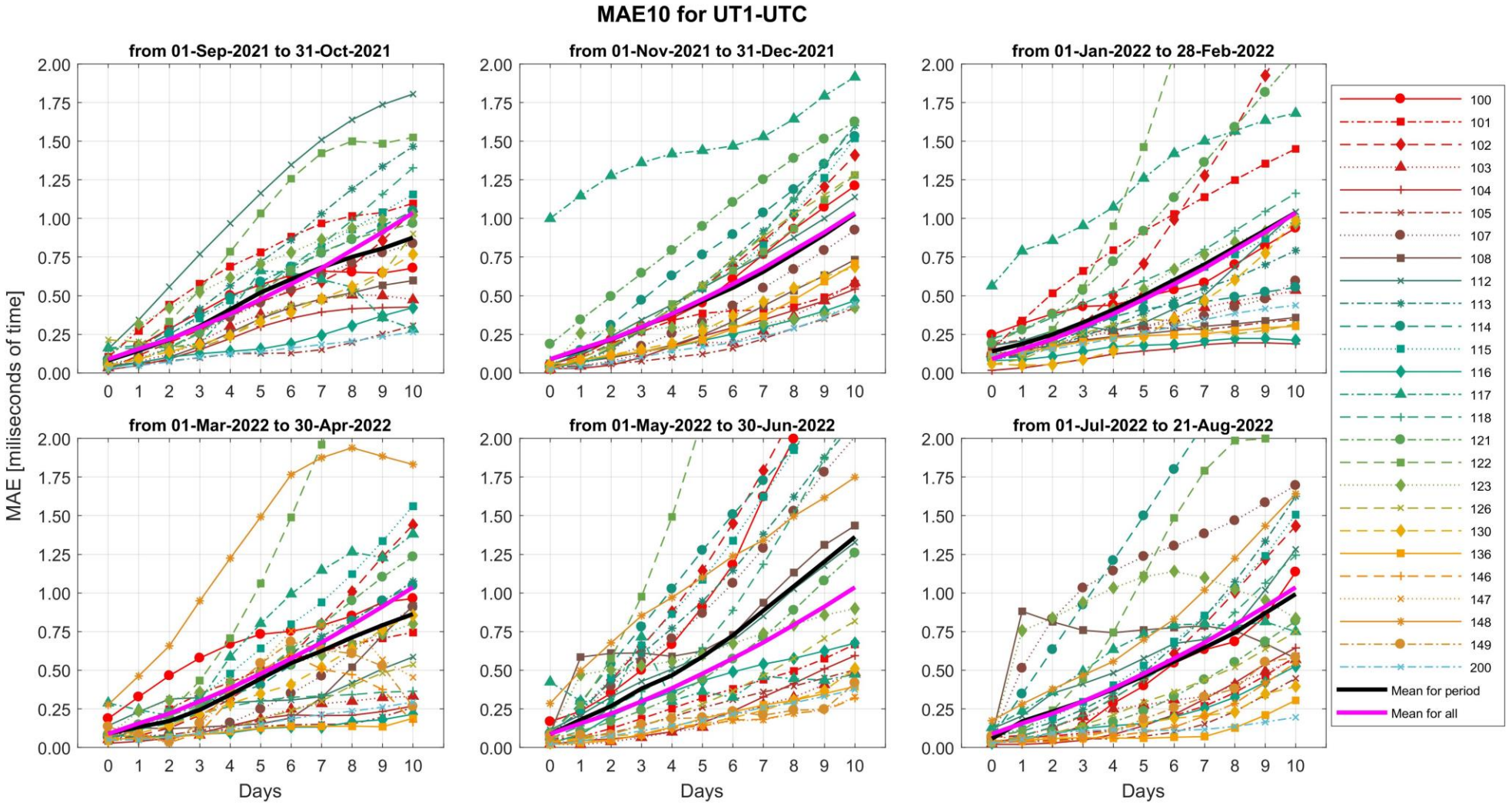


Table 4 Statistics of Percentage Change (PCh)

Mean PCh	-18.5%
Min PCh	-380.5%
Max PCh	65.6%
Median PCh	1.5%
#(PCh > 0)	59
#(PCh < 0)	58

Figure 5 Change of MAE for UT1-UTC during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

General comparison of Percentage Change

Table 5 Summary of Percentage Change (PCh) during the campaign

	x pole	y pole	UT1-UTC	LOD	dPsi	dEpsilon	dX	dY	ALL
With outliers									
Min PCh	-362.8%	**-1832.8%**	-380.5%	**-630.0%**	-62.1%	-127.9%	**-671.7%**	**-966.7%**	-1832.8%
Max PCh	77.2%	**91.1%**	65.6%	**79.9%**	73.3%	58.0%	**83.1%**	**78.5%**	91.1%
Without outliers - values higher than 1σ computed for PCh for each parameter were removed									
Mean PCh	**-3.5%**	**-11.1%**	**8.0%**	**-6.2%**	**3.1%**	**14.3%**	**-5.1%**	**-20.9%**	**-4.7%**
Min PCh	-57.7%	-166.6%	-73.4%	-83.2%	-17.2%	-54.0%	-103.6%	-171.8%	-171.8%
Max PCh	60.2%	91.1%	65.6%	79.9%	27.5%	58.0%	83.1%	78.5%	91.1%
Median PCh	-2.1%	-0.7%	10.8%	-1.6%	5.4%	21.5%	-3.0%	-15.9%	0.0%
#(PCh > 0)	56	66	**59**	39	**5**	**8**	17	15	265
#(PCh < 0)	63	68	39	43	4	2	22	24	265

- After removing outliers, 74 values of PCh were discarded.
- At this stage, we consider mean values of PCh ≥ -10% as the acceptable changes caused by external effect, e.g., input data.
- Mean PCh for y pole and dY is 3 – 4 times larger than for x pole and dX – it is possible that algorithms are individually tuned for x pole and dX, but not for y pole and dY.

II. Selection of predictions with β-parameter

β-parameter

$$\boldsymbol{\beta_j = \sum_{i=1}^{I} \left(\alpha * MDAE_i - \left| \varepsilon_{i,j} \right| \right)}$$

$$\boldsymbol{MDAE_i = median\left(\left| \varepsilon_{i,1} \right|, \left| \varepsilon_{i,2} \right|, \dots, \left| \varepsilon_{i,j} \right|, \left| \varepsilon_{i,n_p} \right| \right)}$$

$$\varepsilon_{i,j} = x_i^{obs} - x_{i,j}^{pred}$$

Where:

$\varepsilon_{i,j}$ - differences between the observed EOP data x_i^{obs} and their ith point of jth prediction $x_{i,j}^{pred}$

n_p - number of predictions related to the same ID and the same parameter

$i = 1,2, \dots, I$

I - length of prediction

If $\boldsymbol{\beta_j < 0}$ the prediction was **not included** in the further studies, while the **α-value was deduced empirically to preserve a representative set of data.**

(*Kalarus et al., 2010*)

Impact of α-value on the number of rejected predictions

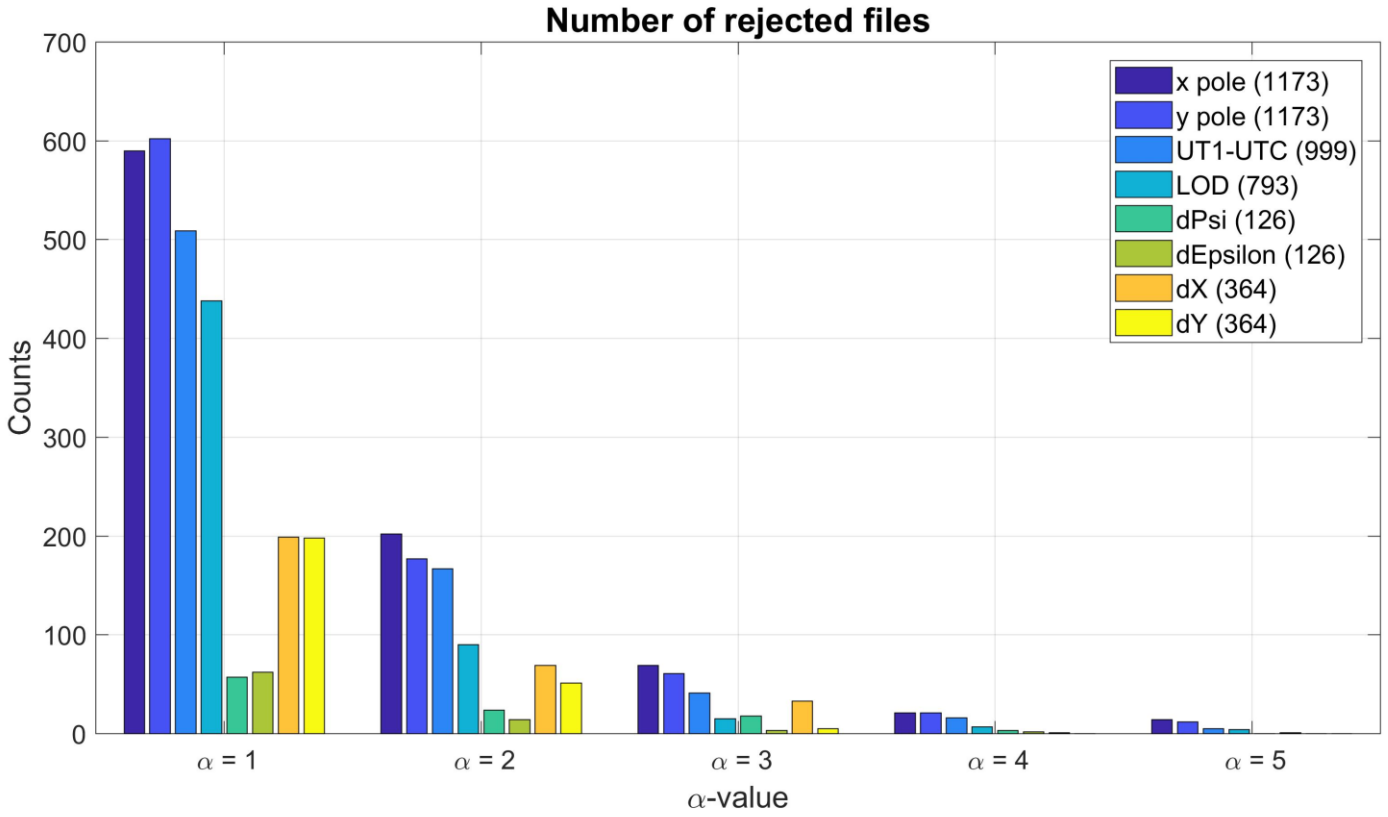


Figure 6 Number of rejected prediction files for each EOP according to α-value. In the legend in brackets are provided total numbers of submitted files.

Table 6 Percentage of rejected prediction files according to chosen α-value

	α = 1	α = 2	α = 3	α = 4	α = 5
x pole	50.3	17.2	5.9	1.8	1.2
y pole	51.3	15.1	5.2	1.8	1.0
UT1-UTC	51.0	16.7	4.1	1.6	0.5
LOD	55.2	11.4	1.9	0.9	0.5
dPsi	45.2	19.1	14.3	2.4	0.0
dEpsilon	49.2	11.1	2.4	1.6	0.8
dX	54.7	19.0	9.1	0.3	0.0
dY	54.4	14.0	1.4	0.0	0.0
Total	51.9	15.5	4.8	1.4	0.7

In the 1st EOPPCC **α-value = 5** was used and **2%** of all files was rejected (*Kalarus et al., 2010*).
In the 2nd EOPPCC with **α-value = 5** it is less than **0.7%**.

Example of impact of filtration for x pole

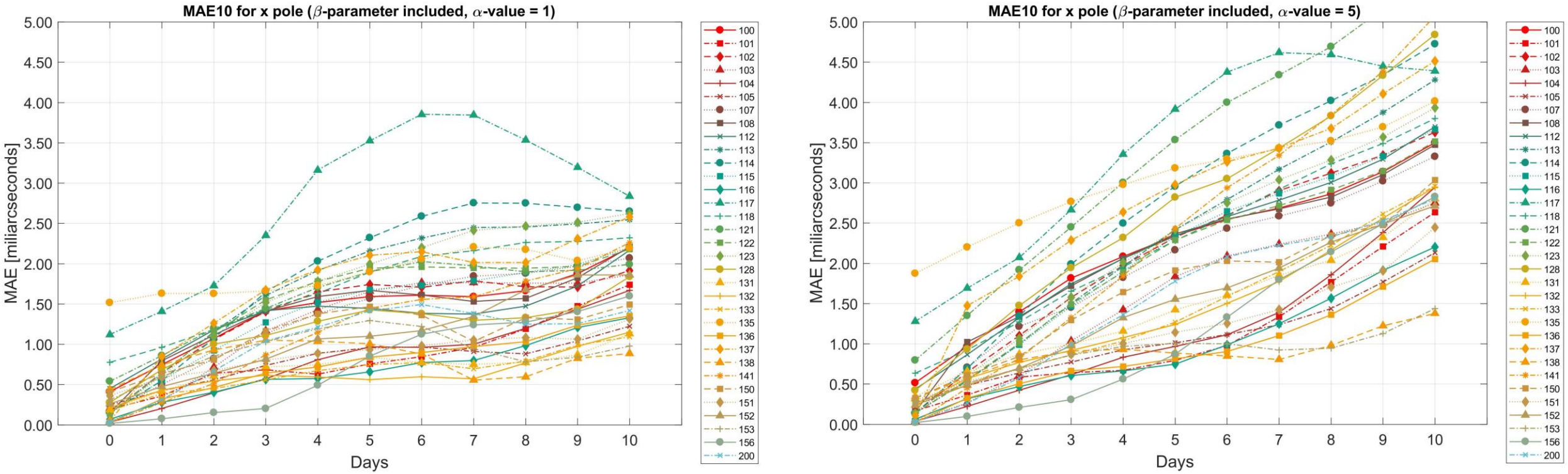
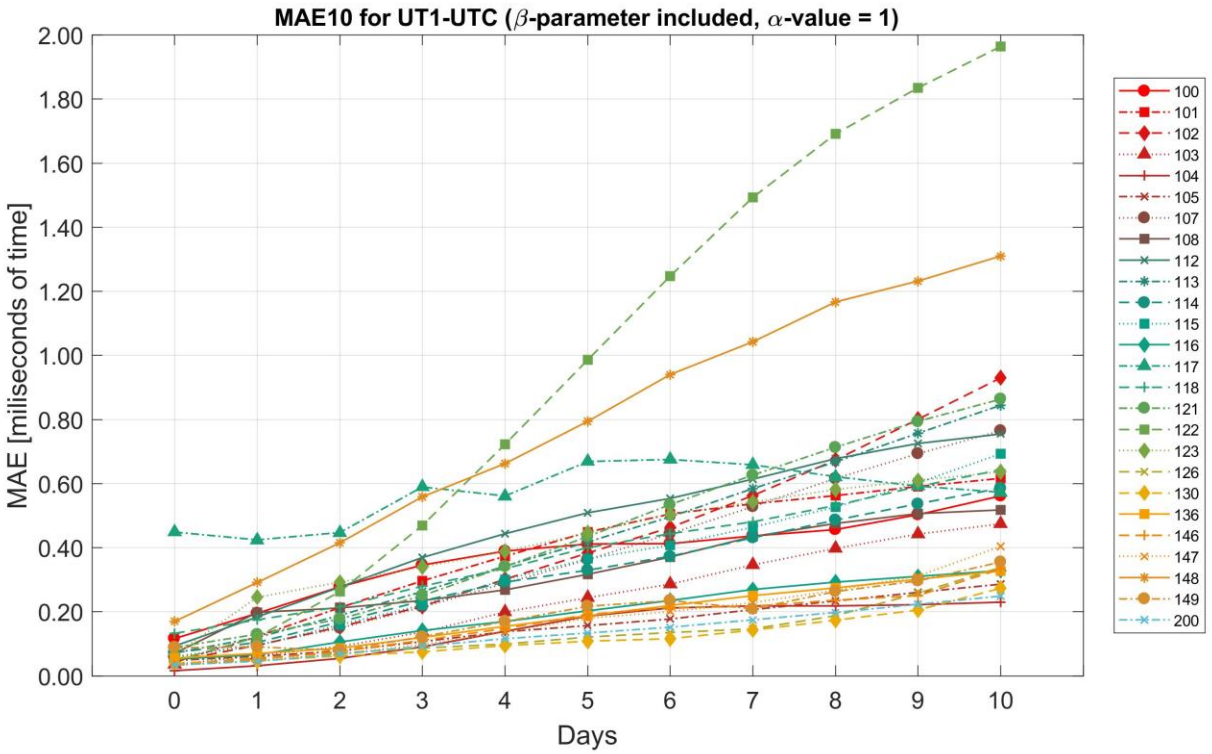


Figure 7 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table 7 Statistics of MAE for α-value = 1 and α-value = 5

[miliarcseconds]	Min MAE	Mean MAE	Max MAE	RMS
α-value = 1	0.02	1.26	3.85	1.44
α-value = 5	0.02	1.87	5.69	2.23

Example of impact of filtration for UT1-UTC



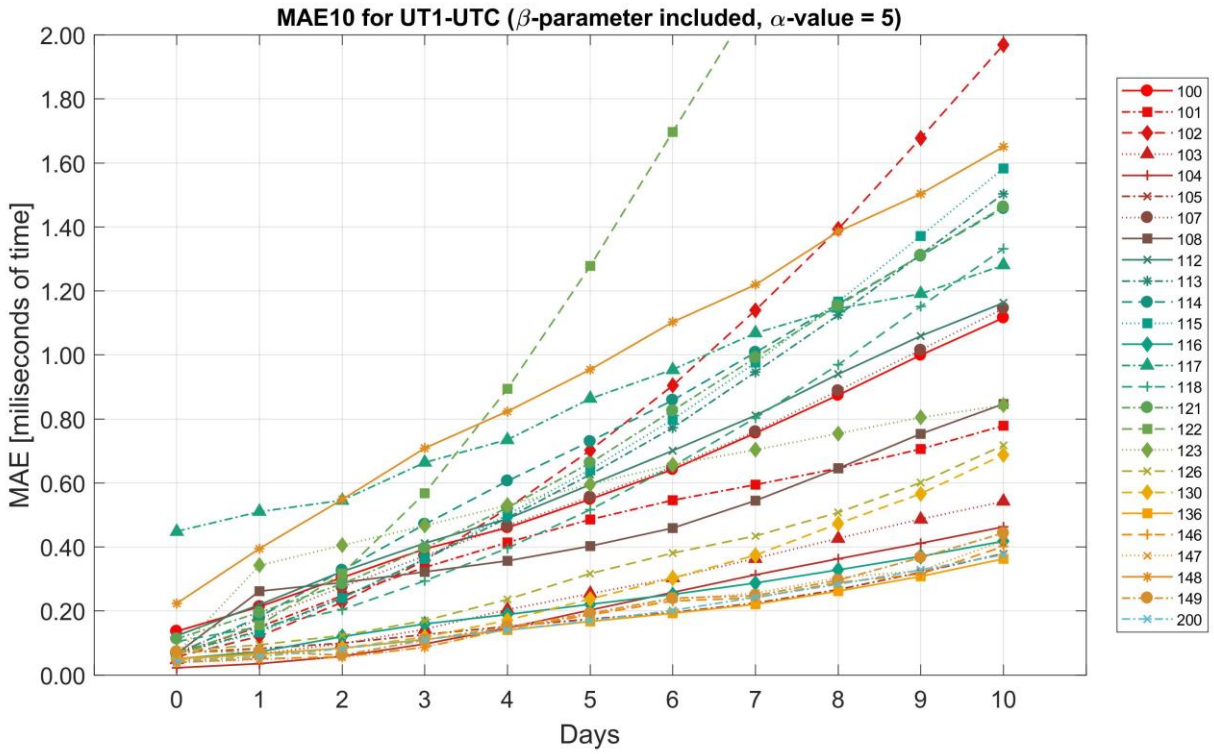


Figure 8 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table 8 Statistics of MAE for α-value = 1 and α-value = 5

[miliseconds]	Min MAE	Mean MAE	Max MAE	RMS
α-value = 1	0.02	0.34	1.96	0.45
α-value = 5	0.02	0.51	3.22	0.70

Conclusions and future plans

Since the start of the 2nd EOP PCC, **22 participants** are registered with a total of **56 prediction methods** used, which is more than in the previous campaign.

A. The main conclusion is that **results obtained in the 2nd EOP PCC are better than in the first campaign**.

B. The accuracy varies between two-month periods – only a few IDs preserve the stability (the same level of accuracy) during the campaign. We assume that the main cause are gross erros in input data preparations. Another cause might be a development and modifications of the method during campaign, which is very appreciated by the EOP PCC Office.

C. The results of the campaign are **promising** as there are **several predictions that achieve similar or even better accuracy than forecasts provided by the IERS**. One year after the start of the 2nd EOP PCC, obtained MAE for the 10th day of prediction was:

- between 1 mas and 6.0 mas for x pole, between 1 mas and 4 mas for y pole,
- between 0.3 ms and 2 ms for UT1–UTC, between 0.0 ms and 0.3 ms for LOD,
- between 0.4 mas and 1.1 mas for dPsi, between 0.1 mas and 0.5 mas for dEpsilon,
- between 0.04 mas and 0.15 mas for dX, between 0.05 mas and 0.15 mas for dY.

D. Eliminating outlier predictions can noticeably reduce the MAE.

E. In further studies we will consider e.g., using other reference data (combined data from other Centres and single technique solutions) to evaluate EOP predictions or evaluating longer predicitons horizons etc…

F. We are considering **extending the length of the campaign by several months** to analyse a larger number of predictions based on the **new 20 C04 series** consistent in the International Terrestrial Reference Frame ITRF2020.

The EOPPCC Office would like to thank all the participants for their efforts and engagement.

Thank you for attention.

Appendix

2nd EOP PCC – milestones

preparations

- **Q1 2021:** open call for participation in IERS Working Group on the 2nd EOP PCC (**24 March 2021**)
- **Q2 2021:** first meeting of WG on the 2nd EOP PCC (**6 May 2021**)
- **Q2 2021:** definition of the validation protocol, website of EOP PCC online, technical document summarizing all the rules and requirements (**2 June 2021**)
- **Q2 2021:** open call for participation in pre-operational phase of the 2nd EOP PCC (**3 June 2021**)

test phase

- **Q2 2021:** open the server for ID applications and preliminary submissions of predictions for testing purposes (**7 June 2021**)
- **Q2 2021:** first weekly submission of test EOP predictions (**9 June 2021**)
- **Q3 2021:** poster about preparations for the 2nd EOP PCC presented during the IAG Scientific Assembly (**1 July 2021**)
- **Q3 2021:** open call for participation in operational phase of 2nd EOP PCC (**13 July 2021**)

operational phase

- **Q3 2021:** first weekly submission of EOP predictions (**1 September 2021**)
- **Q4 2021**: preliminary results presented during ICCC JWG C.1 Meeting (**25 November 2021**)
- **Q4 2021**: call for participation in the 2nd EOP PCC Workshop (**10 December 2021**)
- **Q4 2021**: poster with campaign overview and first results presented during AGU Fall Meeting (**16 December 2021**)
- **Q1 2022**: 2nd EOP PCC Workshop (**15-16 February 2022**)
- **Q2 2022**: invited presentation with campaign overview presented during EGU General Assembly 2022 (**25 May 2021**)

MAE10 for y pole (1.09.2021 – 21.08.2022)

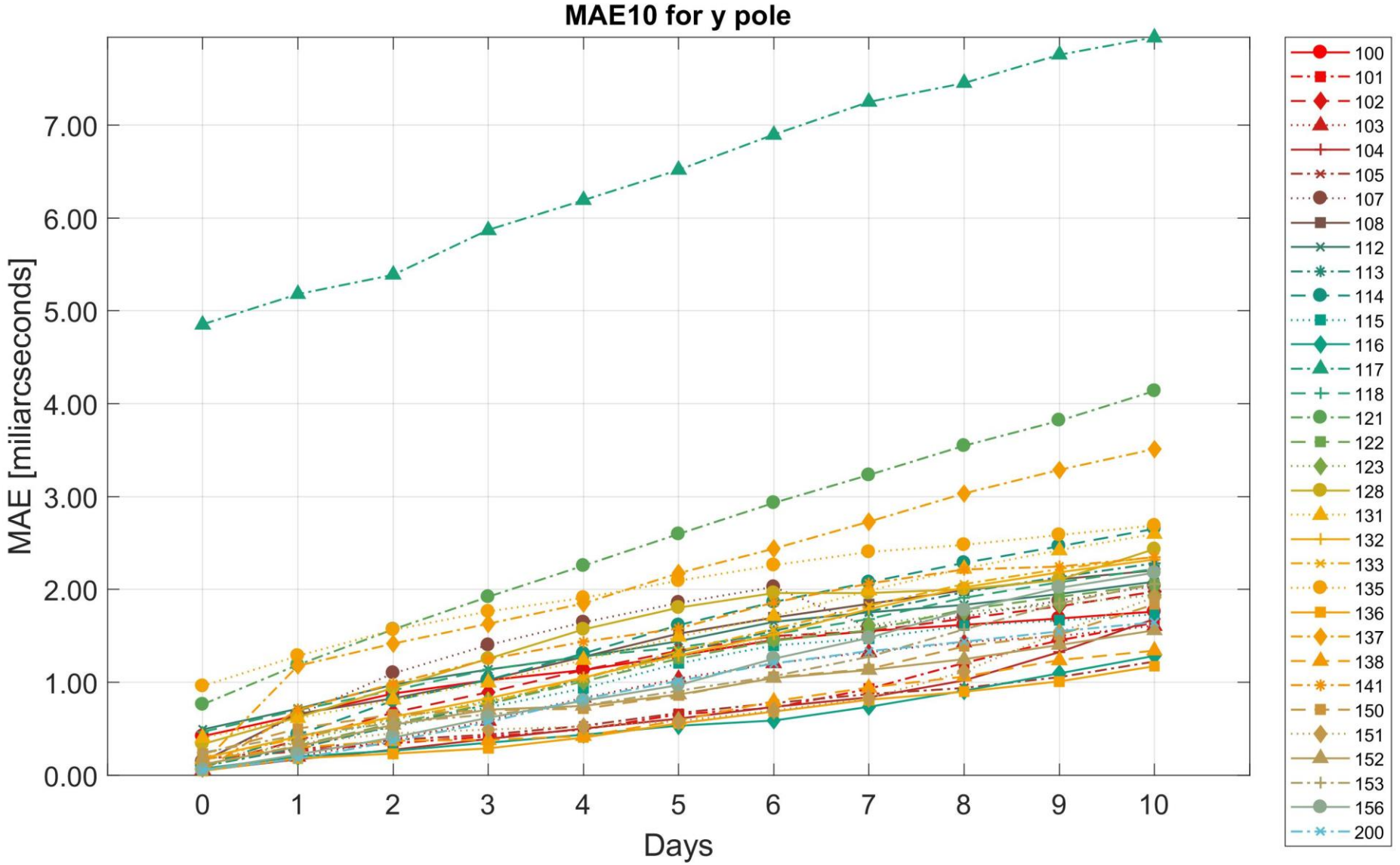


Figure A1 MAE for y pole for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – y pole

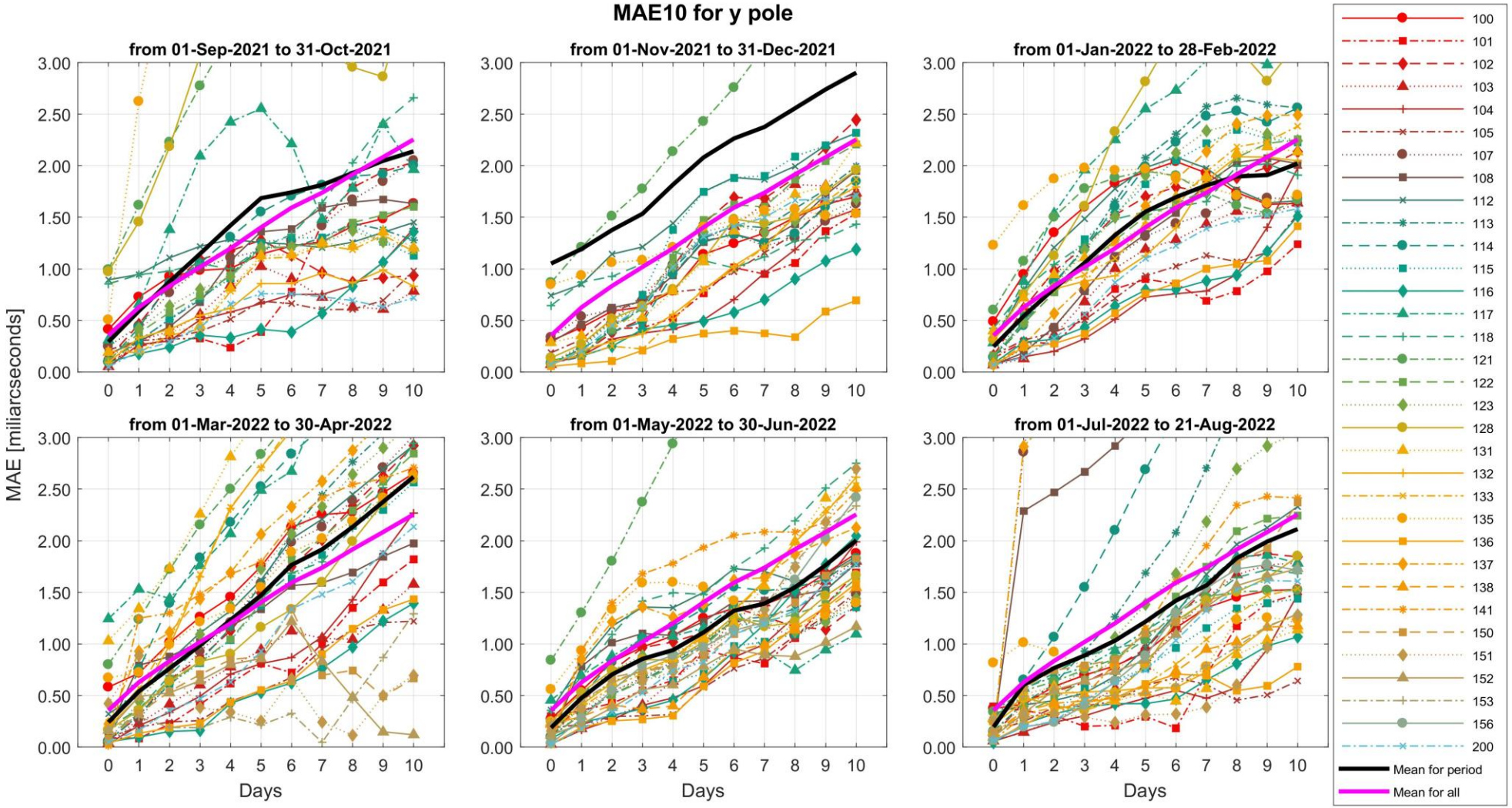


Table A1 Statistics of Percentage Change (PCh)

Mean PCh	-33.2%
Min PCh	-1832.8%
Max PCh	91.1%
Median PCh	-1.8%
#(PCh > 0)	66
#(PCh < 0)	73

Figure A2 Change of MAE for y pole during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for LOD (1.09.2021 – 21.08.2022)

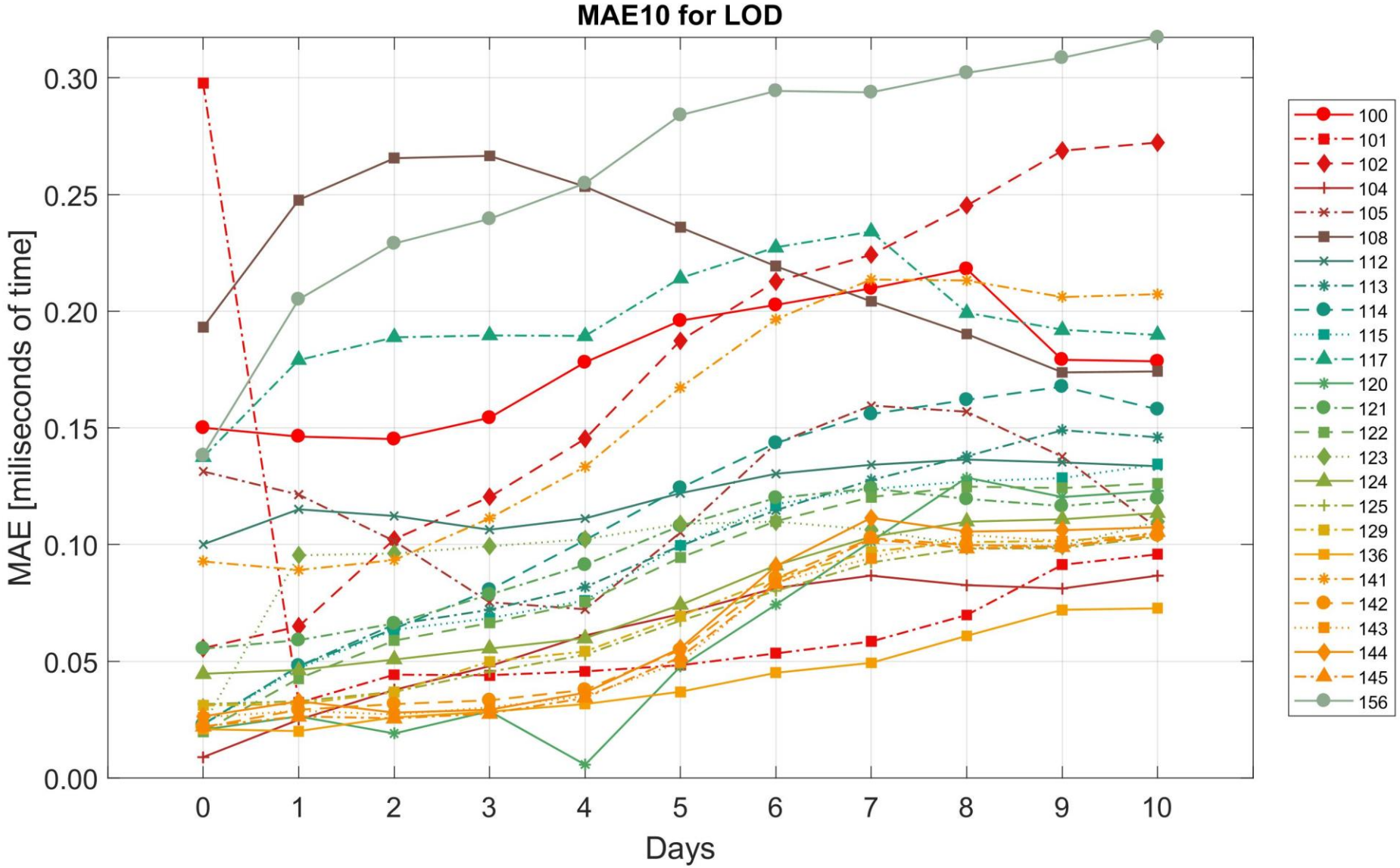


Figure A3 MAE for LOD for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – LOD

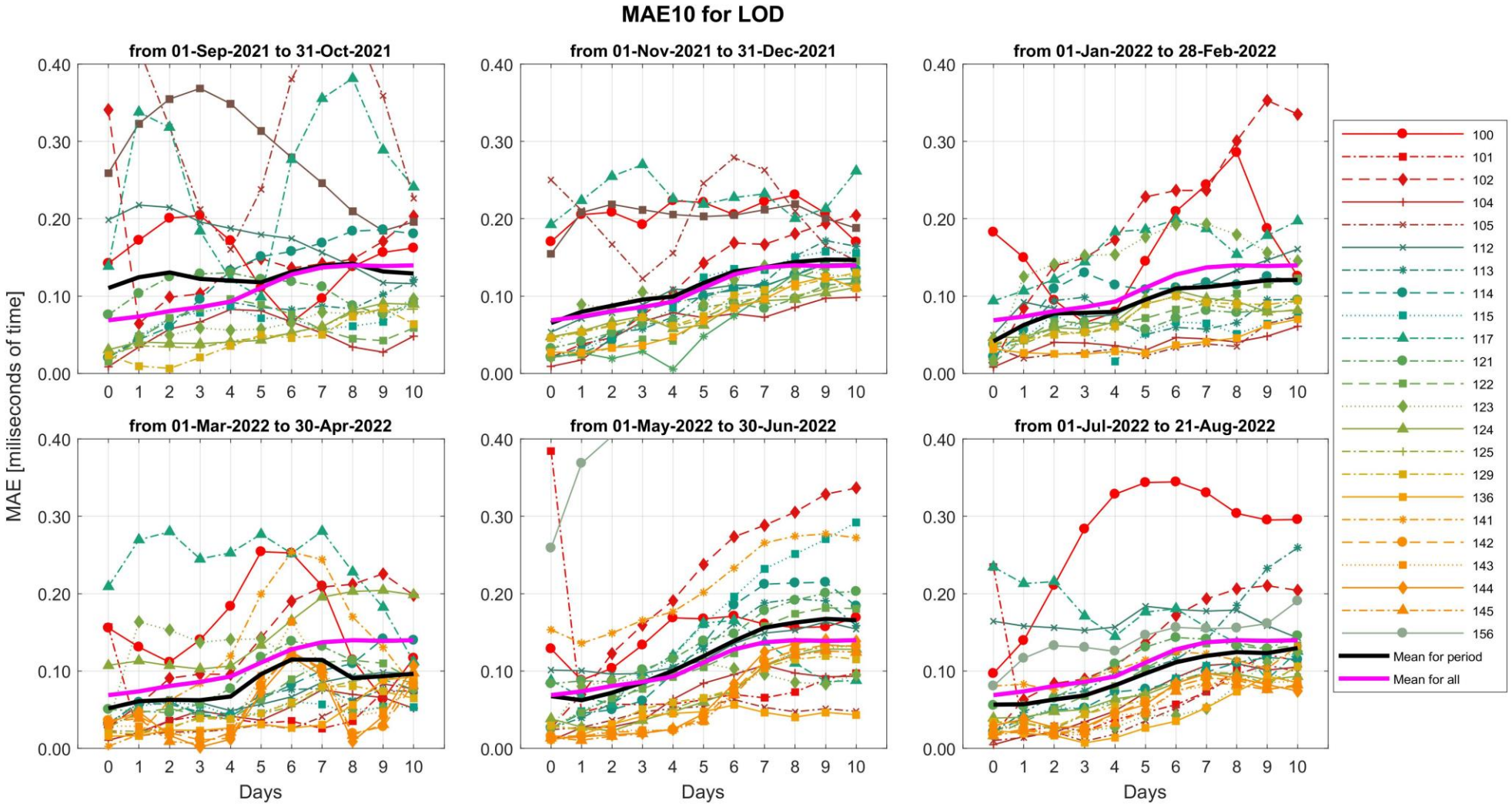


Table A2 Statistics of Percentage Change (PCh)

Mean PCh	-24.9%
Min PCh	-630.0%
Max PCh	79.9%
Median PCh	-9.5%
#(PCh > 0)	39
#(PCh < 0)	52

Figure A4 Change of MAE for LOD during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for dPsi (1.09.2021 – 21.08.2022)

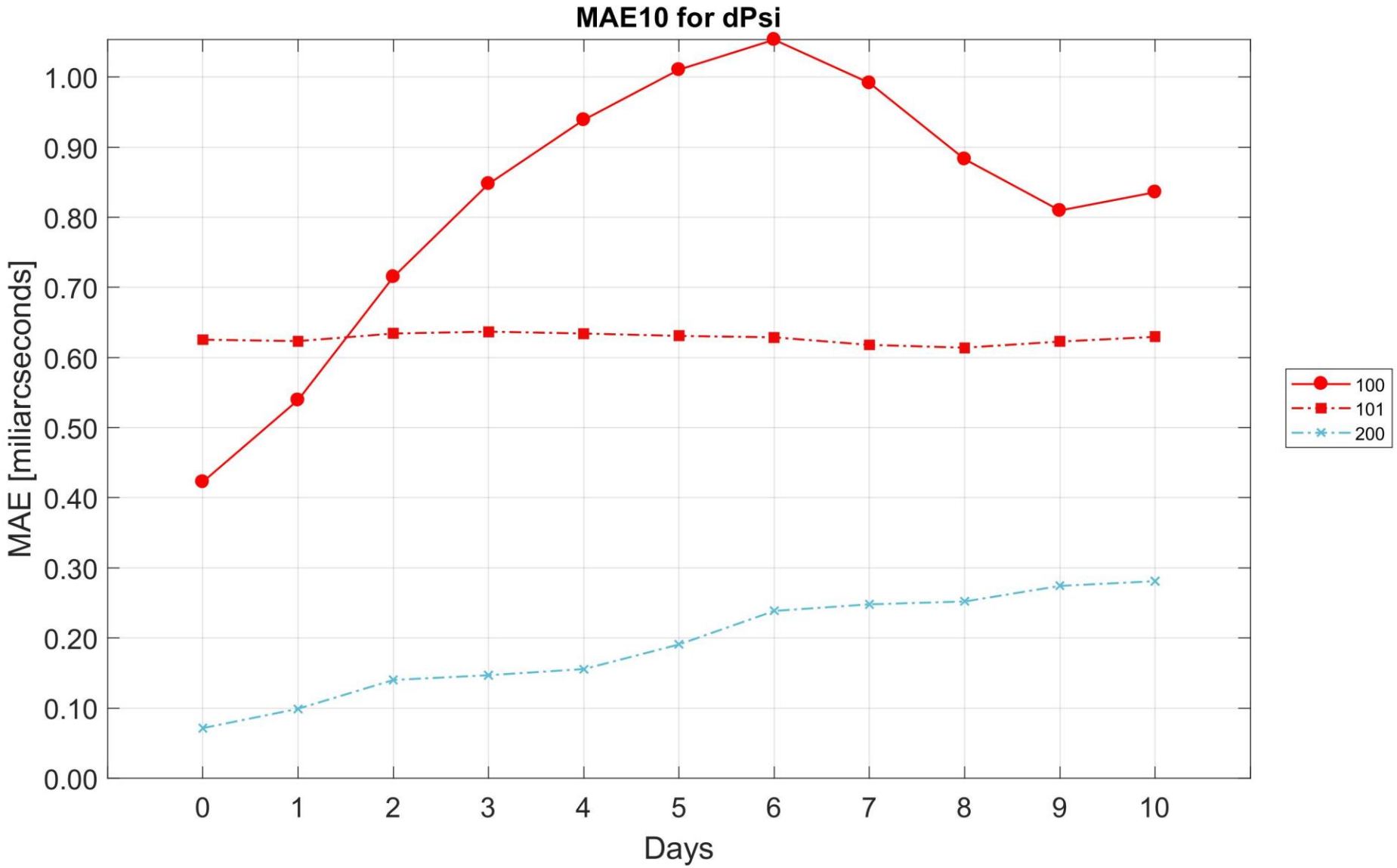


Figure A5 MAE for dPsi for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – dPsi

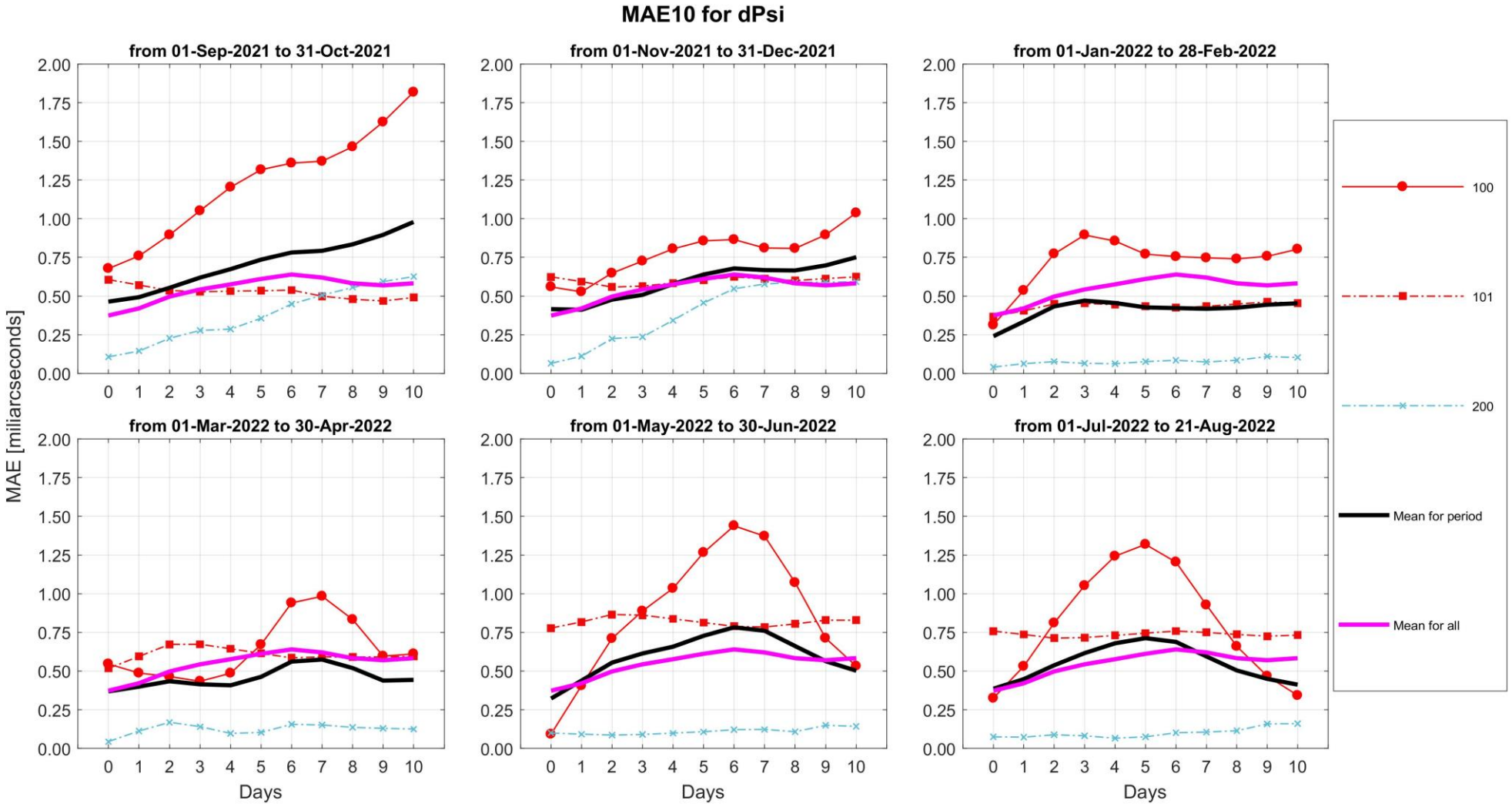


Table A3 Statistics of Percentage Change (PCh)

Mean PCh	-2.4%
Min PCh	-62.1%
Max PCh	73.3%
Median PCh	-0.2%
#(PCh > 0)	7
#(PCh < 0)	8

Figure A6 Change of MAE for dPsi during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for dEpsilon (1.09.2021 – 21.08.2022)

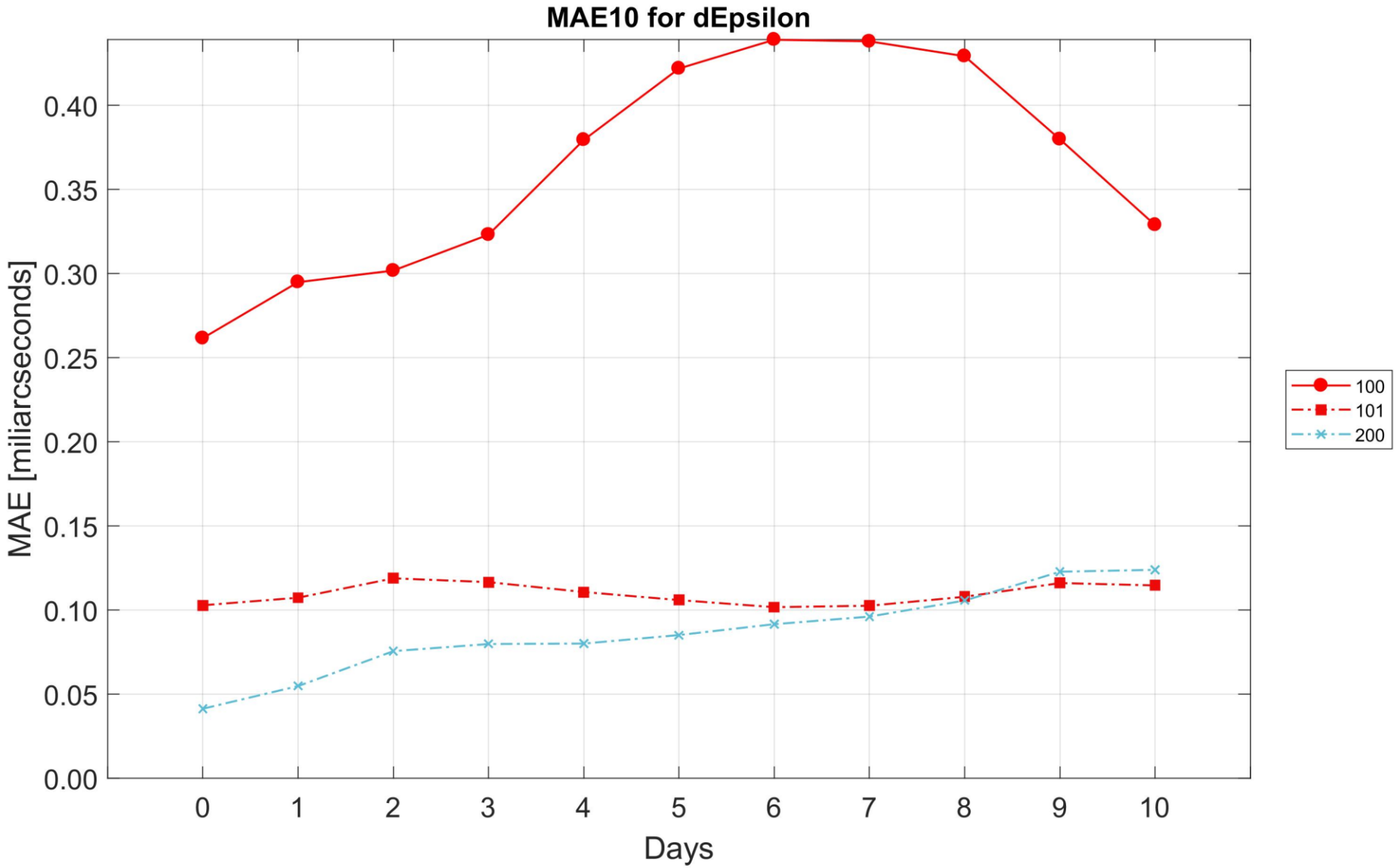


Figure A7 MAE for dEpsilon for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – dEpsilon

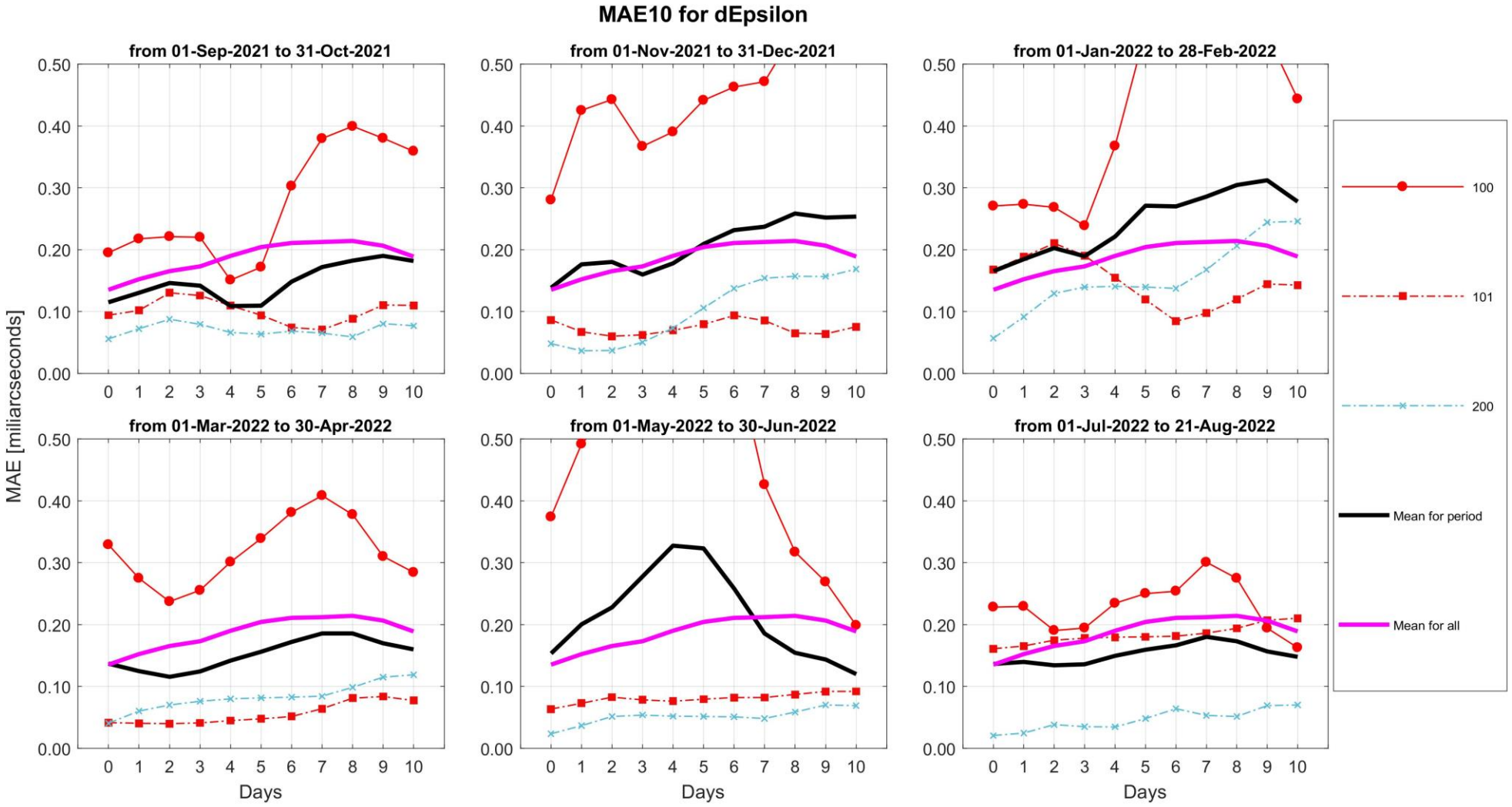


Table A4 Statistics of Percentage Change (PCh)

Mean PCh	-21.1%
Min PCh	-127.9%
Max PCh	58.0%
Median PCh	4.3%
#(PCh > 0)	8
#(PCh < 0)	7

Figure A8 Change of MAE for dEpsilon during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for dX (1.09.2021 – 21.08.2022)

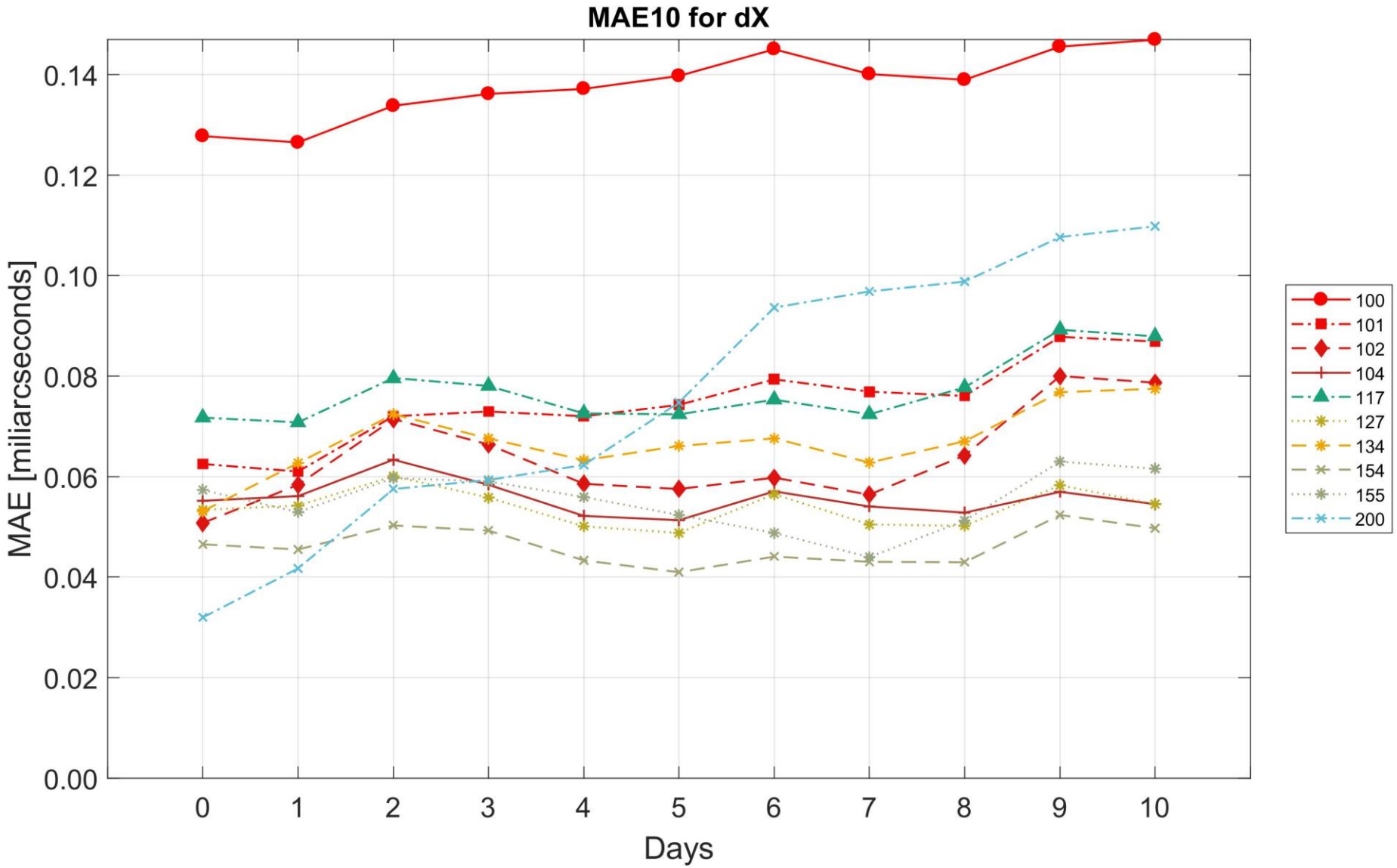


Figure A9 MAE for dX for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – dX

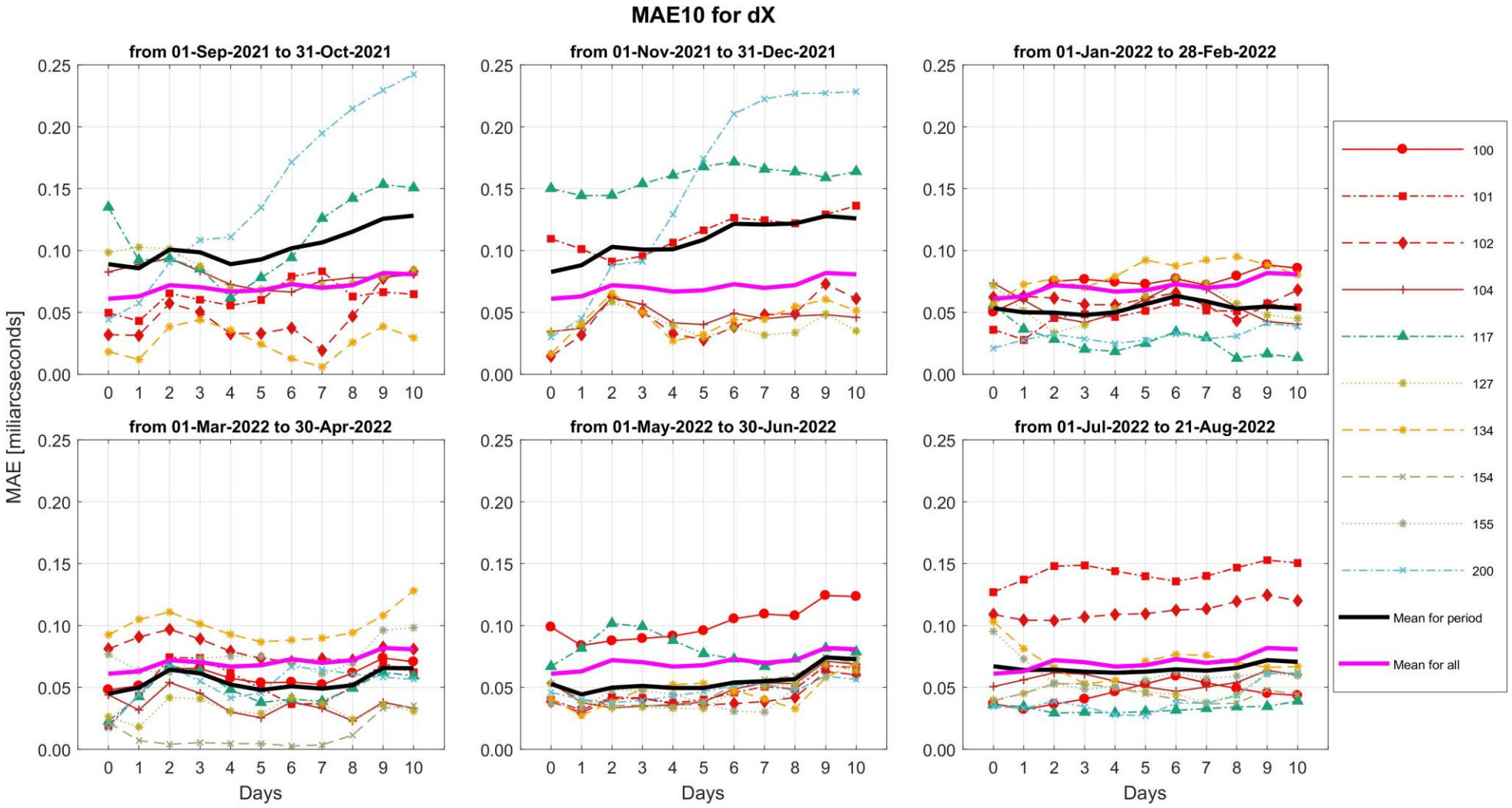


Table A5 Statistics of Percentage Change (PCh)

Mean PCh	-34.9%
Min PCh	-671.7%
Max PCh	83.1%
Median PCh	-12.1%
#(PCh > 0)	17
#(PCh < 0)	27

Figure A10 Change of MAE for dX during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

MAE10 for dY (1.09.2021 – 21.08.2022)

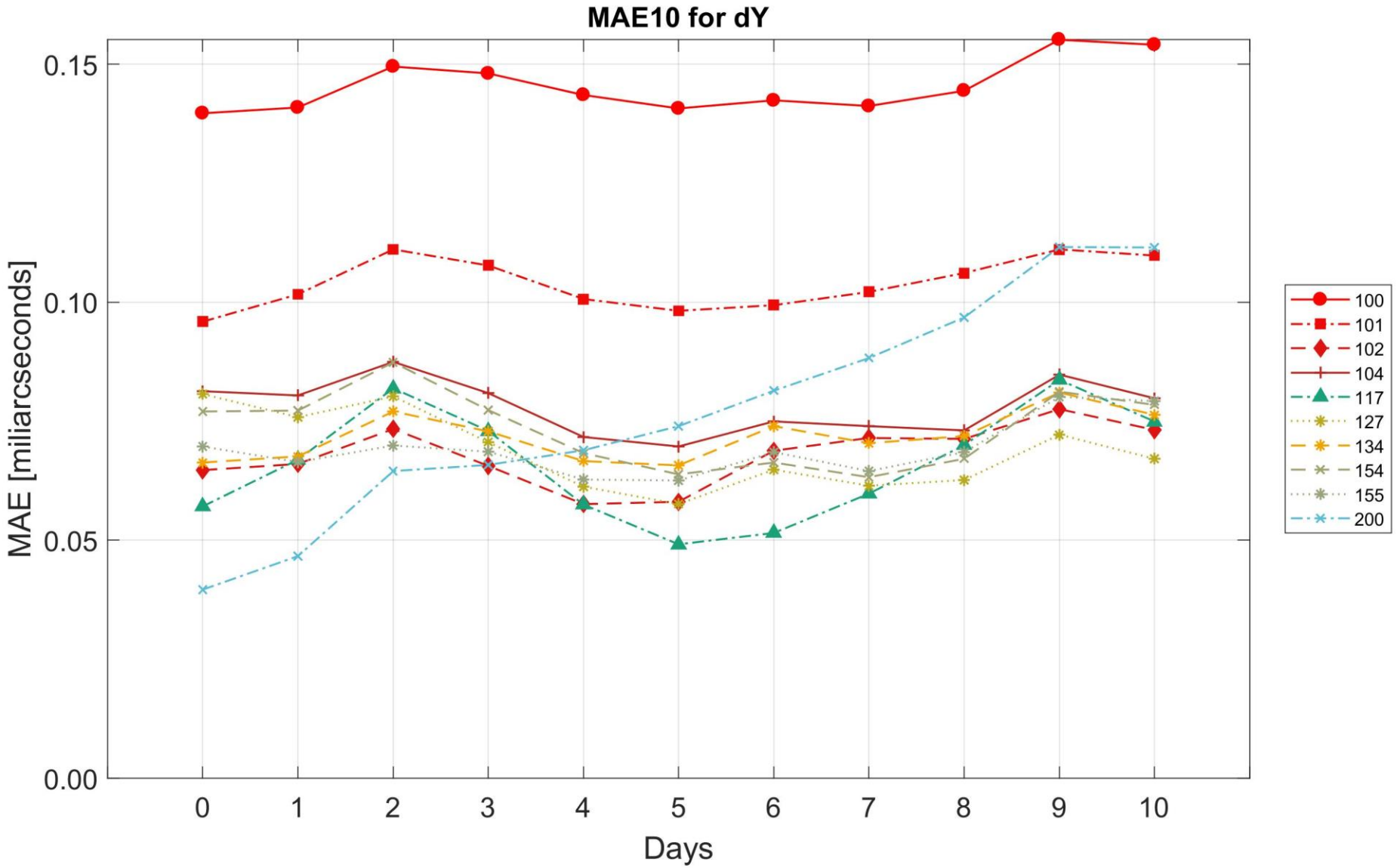


Figure A11 MAE for dY for up to 10 days into the future for the year of the campaign duration. Day 0 means last solution used to predict, numbers in the legend represent participants' IDs.

Evolution of the prediction's accuracy – dY

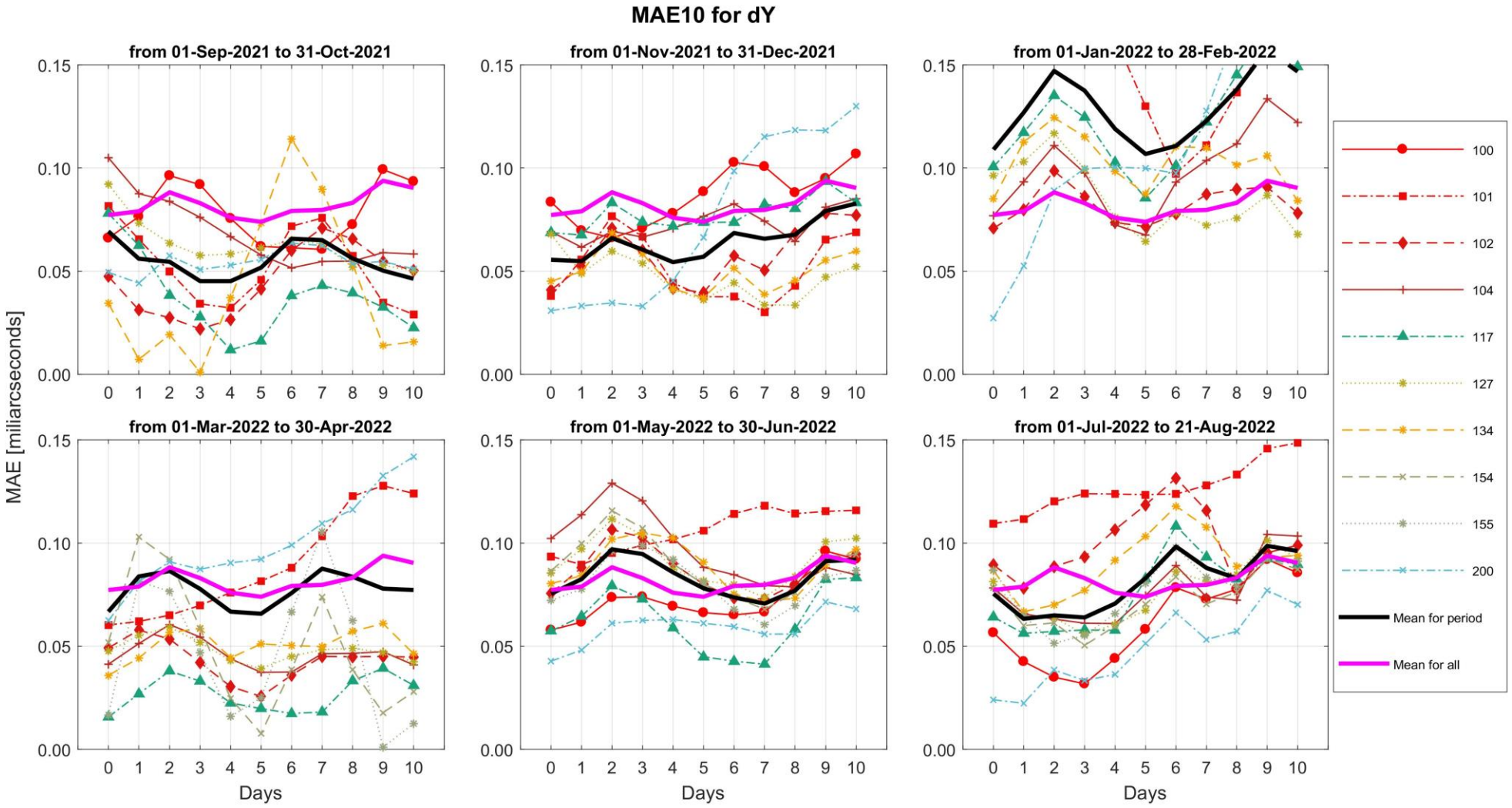


Table A6 Statistics of Percentage Change (PCh)

Mean PCh	-70.5%
Min PCh	-966.7%
Max PCh	78.5%
Median PCh	-18.8%
#(PCh > 0)	15
#(PCh < 0)	29

Figure A12 Change of MAE for dY during the campaign. Black thick line represents mean value of MAE from two months, magenta thick line represents mean value of MAE from the year, numbers in the legend represent participants' IDs.

General comparison of Percentage Change

	x_pole	y_pole	UT1_UTC	LOD	dPsi	dEpsilon	dX	dY	All
Mean PCh	-17,0%	-33,2%	-18,5%	-24,9%	-2,4%	-21,1%	-34,9%	-70,5%	-27,2%
Mean PCh (w/o outliers)	-3,5%	-11,1%	8,0%	-6,2%	3,1%	14,3%	-5,1%	-20,9%	-4,7%
Std PCh	62,6%	169,6%	73,8%	85,0%	33,8%	61,8%	119,5%	184,7%	115,7%
Std (w/o outliers)	29,3%	46,3%	33,1%	37,4%	13,6%	38,5%	51,2%	59,8%	41,1%
Minimum	-362,8%	-1832,8%	-380,5%	-630,0%	-62,1%	-127,9%	-671,7%	-966,7%	-1832,8%
Minimum (w/o outliers)	-57,7%	-166,6%	-73,4%	-83,2%	-17,2%	-54,0%	-103,6%	-171,8%	-171,8%
Maximum	77,2%	91,1%	65,6%	79,9%	73,3%	58,0%	83,1%	78,5%	91,1%
Maximum (w/o outliers)	60,2%	91,1%	65,6%	79,9%	27,5%	58,0%	83,1%	78,5%	91,1%
Median	-5,9%	-1,8%	1,5%	-9,5%	-0,2%	4,3%	-12,1%	-18,8%	-5,6%
Median (w/o outliers)	-2,1%	-0,7%	10,8%	-1,6%	5,4%	21,5%	-3,0%	-15,9%	0,0%
#(PCh > 0)	61	66	59	39	7	8	17	15	272
#(PCh > 0) (w/o outliers)	56	66	59	39	5	8	17	15	265
#(PCh < 0)	78	73	58	52	8	7	27	29	332
#(PCh < 0) (w/o outliers)	63	68	39	43	4	2	22	24	265

Example of impact of filtration for y pole

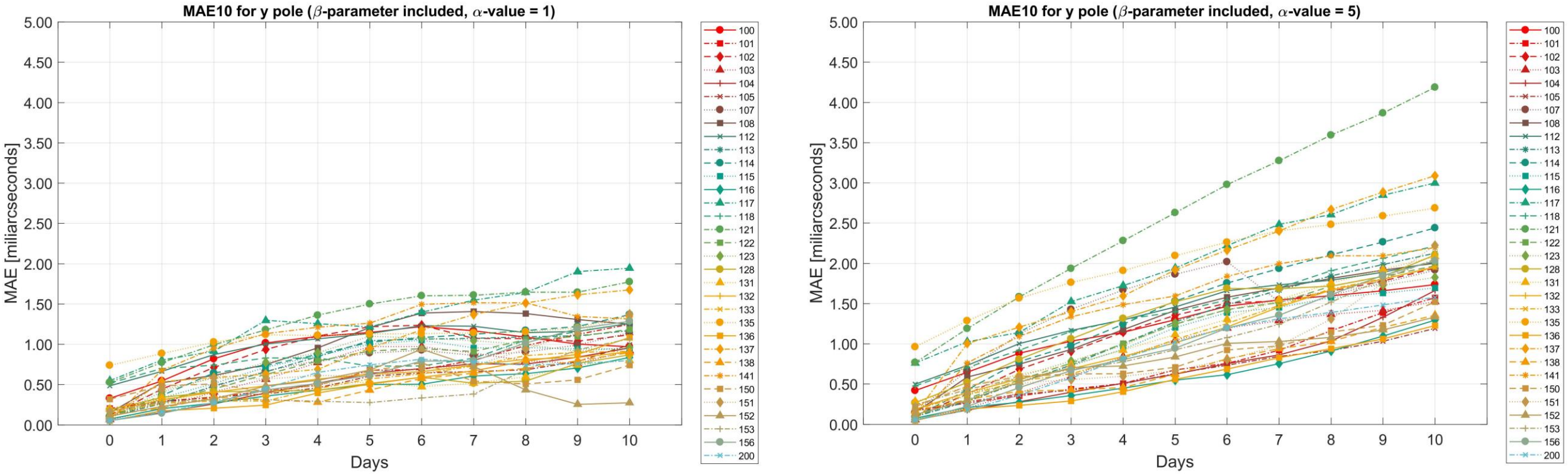


Figure A13 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A7 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.05	0.75	1.95	0.85
α-value = 5	0.04	1.17	4.19	1.37

Example of impact of filtration for LOD

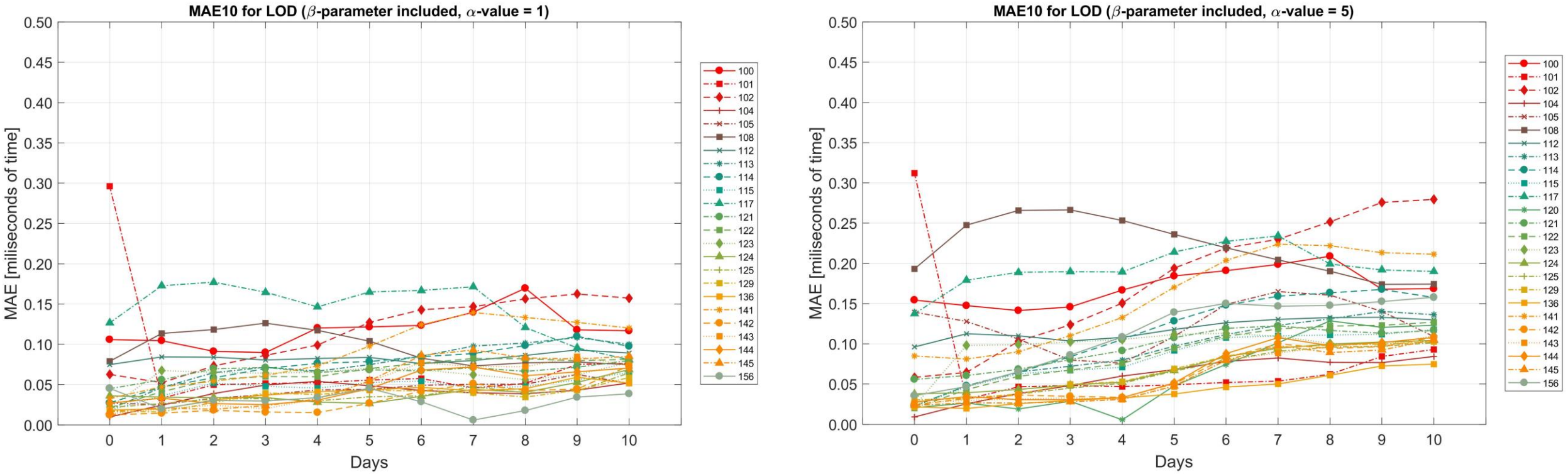
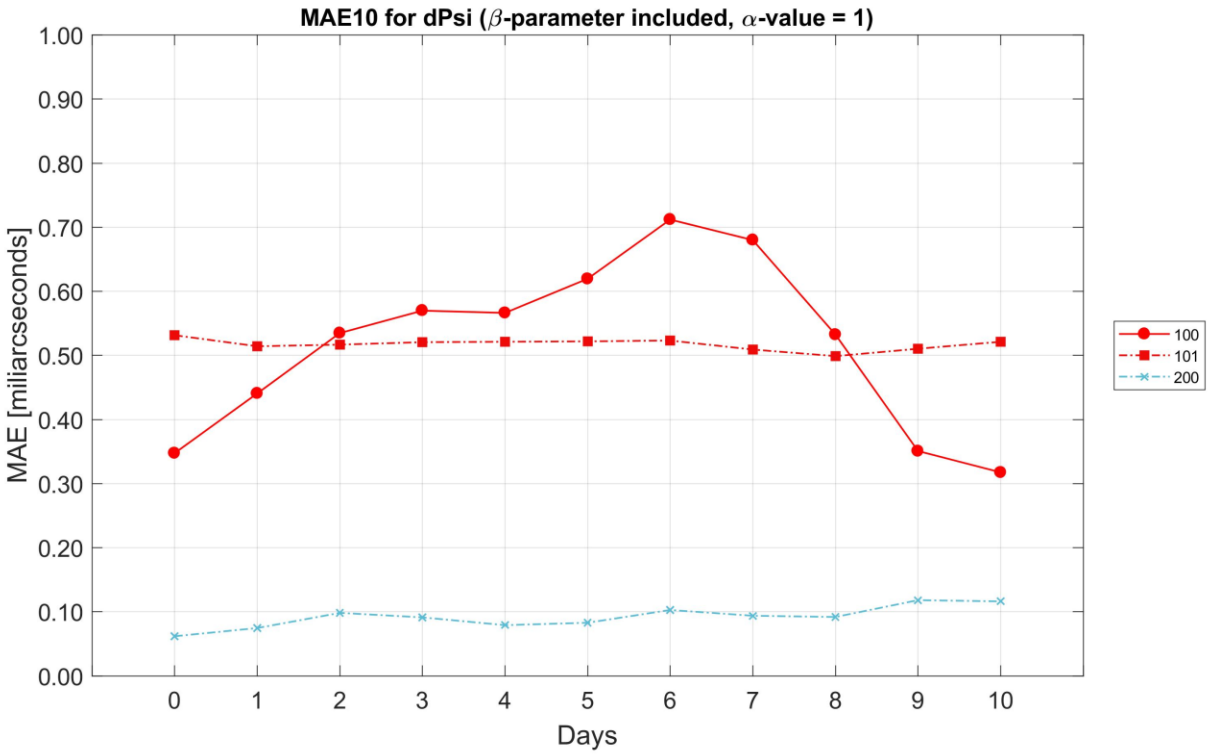


Figure A14 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A8 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.01	0.07	0.30	0.08
α-value = 5	0.01	0.10	0.31	0.12

Example of impact of filtration for dPsi



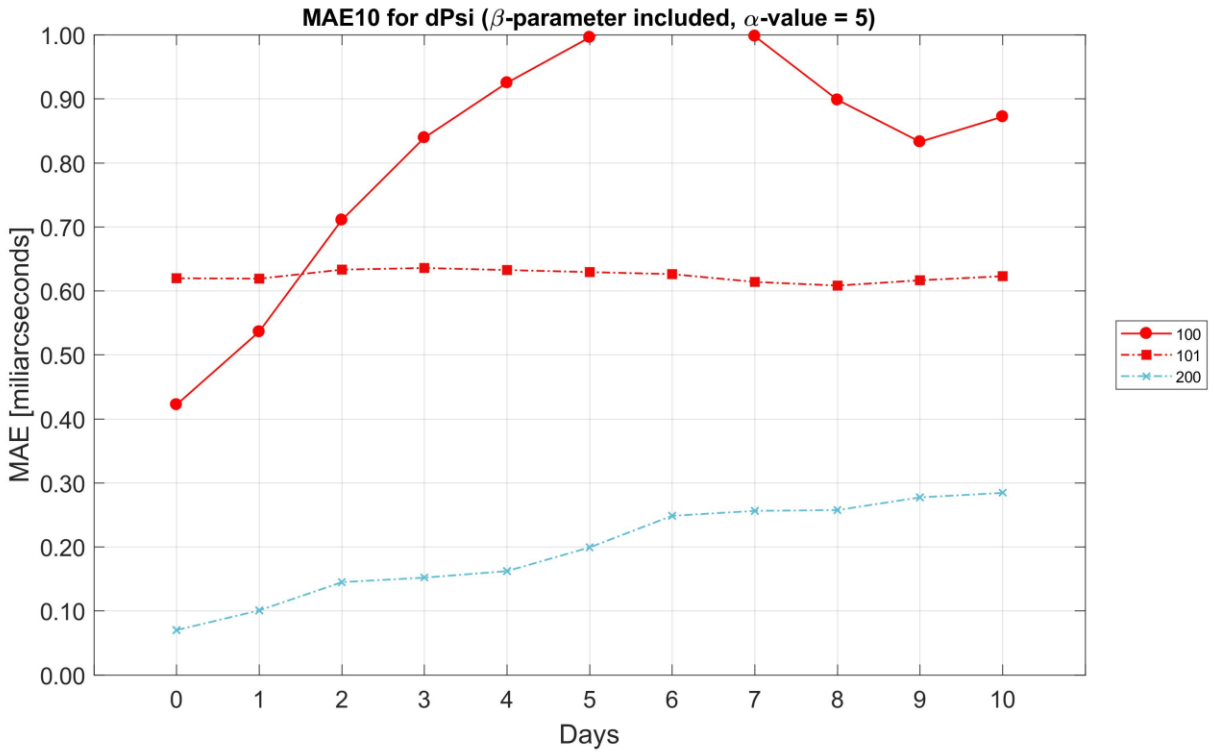
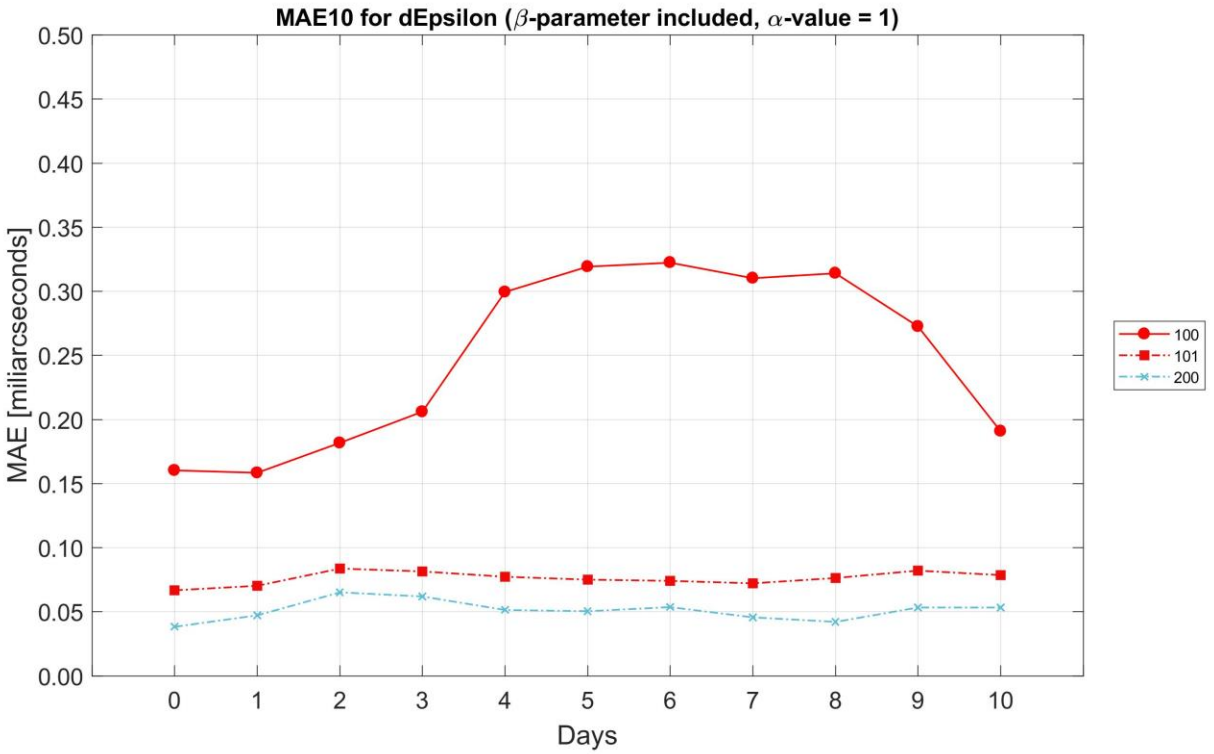


Figure A15 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A9 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.06	0.37	0.71	0.43
α-value = 5	0.07	0.55	1.05	0.62

Example of impact of filtration for dEpsilon



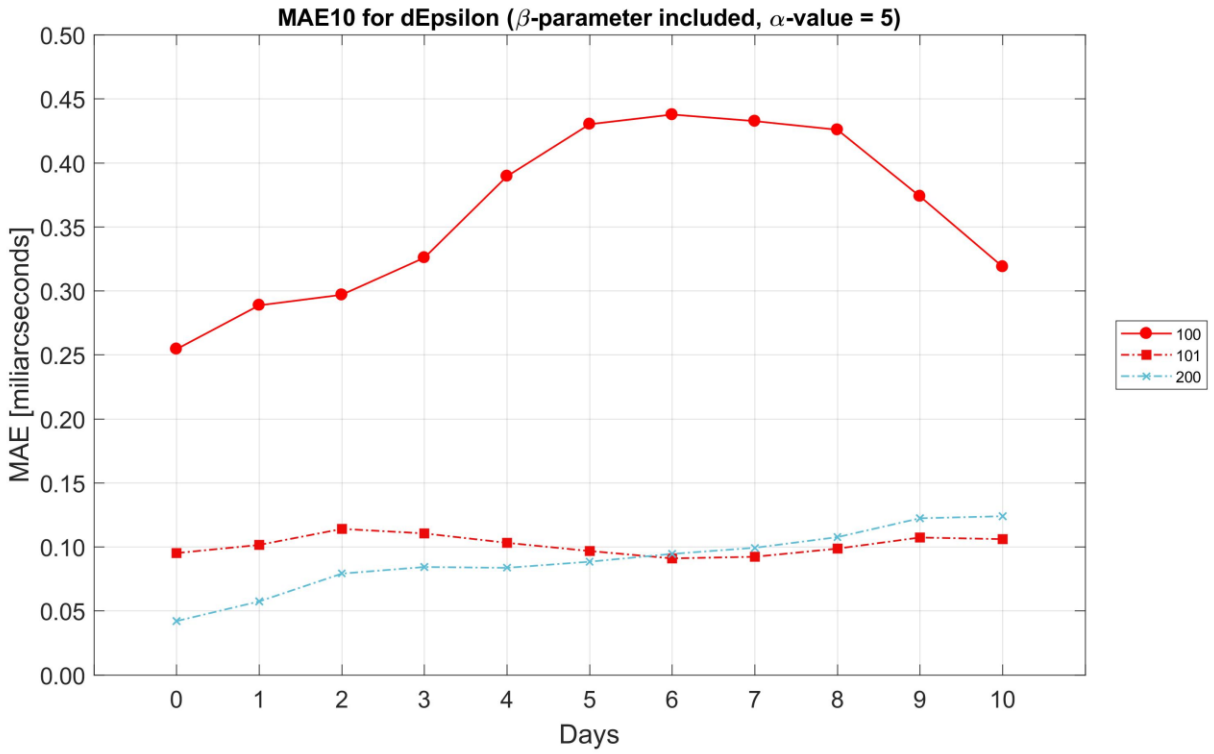
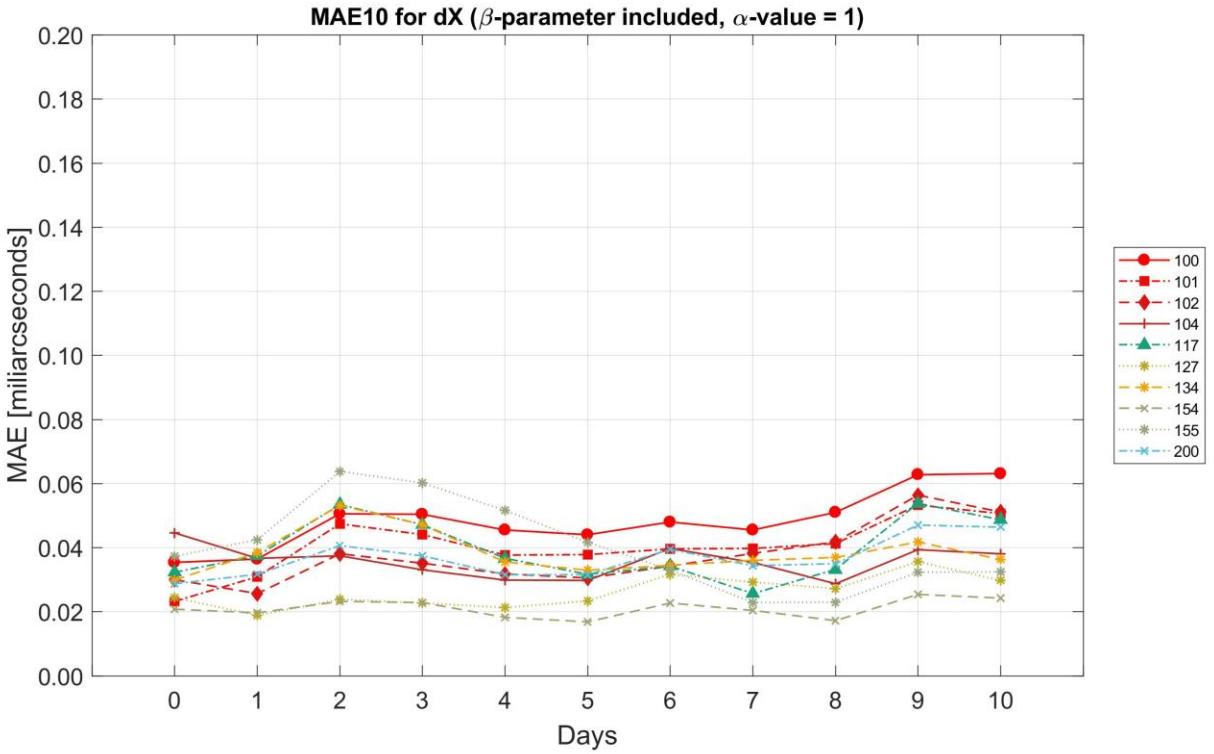


Figure A16 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A10 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.04	0.13	0.32	0.16
α-value = 5	0.04	0.18	0.44	0.23

Example of impact of filtration for dX



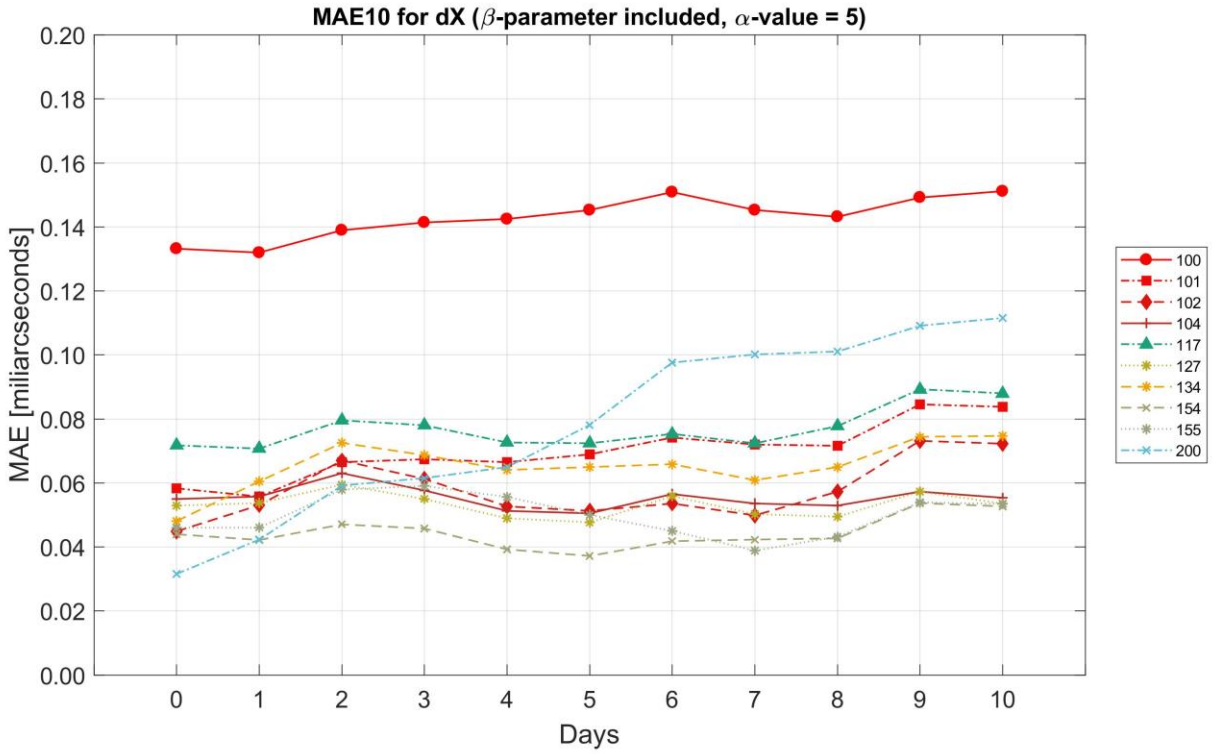


Figure A17 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A11 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.02	0.04	0.06	0.04
α-value = 5	0.03	0.07	0.15	0.08

Example of impact of filtration for dY

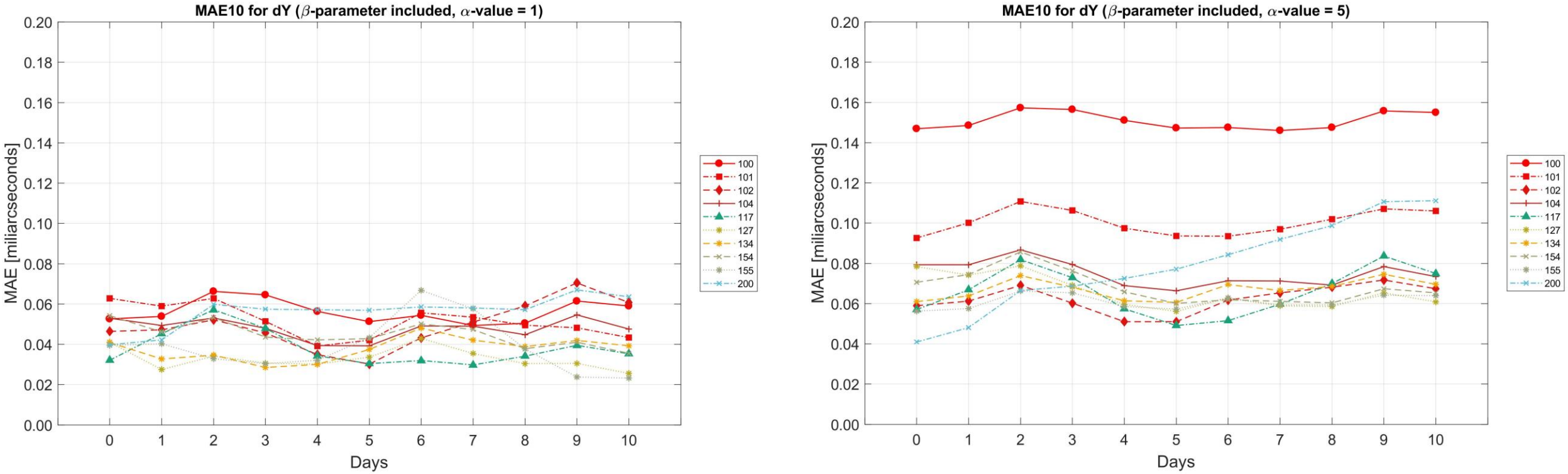


Figure A18 Impact of α-value and number of rejected predictions on MAE, numbers in the legend represent participants' IDs.

Table A12 Statistics of MAE for α-value = 1 and α-value = 5

	Min MAE	Mean MAE	Max MAE	RMS MAE
α-value = 1	0.02	0.05	0.07	0.05
α-value = 5	0.04	0.08	0.16	0.08