Supplementary information for the paper:

Rapid rise in the global ocean carbon sink determined from atmospheric oxygen observations

E. Kozlova[1], A. C. Manning[2], R. F Keeling[3], M. Heimann[4], Y. Tohjima[5], S. Zaehle[4], A. J. Watson[1]

1. Faculty of Environment, Science and Economy, University of Exeter, Exeter EX4 4QE UK

2. Centre for Ocean and Atmospheric Sciences, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK.

3. Scripps Institution of Oceanography, UC San Diego, La Jolla, Ca 92093, USA

4. Max Planck Institute for Biogeochemistry, 07745 Jena, Germany

5. National Institute for Environmental Studies, Tsukuba 305-8506, Japan

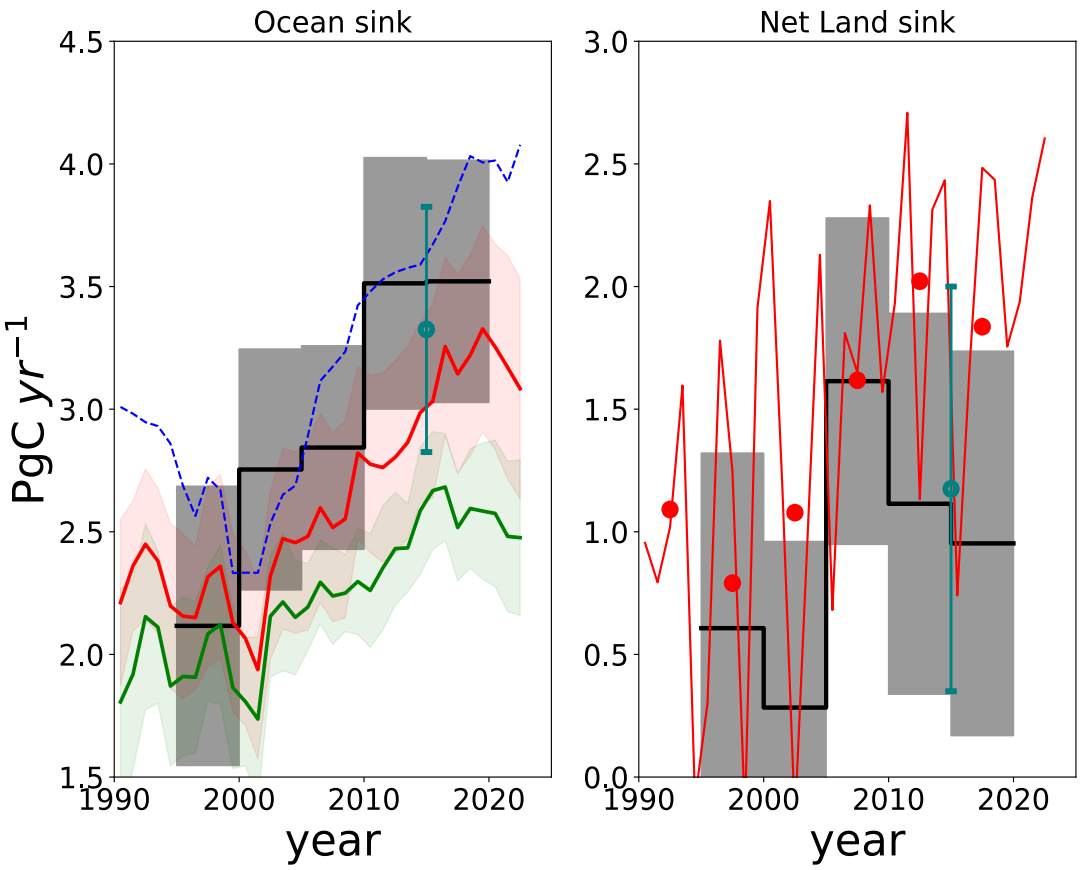


Figure S1: As Figure 4 in the text, but the O_2/N_2 method ocean and net land carbon sinks (black lines, grey uncertainties) are calculated using the mean of the stations shown in figure 2, with uncertainties on δAPO taken as the standard deviation of the stations. All other symbols have the same values as in Figure 4.

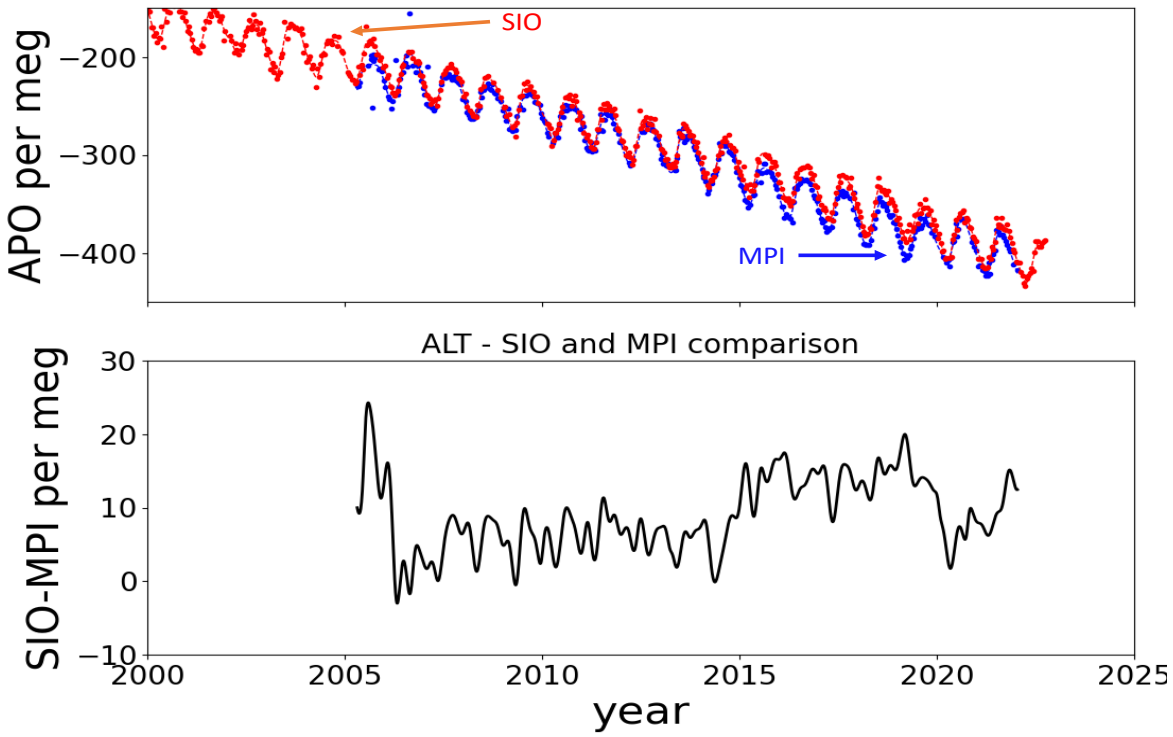


Figure S2: Comparison of the APO records from Alert, for SIO and MPI-BGC. Upper panel shows the flask records, and the lower panel shows the difference between SIO and MPI-BGC, from smoothed curves fitted to each record. There is good agreement, but with an offset that over the period 2005-2014 averages 6.9 per meg. For a period between early 2015 and late 2019 the offset is larger, averaging 13.4 per meg, believed to be due to a micro-leak in the instrument at Jena that was replaced in 2020. Further discussion of this offset is given in ref [1]

Table S1: Numerical data for anthropogenic carbon sinks using O_2/N_2 method: results shown in plots of Figure 4 of the main text.

Figure 4a, b, Carbon sinks using marine boundary layer function for δAPO change (Pg Cyr^{-1})				
Year	**Ocean sink**	**Ocean 1-σ**	**Net Land sink**	**Net Land 1-σ**
1995-2000	2.10	0.29	0.63	0.51
2000-2005	2.81	0.39	0.24	0.61
2005-2010	2.74	0.35	1.73	0.63
2010-2015	3.54	0.46	1.10	0.74
2015-2020	3.46	0.43	1.03	0.74

Table S2: Numerical data for anthropogenic carbon sinks using O_2/N_2 method: results shown in plots of Figure S1

Figure 4c,d, Carbon sinks using unweighted mean of stations for δAPO change (Pg Cyr^{-1})				
Year	**Ocean sink**	**Ocean 1-σ**	**Net Land sink**	**Net Land 1-σ**
1995-2000	2.12	0.57	0.61	0.71
2000-2005	2.75	0.49	0.28	0.68
2005-2010	2.84	0.41	1.61	0.67
2010-2015	3.51	0.51	1.11	0.78
2015-2020	3.52	0.49	0.95	0.78

Table S3: Contributions to uncertainty in ocean and land sinks for CO_2 from different sources as described in Methods section. Except for the "all uncertainties" entry, these are for each source propagated through the calculations with others held constant, for the 2010-2020 decade. The last term is the 2010-2020 uncertainty as shown in Figure 4.

Source of uncertainty estimated at 1-sigma	1-sigma, Ocean sink (Pg Cyr^{-1})	1-sigma, land sink (Pg Cyr^{-1})
5% uncertainty in amount of fossil fuel combustion	0.12	0.64
Uncertainties on O_2:CO_2 consumption/release for fossil fuels (taken from Table 2 of Keeling and Manning, 2014) [2]	0.28	0.28
5% uncertainty in α_B, ratio O_2:CO_2 of land photosynthesis and respiration	0.05	0.05
Calculated uncertainty on global rate of decline of δAPO	0.13	0.13

Uncertainty on ocean outgassing of 25 Tmol yr^{-1}	0.31	0.31
All uncertainties	0.44	0.74

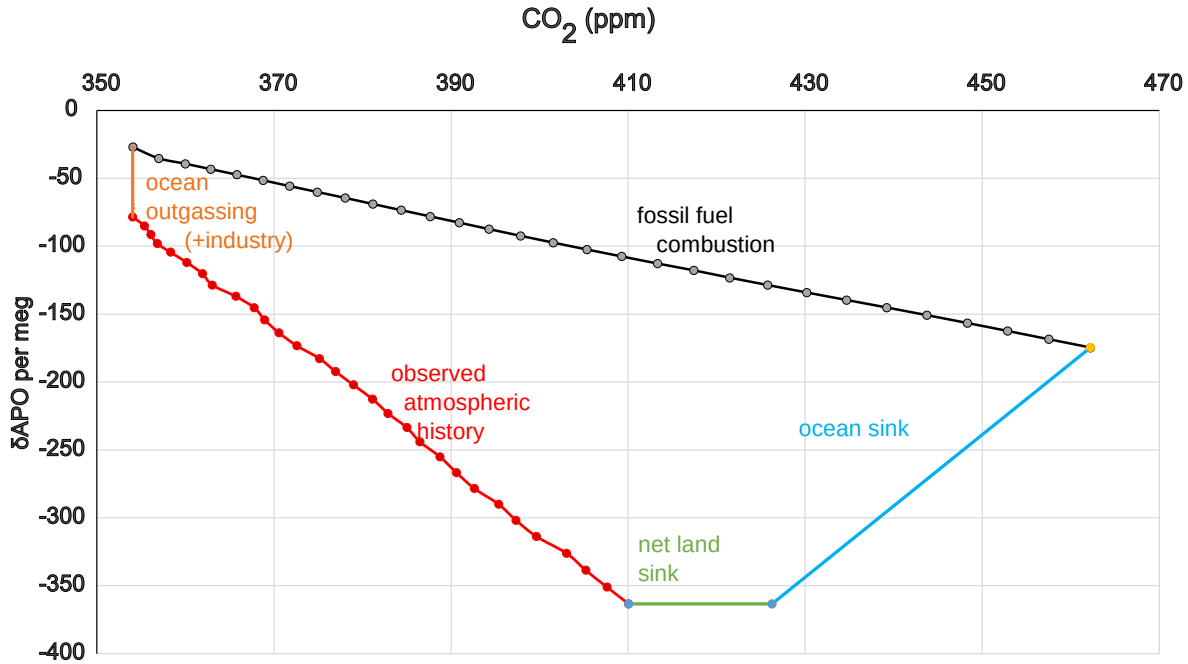


Figure S3: Vector diagram in δAPO – XCO_2 plane of the changes in atmospheric composition from 1990 to 2020, and the processes contributing to it. For the observed atmospheric history, each point represents a global annual mean, starting in 1990 at the top left of the figure. The other lines represent the processes affecting atmospheric composition (ocean O_2 outgassing including a small contribution of oxygen release from industry, fossil fuel combustion, land and ocean sinks) each of which affects CO_2 and APO in known ratios and therefore has a characteristic slope on this figure. Starting from the atmospheric composition in 1990, the trajectory of ocean O_2 outgassing is shown (parallel to the APO axis since atmospheric CO_2 is not affected). From this vector's endpoint, the fossil fuel vector is plotted, which represents how atmospheric composition changes as a result of fossil fuel combustion. This vector ends where the atmospheric composition would be if only ocean outgassing and fossil fuel burning were operating. The two unknowns, the land and ocean sinks, are then constructed as vectors of known slope that connect this point to the observed composition in 2020.

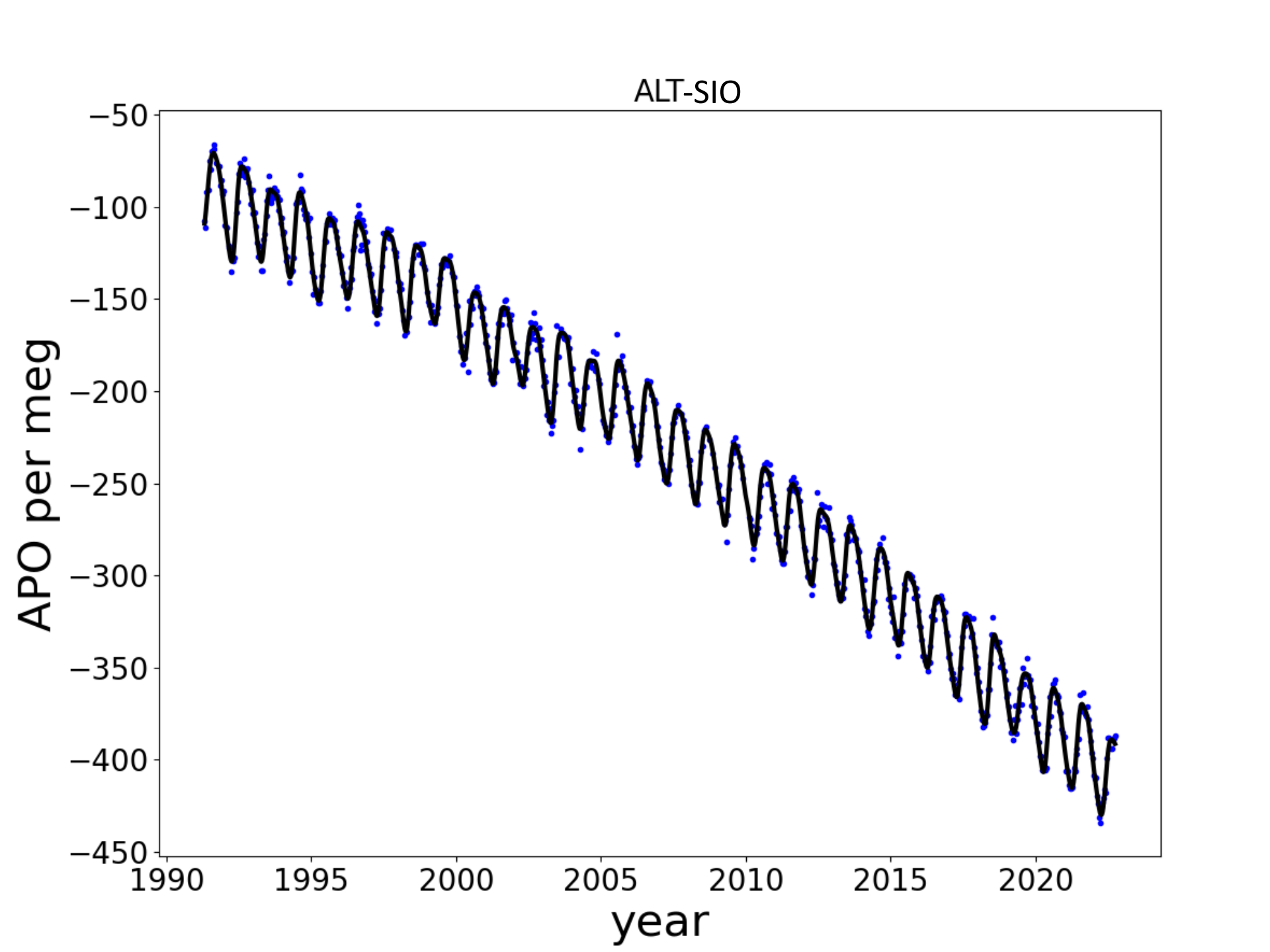
Table S4: five-year averages of fossil fuel and oxygen terms in the equations for global ocean sink: (values are in PgC equivalent per year, e.g. O_2 fluxes are in moles x 12 gC)

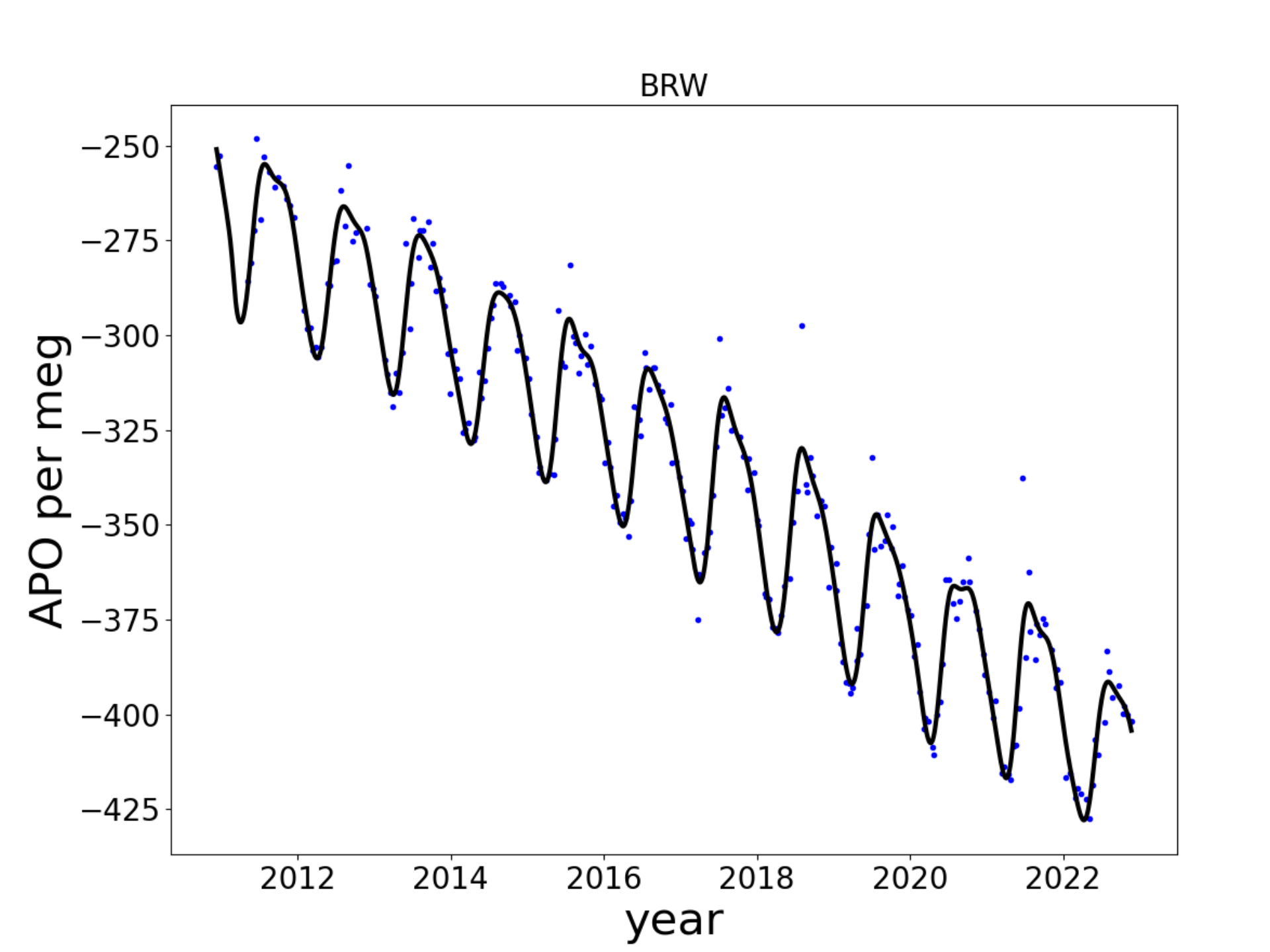
Period	Fossil fuel combustion	O_2 consumption by fossil fuel combustion	"Zeff": O_2 release from ocean compensated for N_2 release	Industrial release of O_2
1995-2000	6.62	9.20	0.60	0.095
2000-2005	7.30	10.12	1.04	0.11
2005-2010	8.47	11.59	0.72	0.18
2010-2015	9.46	12.84	1.24	0.22
2015-2020	9.87	13.48	1.03	0.25

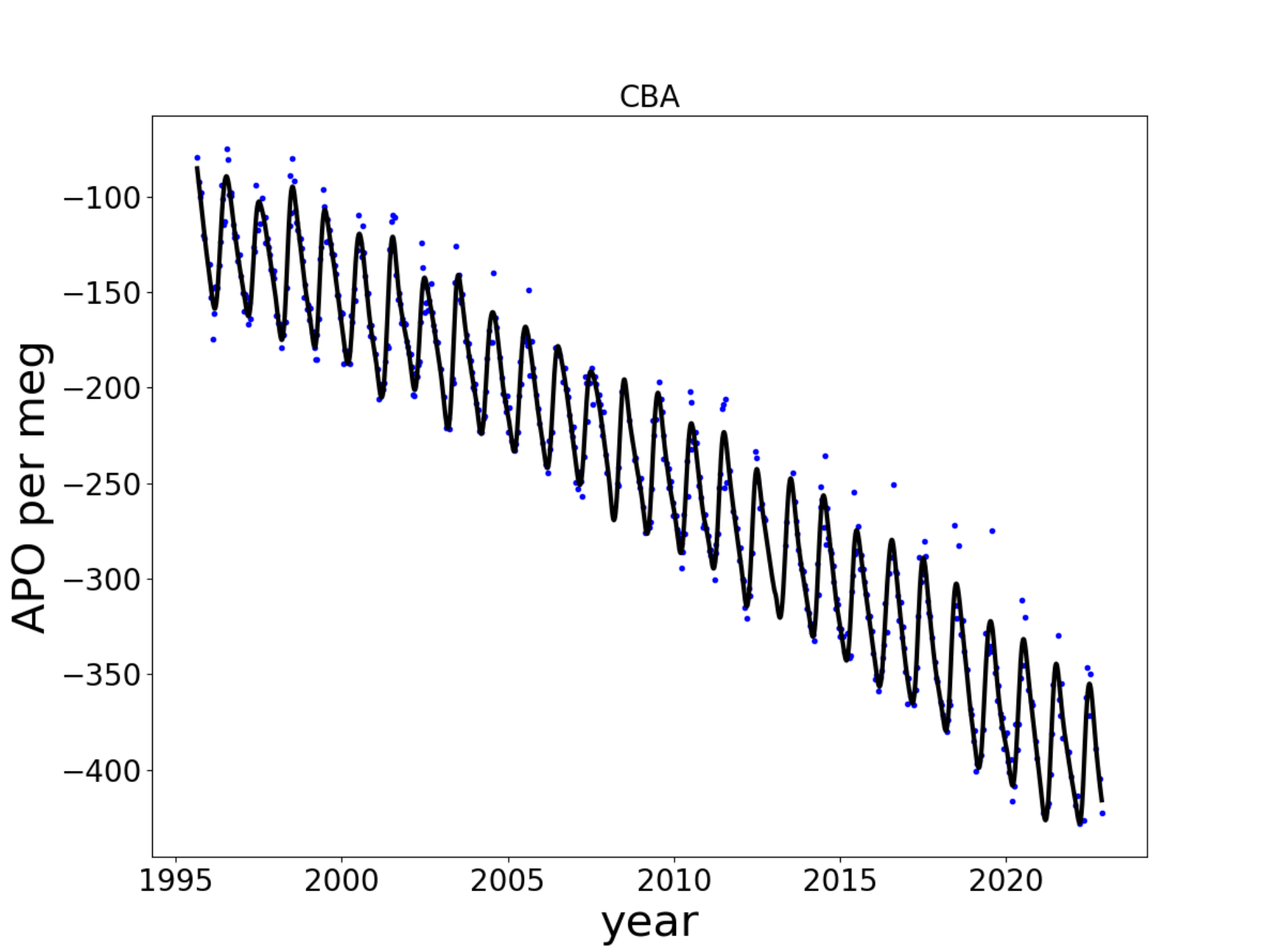
1 Rödenbeck, C. *et al.* The suitability of atmospheric oxygen measurements to constrain western European fossil-fuel CO2 emissions and their trends. *Atmospheric Chemistry and Physics* **23**, 15767-15782 (2023). https://doi.org:10.5194/acp-23-15767-2023

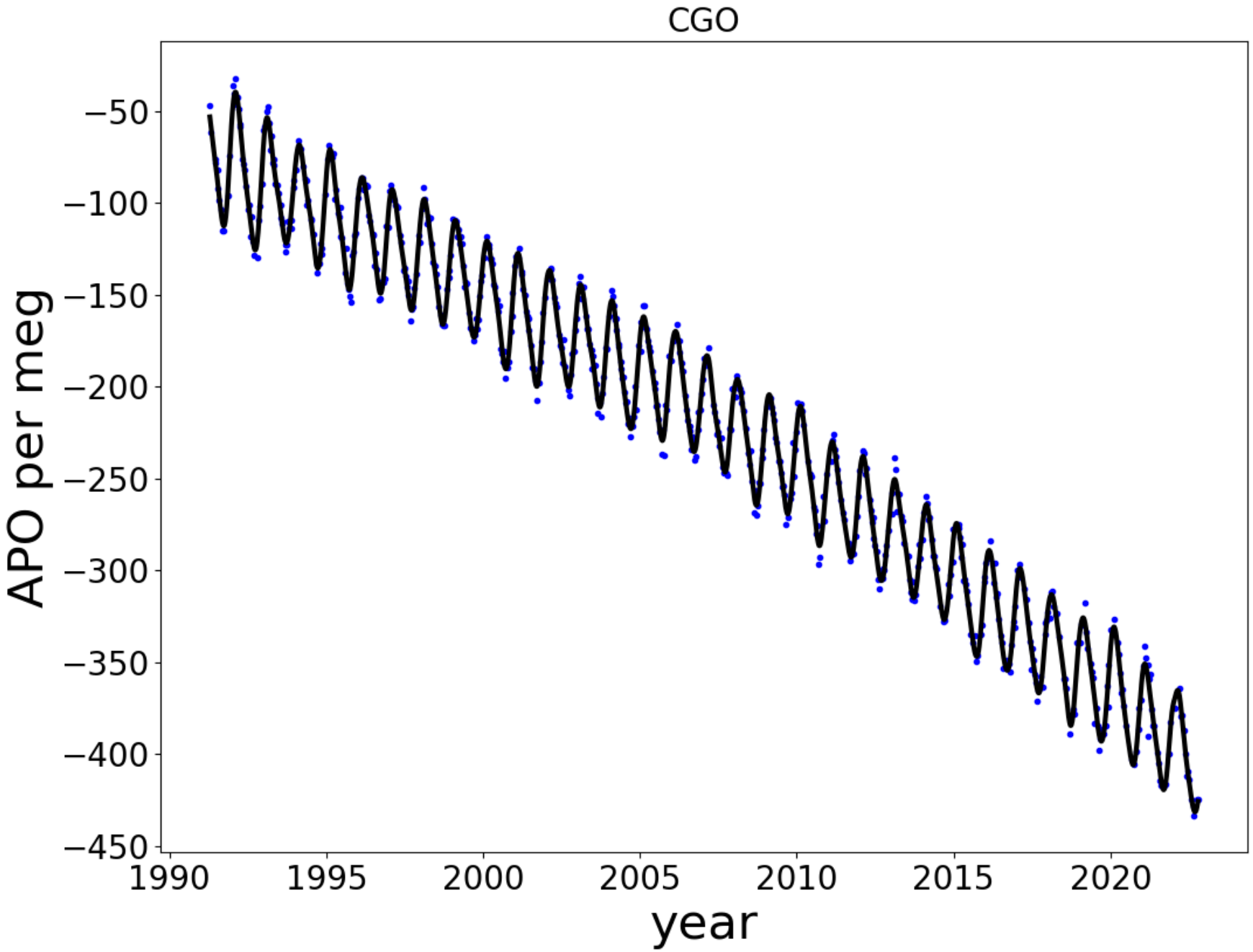
2 Keeling, R. F. & Manning, A. C. in *Treatise on Geochemistry: Second Edition* Vol. 5 385-404 (2014).

Figure S4 – S 29: Individual APO records used in this publication, with the smoothing curves fitted to them: The data are shown on the SIO2017 scale, with adjustments as described in the Methods. Stations are identified by their 3-letter codes (Figure 1 and Table 1 in methods). The NIES ship data are binned into ten-degree latitude bands, and are identified by the central latitude of each band.


ALT-SIO
−50
−100
−150
−200
−250
−300
−350
−400
−450
APO per meg
1990
1995
2000
2005
2010
2015
2020
year


BRW
−250
−275
−300
−325
−350
−375
−400
−425
APO per meg
2012
2014
2016
2018
2020
2022
year


CBA
APO per meg
−100
−150
−200
−250
−300
−350
−400
1995
2000
2005
2010
2015
2020
year


CGO
APO per meg
−50
−100
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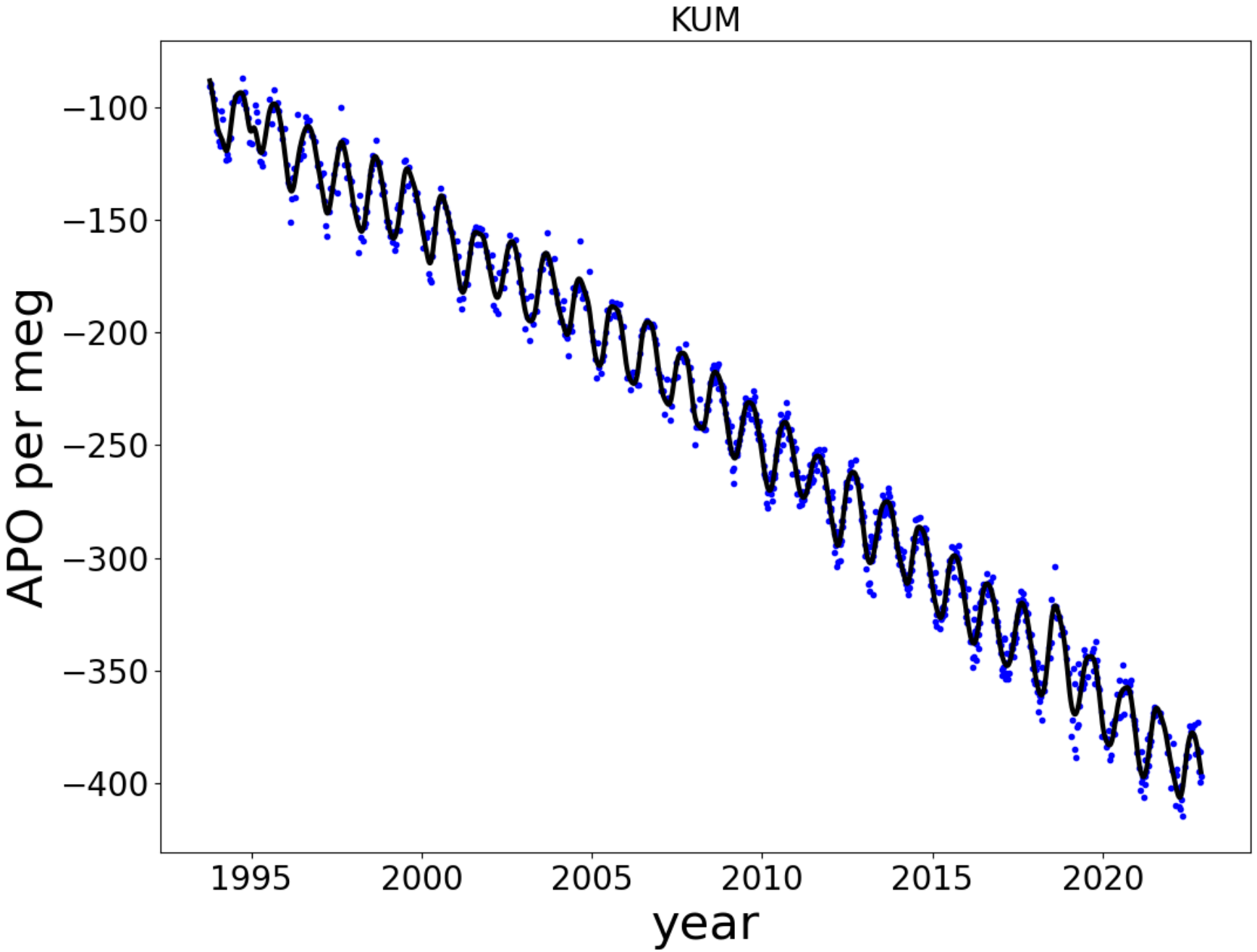
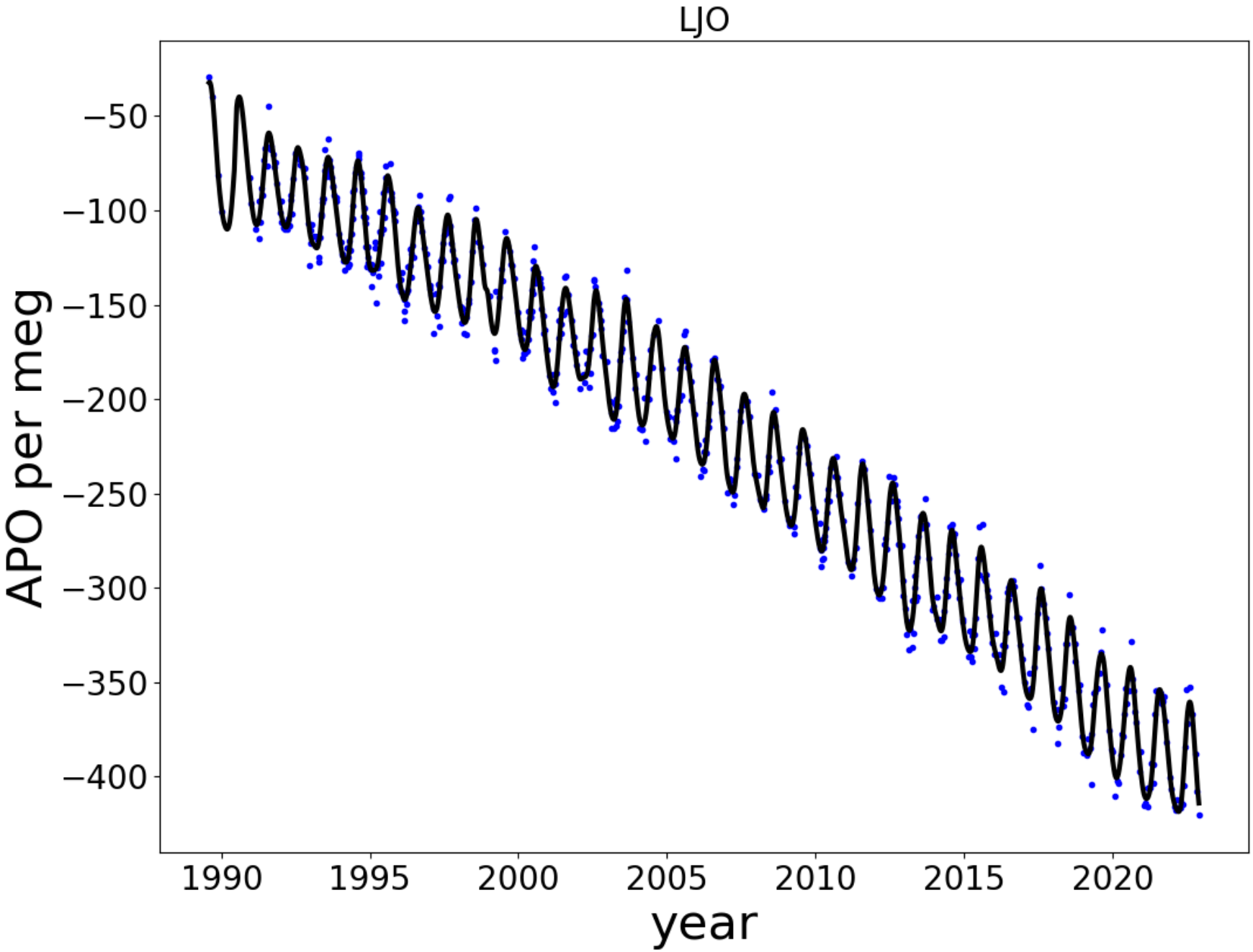
−200
−250
−300
−350
−400
−450
1990
1995
2000
2005
2010
2015
2020
year


KUM
−100
−150
−200
−250
−300
−350
−400
APO per meg
1995
2000
2005
2010
2015
2020
year


LJO
APO per meg
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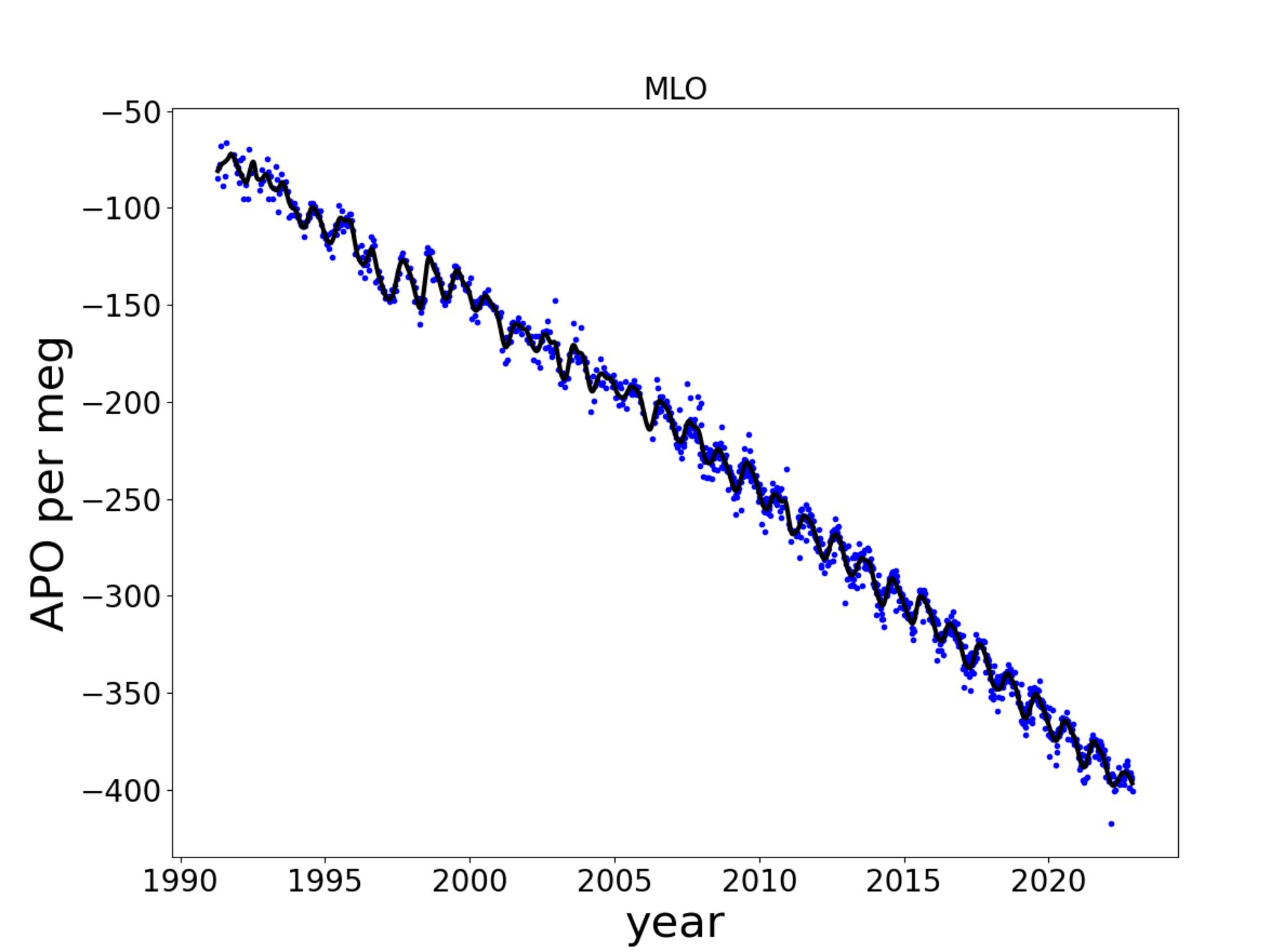
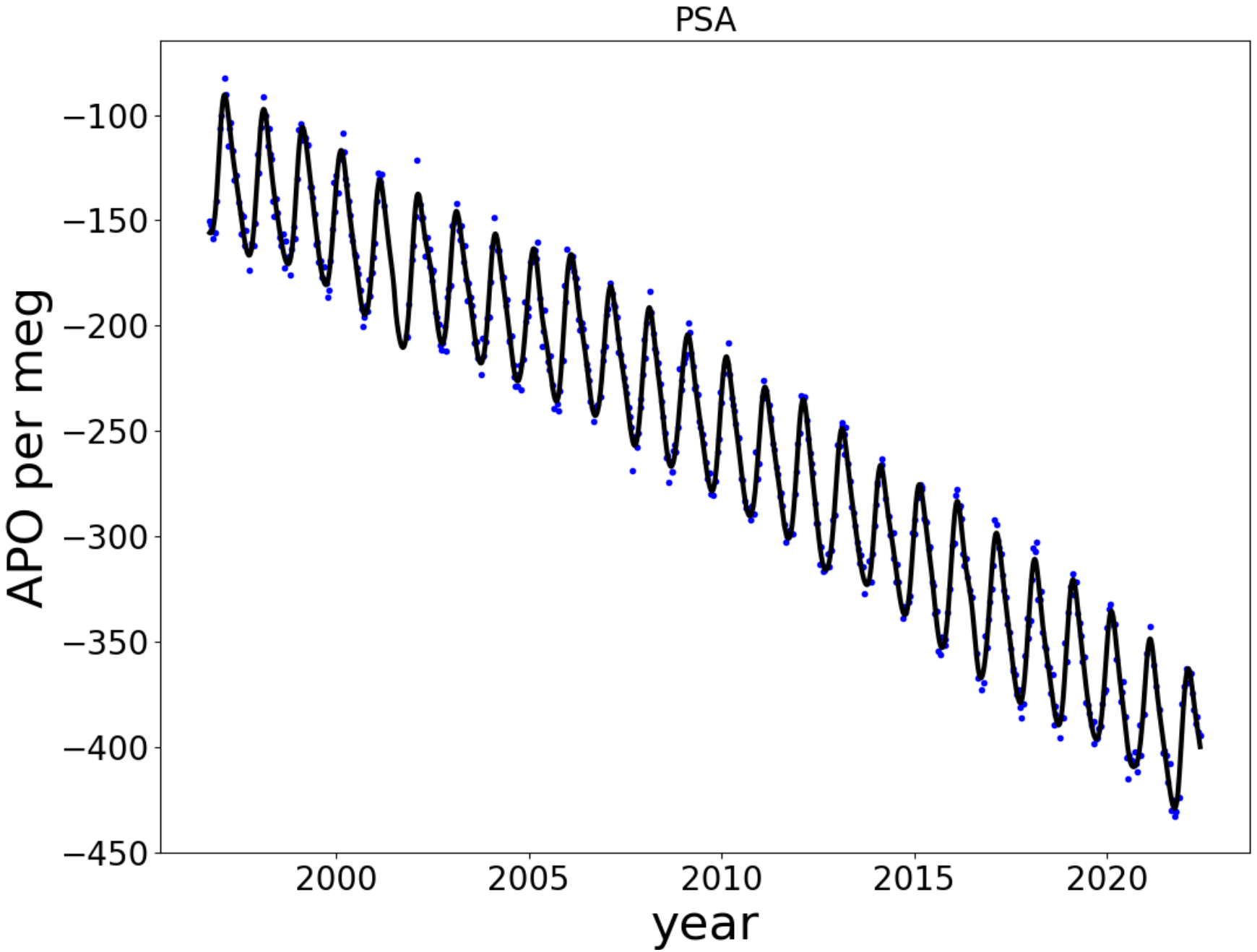
−100
−150
−200
−250
−300
−350
−400
1990
1995
2000
2005
2010
2015
2020
year


MLO
−50
−100
−150
−200
−250
−300
−350
−400
APO per meg
1990
1995
2000
2005
2010
2015
2020
year


PSA
APO per meg
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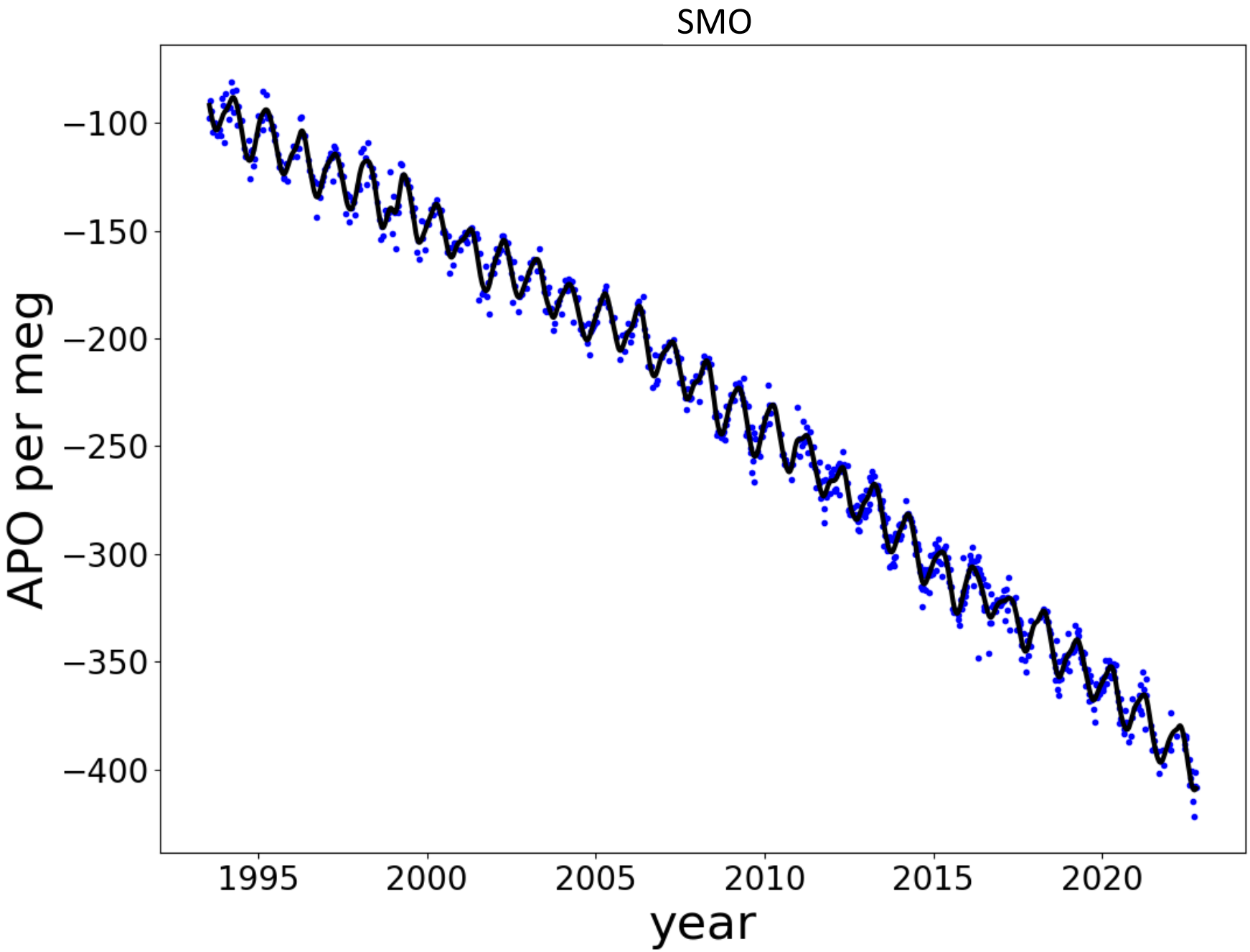
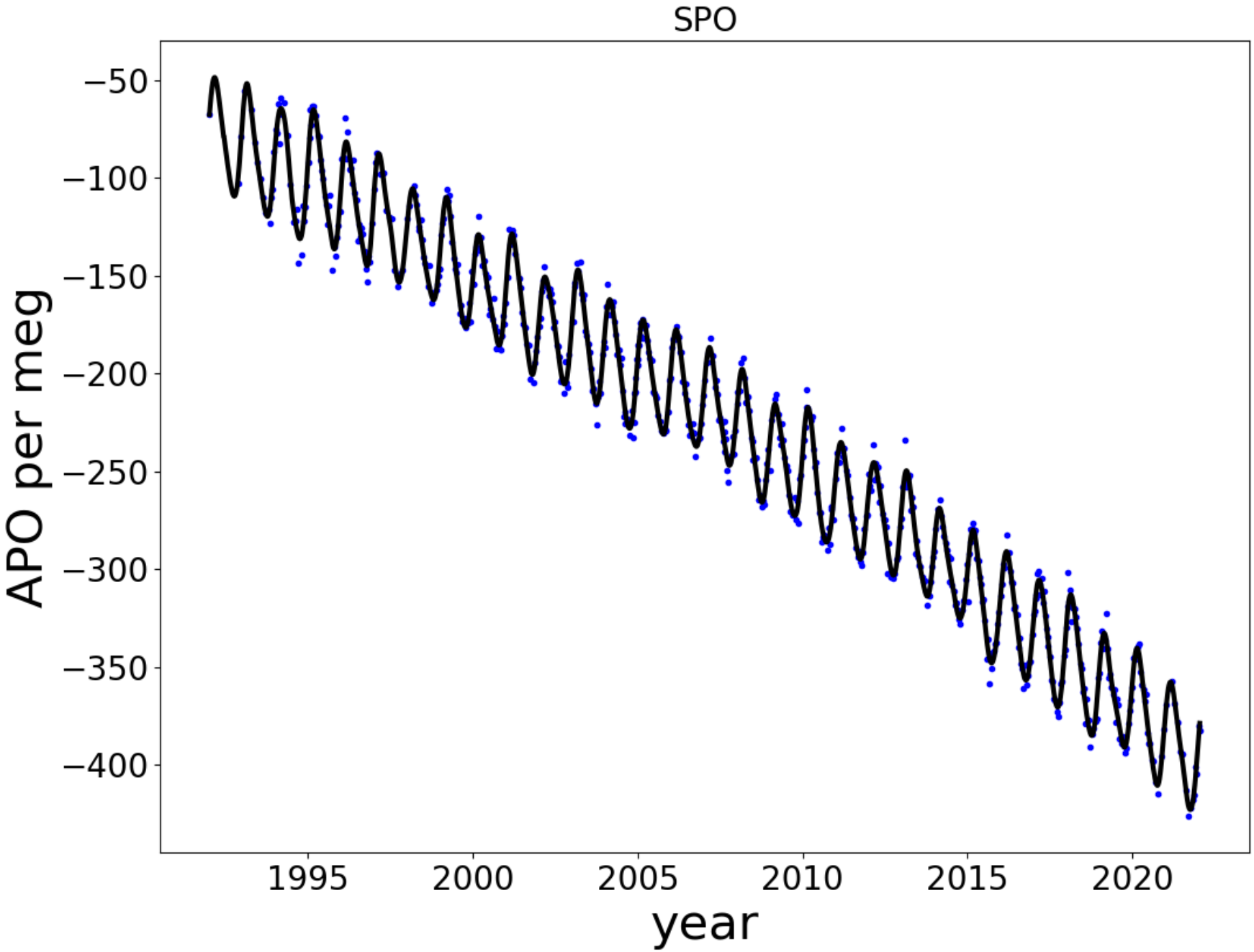
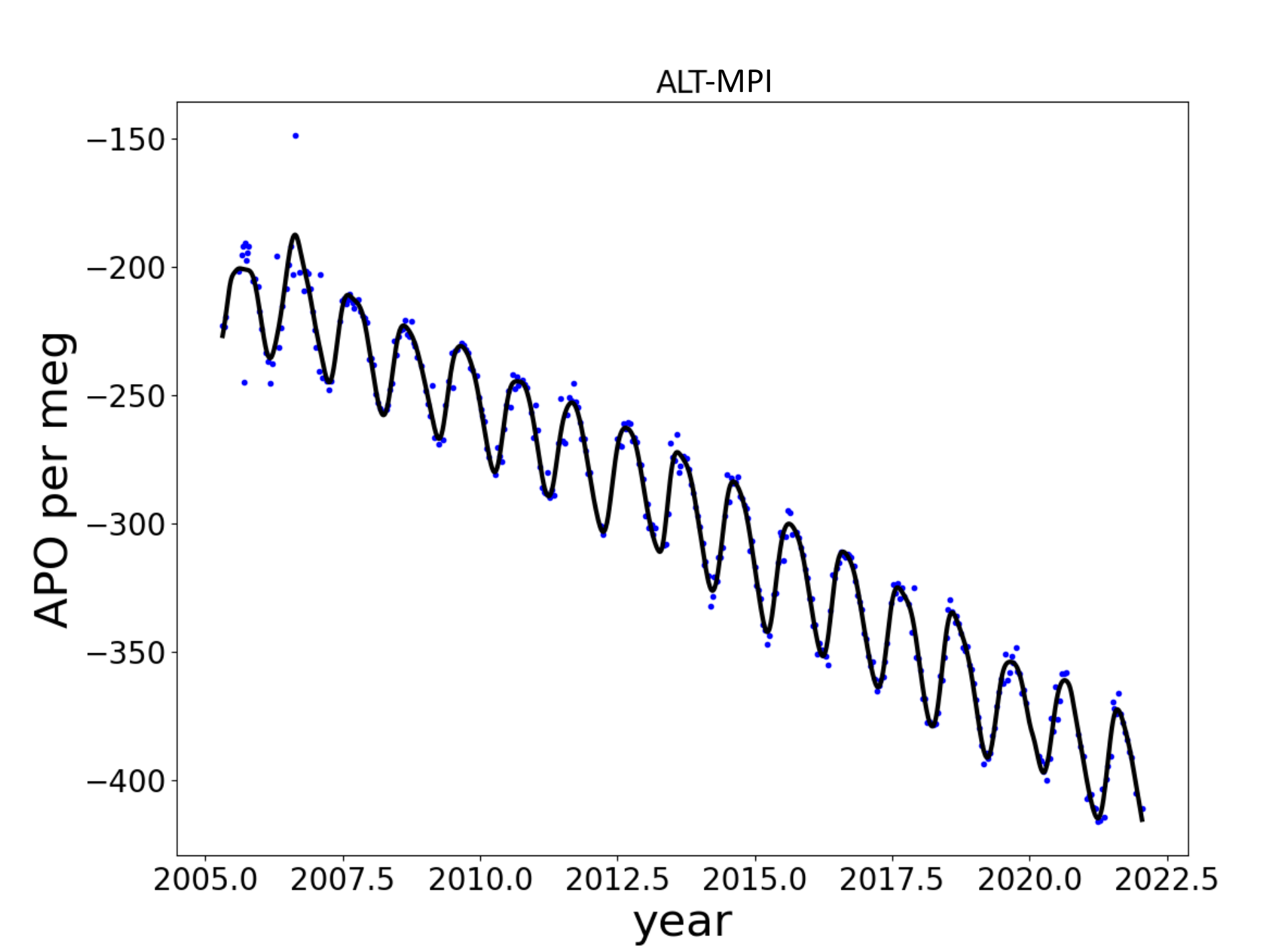
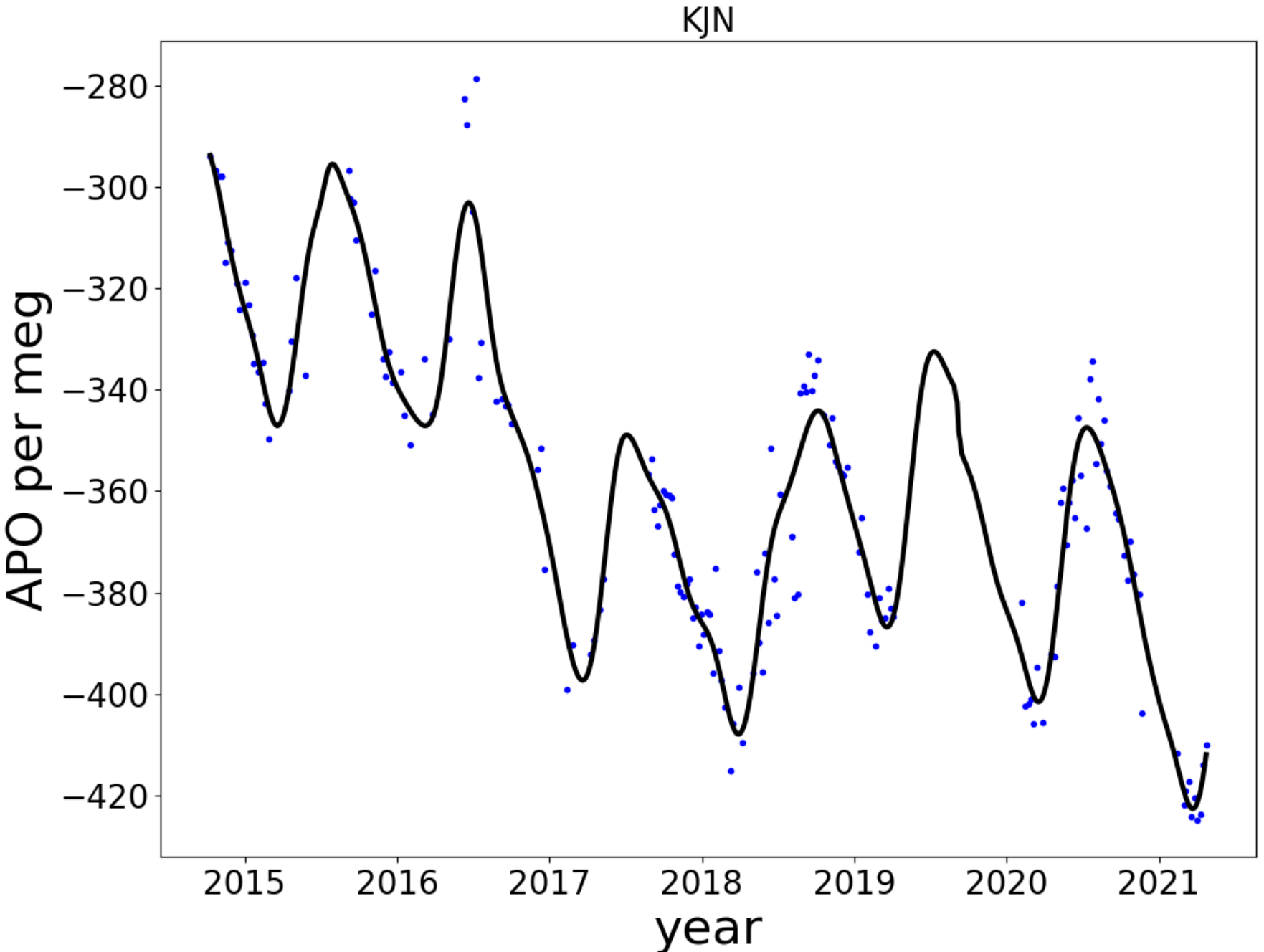
−150
−200
−250
−300
−350
−400
−450
2000
2005
2010
2015
2020
year


SMO
−100
−150
−200
−250
−300
−350
−400
APO per meg
1995
2000
2005
2010
2015
2020
year


SPO
−50
−100
−150
−200
−250
−300
−350
−400
APO per meg
1995
2000
2005
2010
2015
2020
year


ALT-MPI
−150
−200
−250
−300
−350
−400
APO per meg
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0
2022.5
year


KJN
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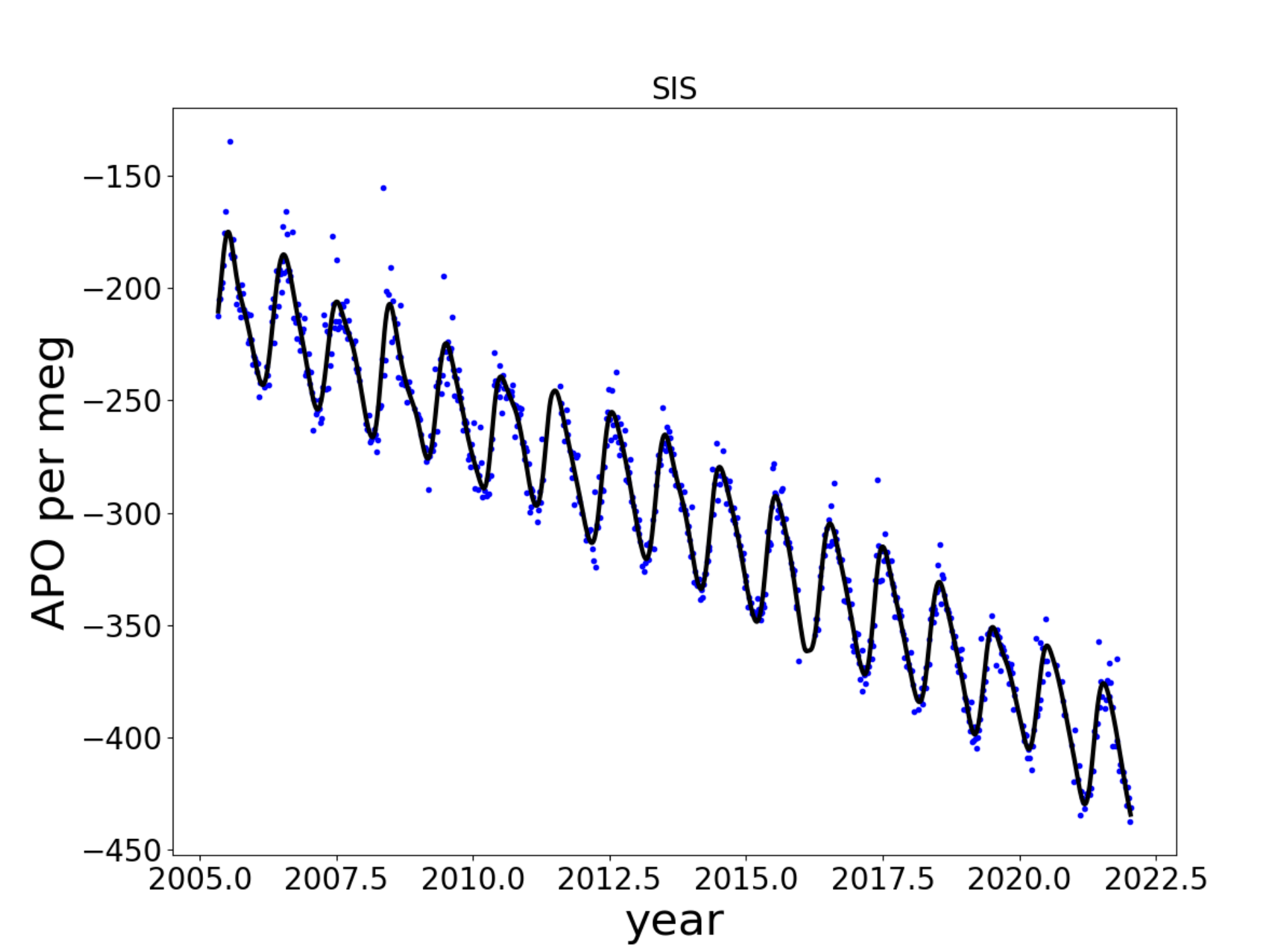
APO per meg
2015
2016
2017
2018
2019
2020
2021
year


SIS
APO per meg
−150
−200
−250
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−350
−400
−450
2005.0
2007.5
2010.0
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2015.0
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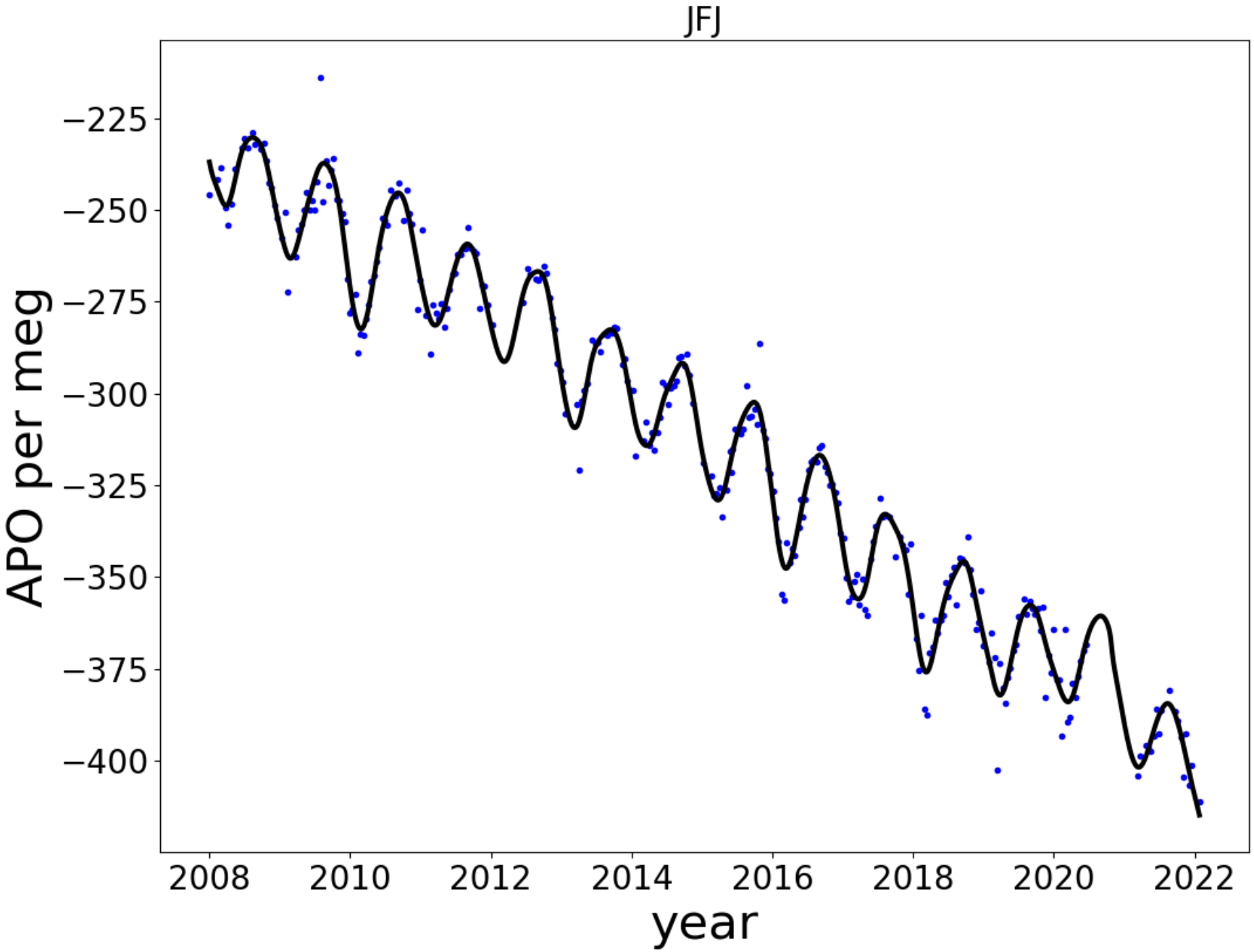
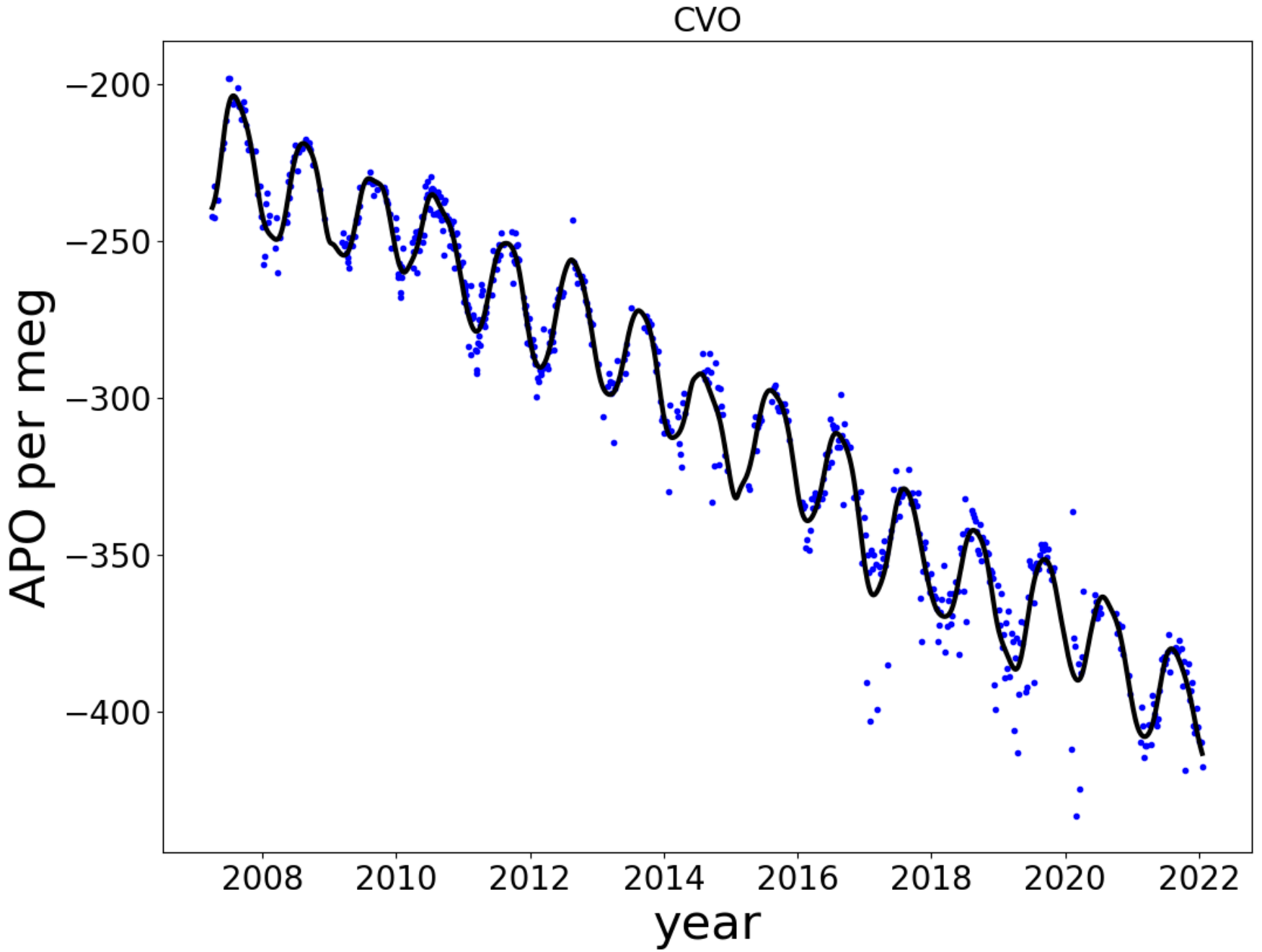
2020.0
2022.5
year


JFJ
APO per meg
−225
−250
−275
−300
−325
−350
−375
−400
2008
2010
2012
2014
2016
2018
2020
2022
year


CVO
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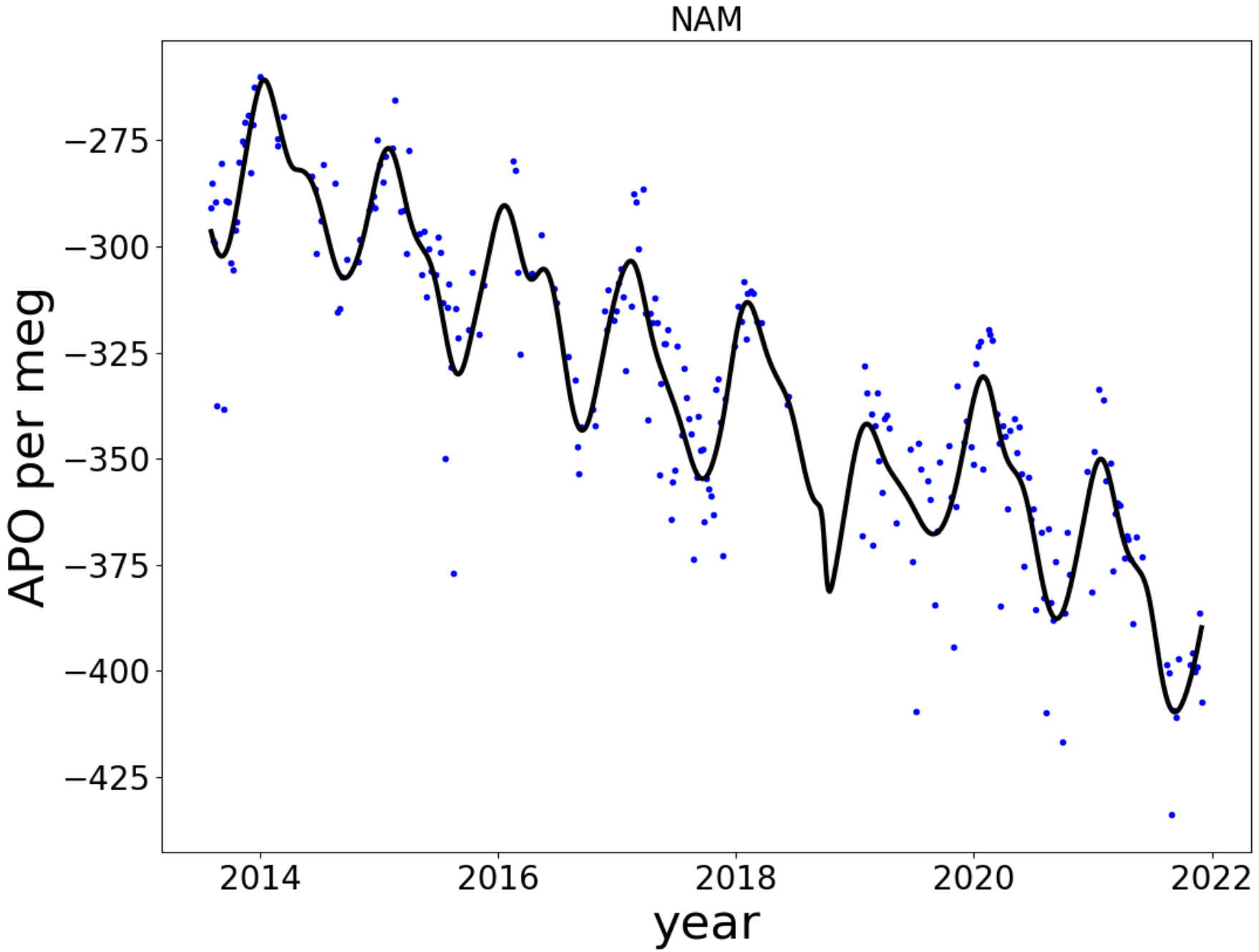
−250
−300
−350
−400
APO per meg
2008
2010
2012
2014
2016
2018
2020
2022
year


NAM
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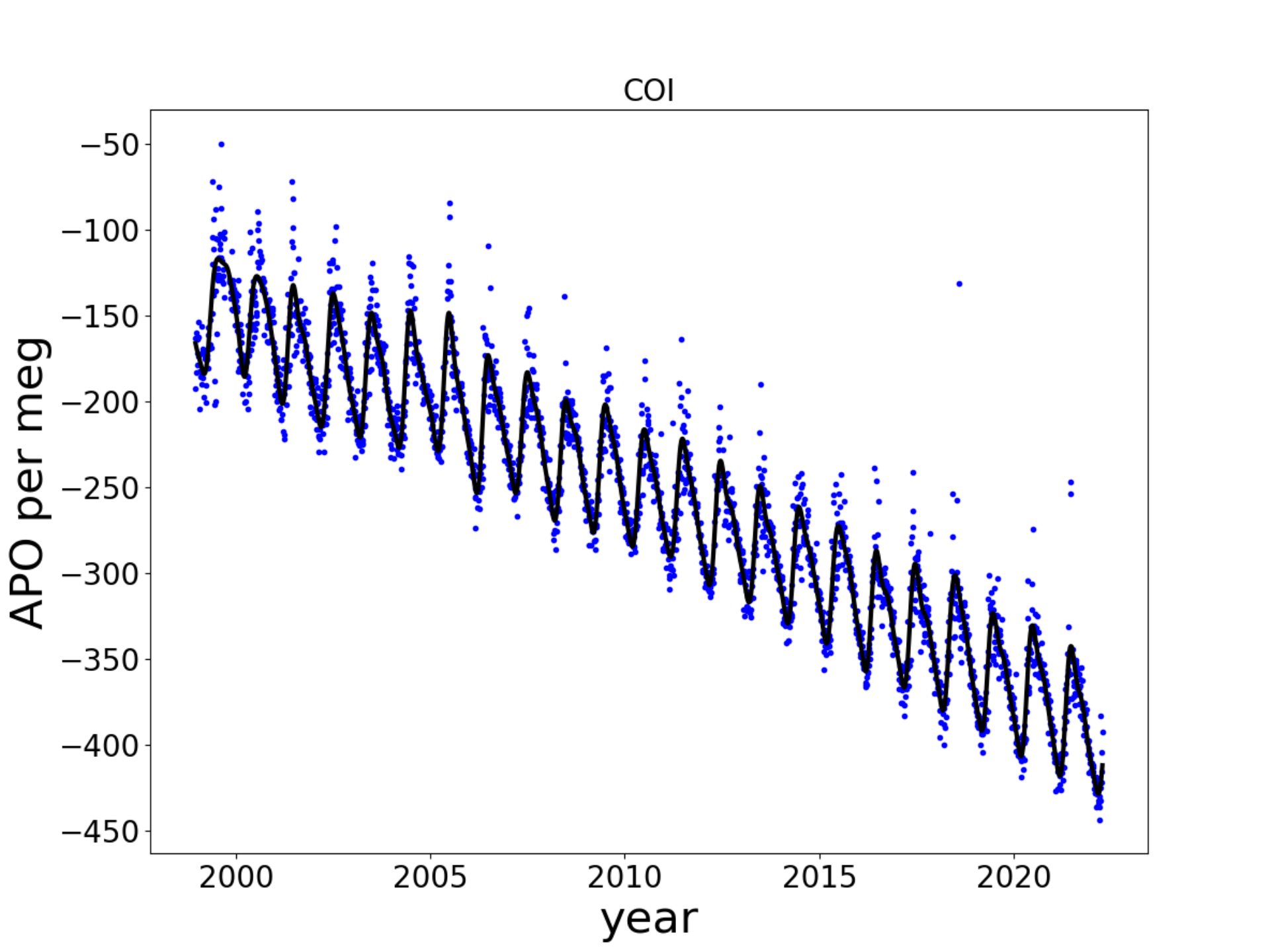
−300
−325
−350
−375
−400
−425
APO per meg
2014
2016
2018
2020
2022
year


COI
APO per meg
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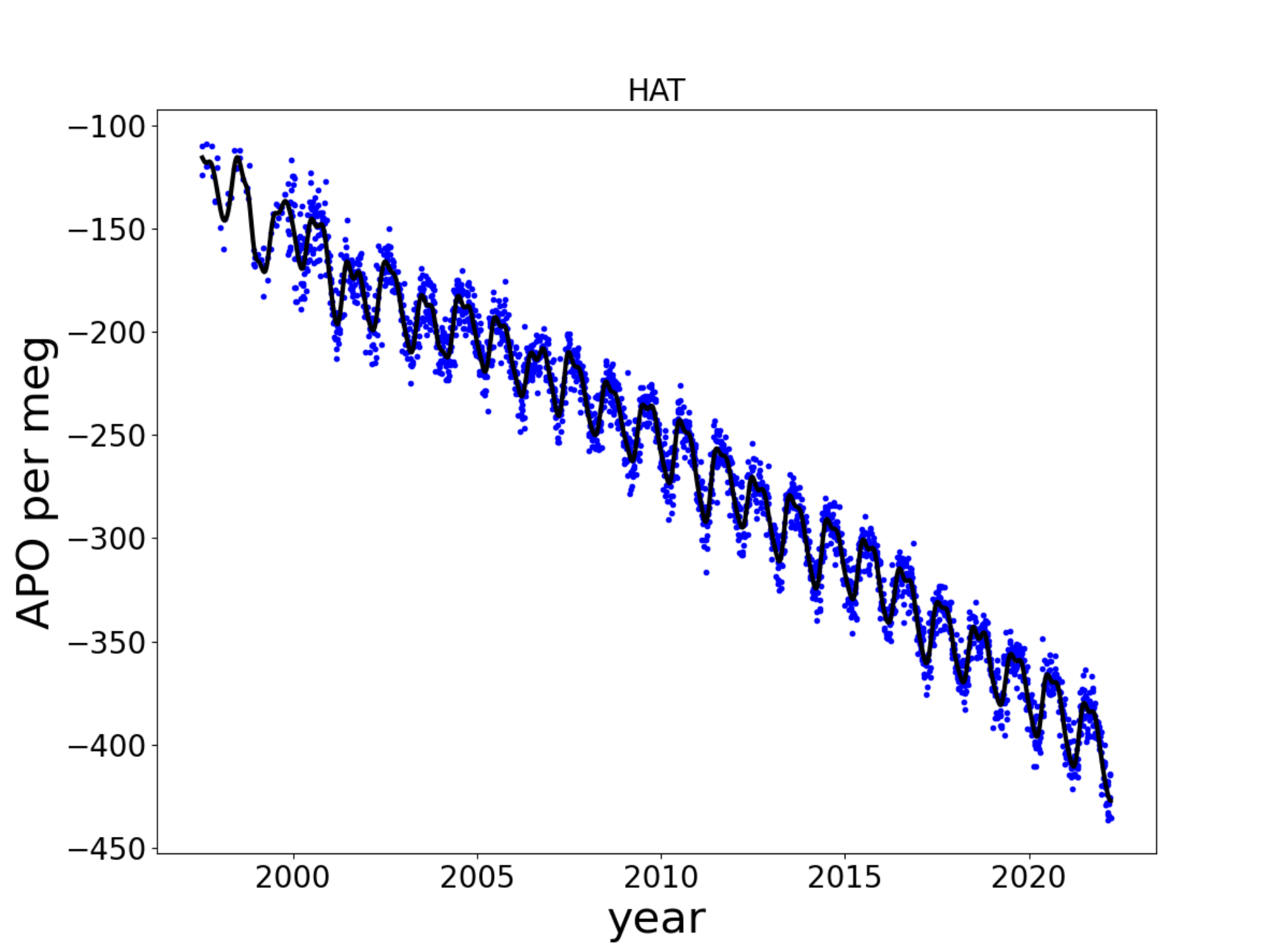
−150
−200
−250
−300
−350
−400
−450
2000
2005
2010
2015
2020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−350
−400
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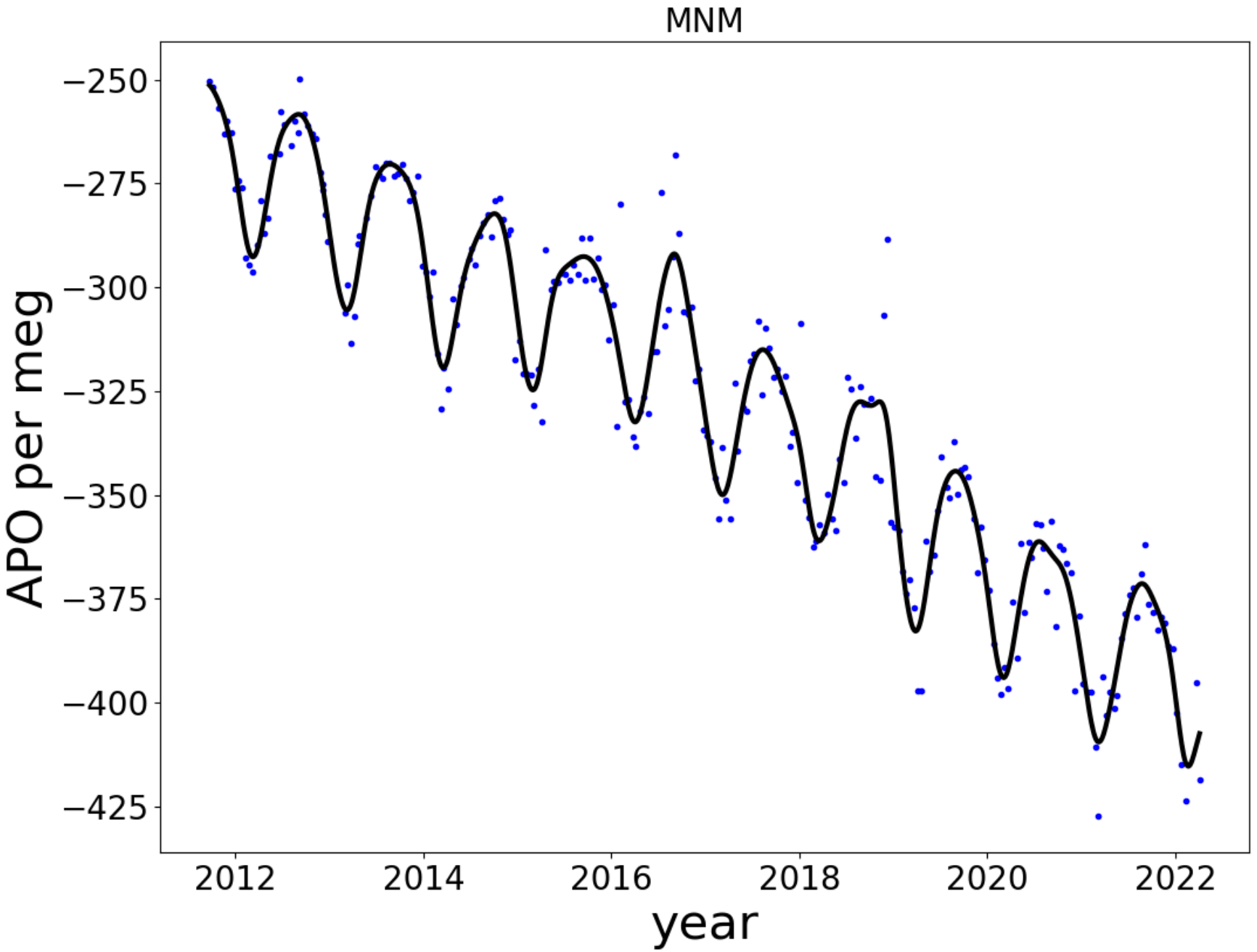
APO per meg
2000
2005
2010
2015
2020
year


MNM
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−275
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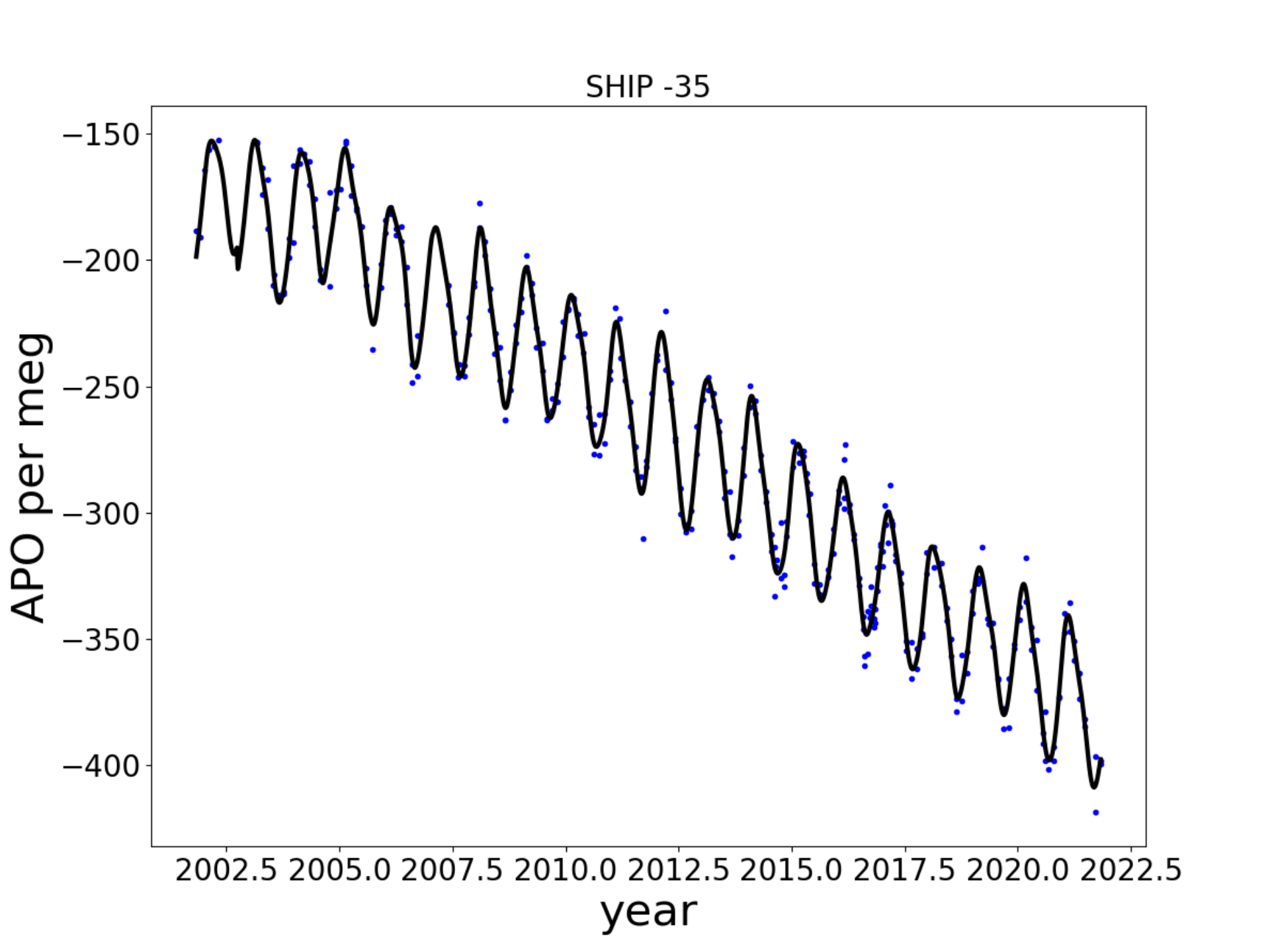
−325
−350
−375
−400
−425
APO per meg
2012
2014
2016
2018
2020
2022
year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APO per meg
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2005.0
2007.5
2010.0
2012.5
2015.0
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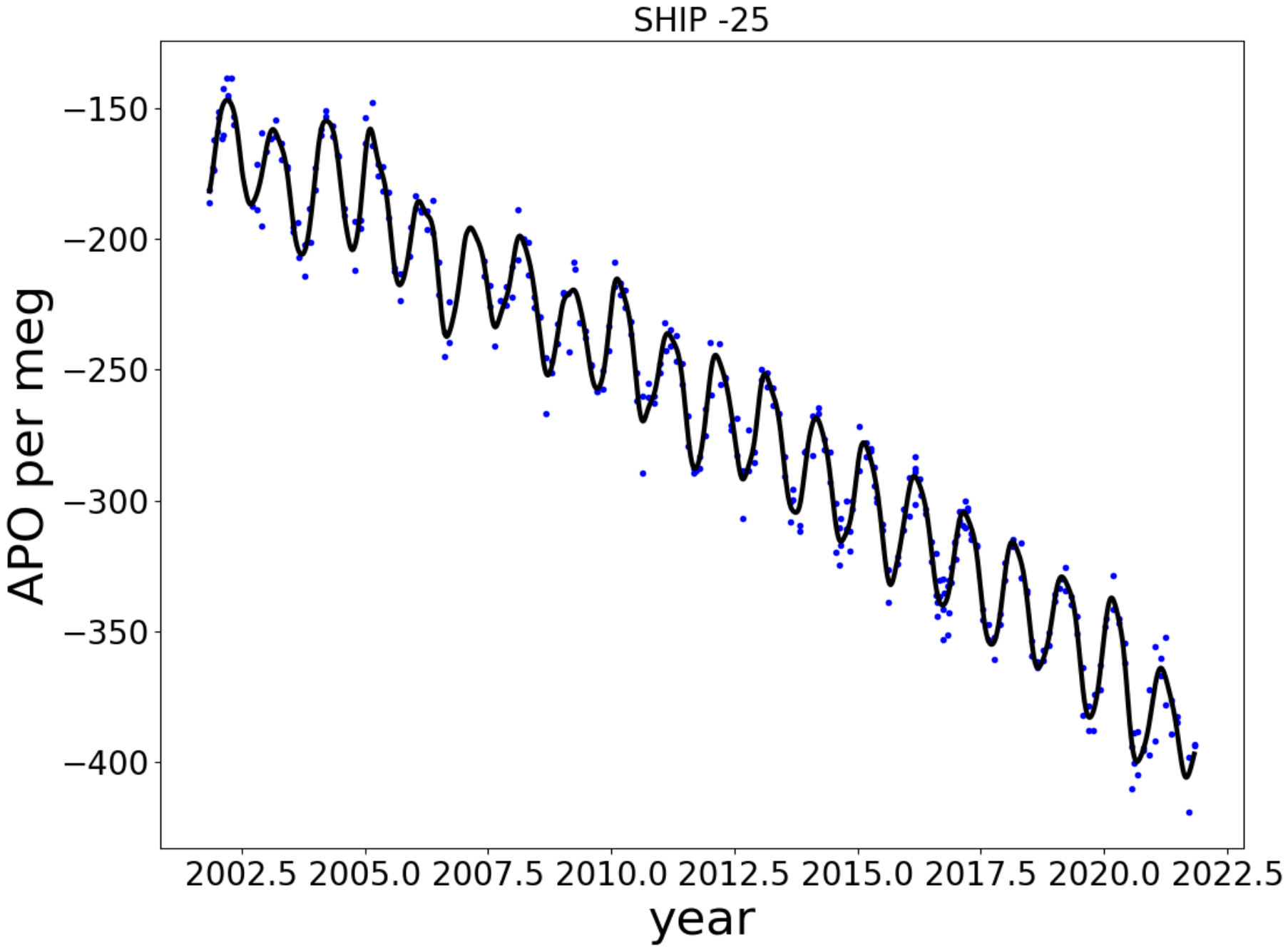
2020.0
2022.5
year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APO per meg
−150
−200
−250
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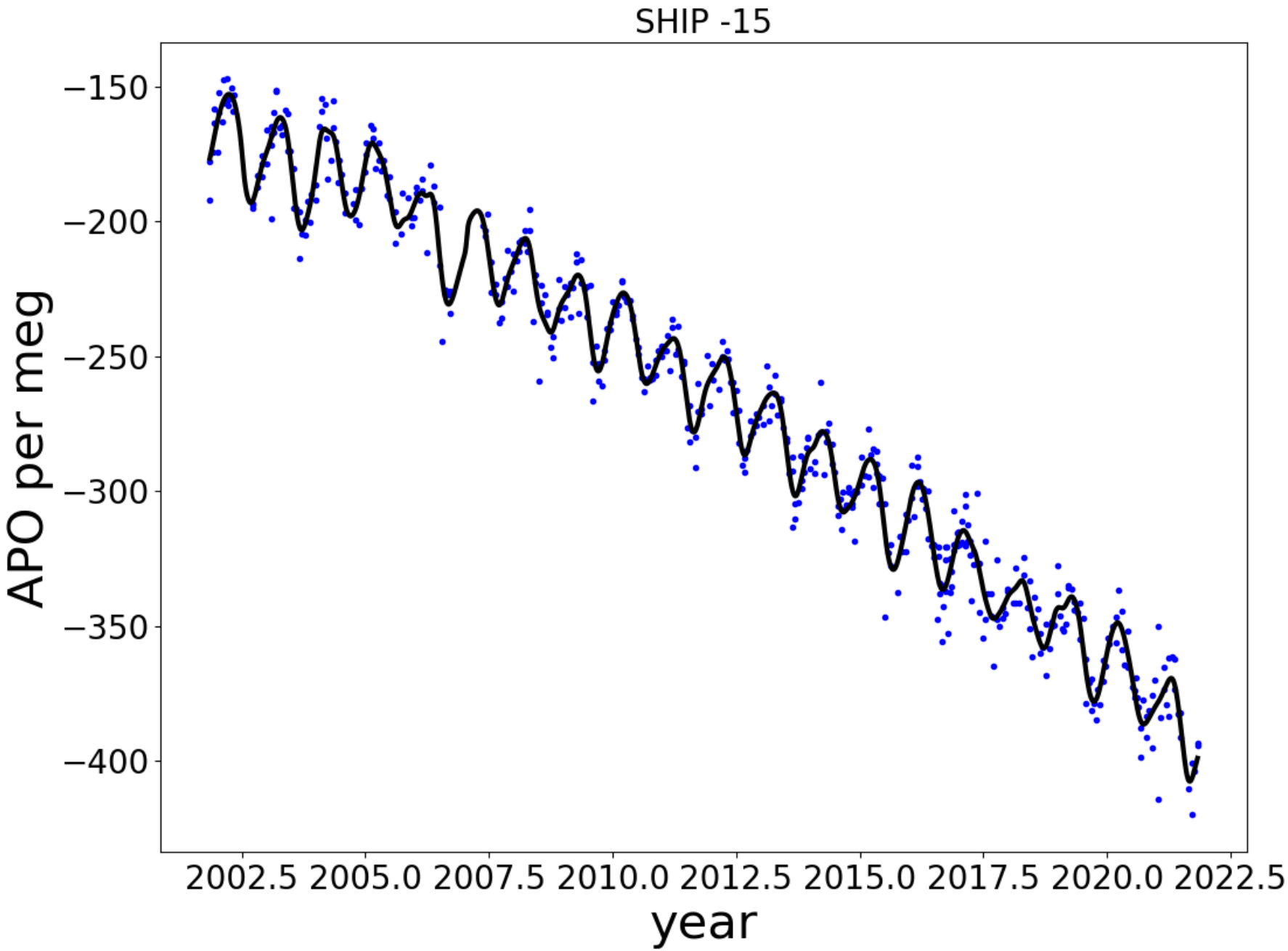
2015.0
2017.5
2020.0
2022.5
year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2005.0
2007.5
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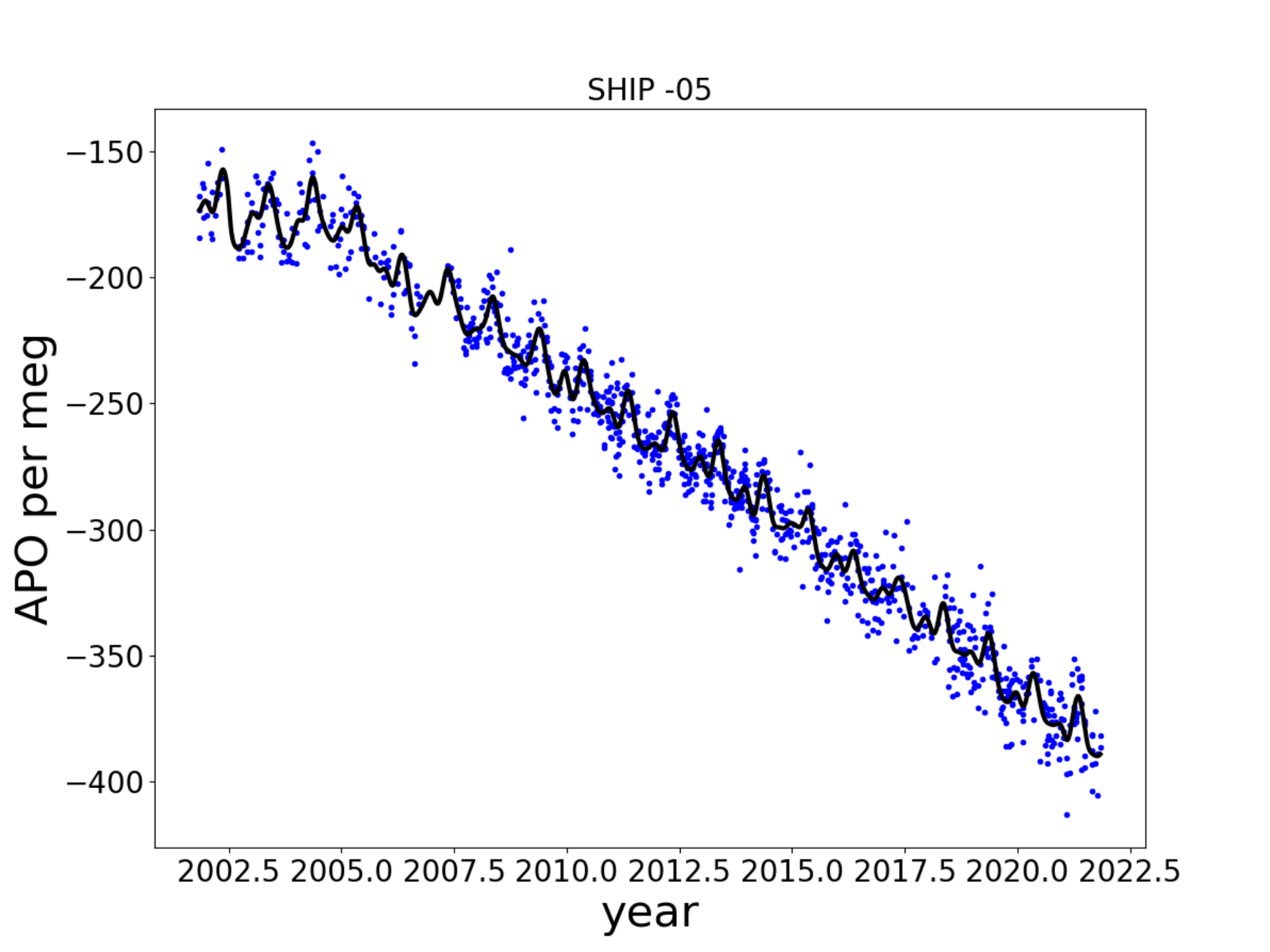
2015.0
2017.5
2020.0
2022.5
year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−150
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APO per meg
2002.5
2005.0
2007.5
2010.0
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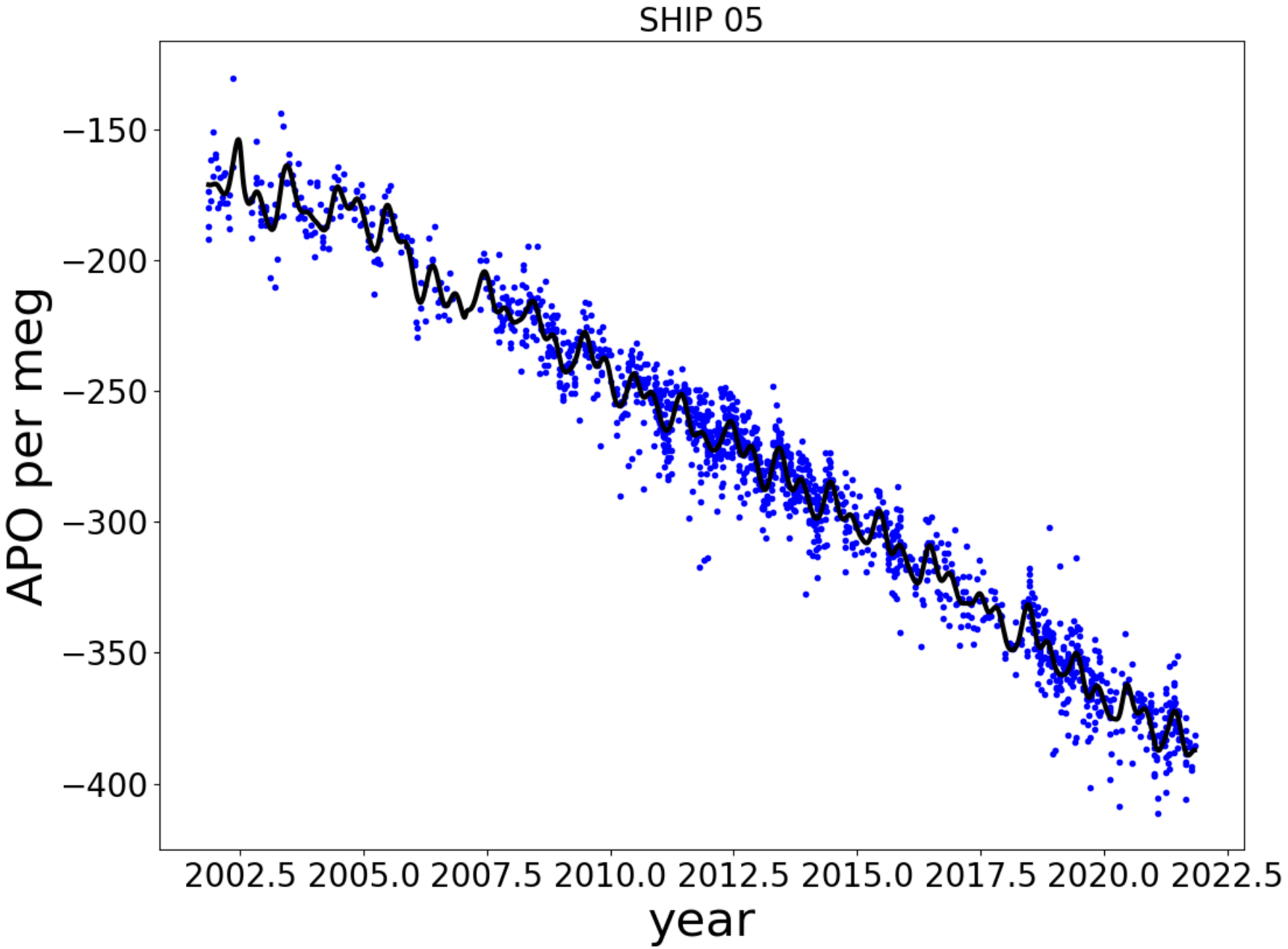
2015.0
2017.5
2020.0
2022.5
year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−200
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2005.0
2007.5
2010.0
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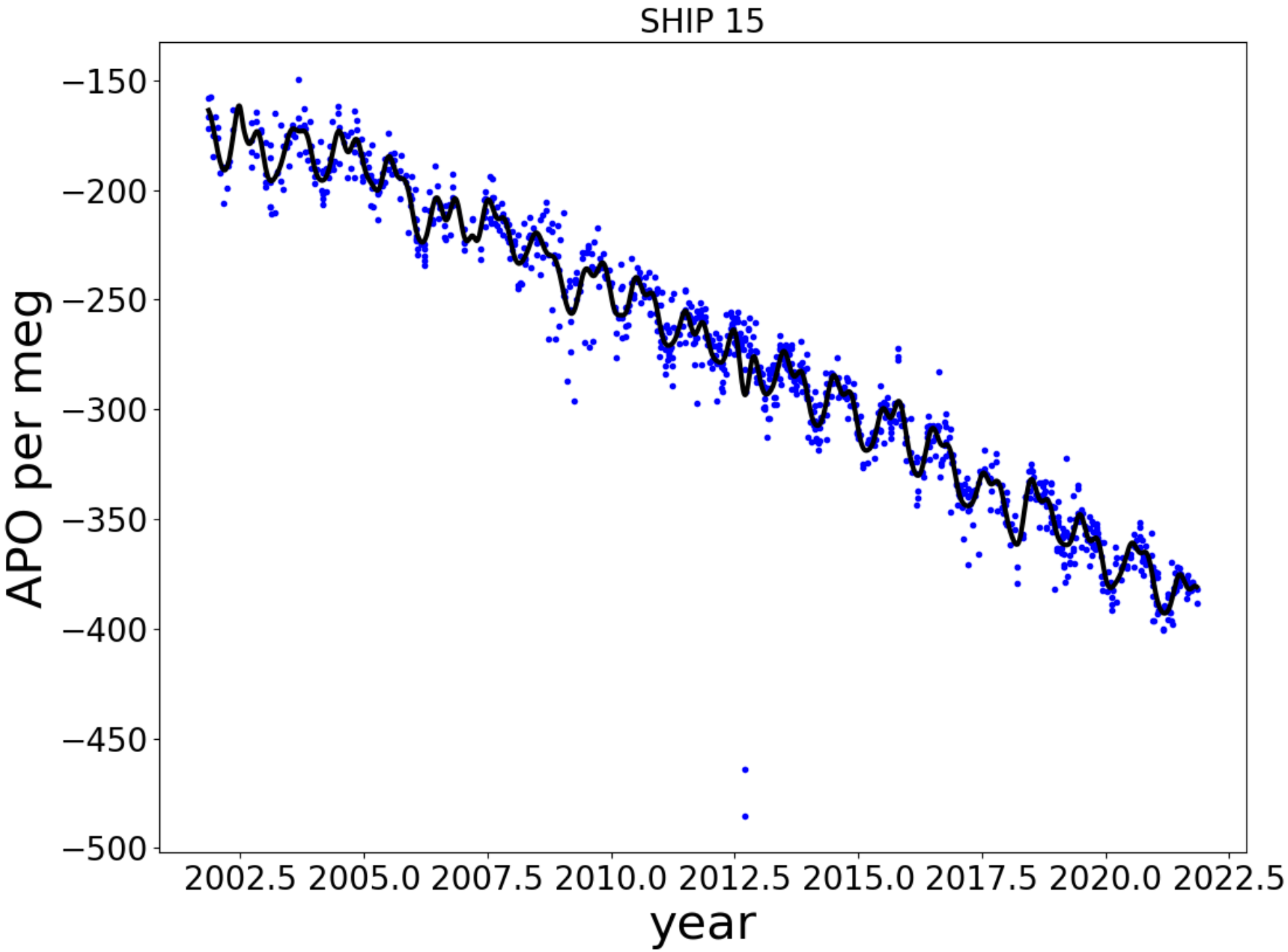
2015.0
2017.5
2020.0
2022.5
year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−300
−350
−400
−450
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2005.0
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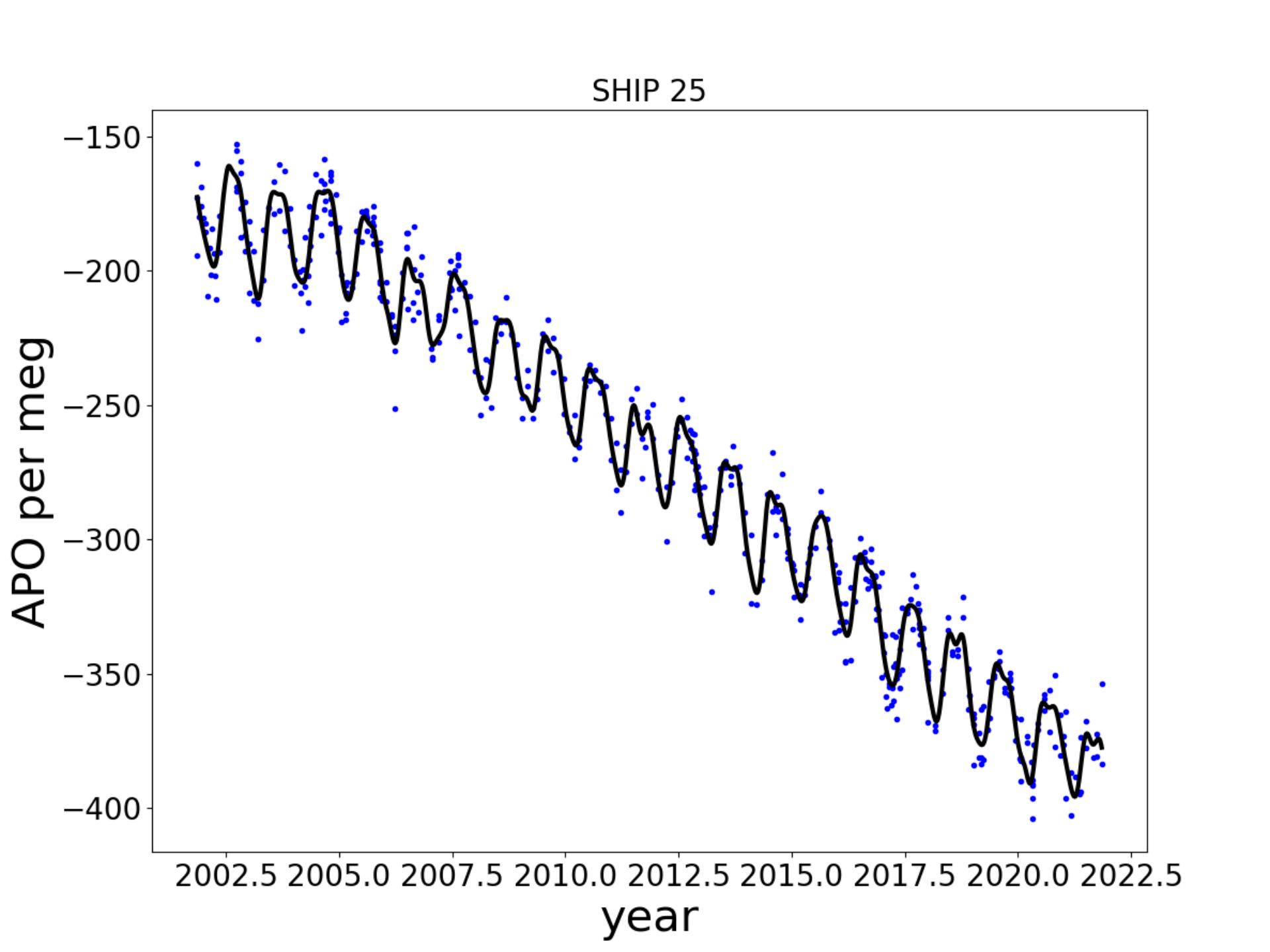
2010.0
2012.5
2015.0
2017.5
2020.0
2022.5
year


SHIP 25
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−200
−250
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−350
−400
APO per meg
2002.5
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0
2022.5
year