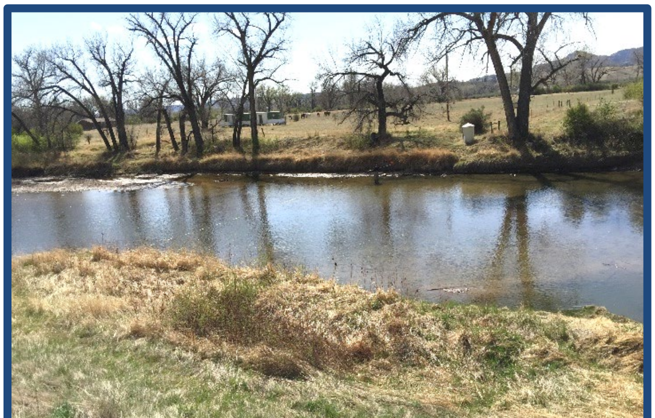

Tongue River Trend Analysis

DEQ Contract 221016

PREPARED FOR:

Montana Department of Environmental Quality
Water Quality Planning Bureau
Water Quality Standards Section
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1.0 Table of Contents

Cover photos (top to bottom): Tongue River at Birney Day School Bridge, Tongue River upstream of Birney, Tongue River Dam.

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Executive Summary

HydroSolutions completed the Tongue River Trend Analysis project to support the Montana Department of Environmental Quality (DEQ) in developing a salinity Total Maximum Daily Load (TMDL) for the Tongue River downstream of the Tongue River Dam in southeastern Montana. DEQ is relying on a watershed model to determine source allocations for the TMDL but wishes to explore the potential effects of ongoing coal-bed methane (CBM)-related discharge on Tongue River water quality and therefore has requested a separate trend analysis.

The focus of this study is a reach of the Tongue River between the Wyoming state line (near Decker, Montana) and the Birney Day School Bridge USGS gage, also in Montana. Specifically, specific conductance (SC) and sodium adsorption ratio (SAR) data from three USGS gage sites—State Line (06306300), Tongue River Dam (06307500), and Birney School (06307616)—were evaluated for trends over the period of 2000 to 2020.

The USGS Time Series Model (TSM) was selected as the primary trend analysis method. Though the TSM requires a lengthy and continuous input dataset, it provides superior handling of variable sampling frequency, serial correlation, and periods without water quality data compared to other trend analysis techniques. Furthermore, it was successfully applied to these and other sites on the Tongue River previously by Sando et al. (2014). In addition to the TSM, the non-parametric Mann-Kendall trend test was applied to water quality data for two specific seasonal periods (early spring and baseflow) because DEQ has a specific interest in potential year over year trends between these seasons.

Preferred TSM models were selected following the approach of Vecchia and Nustad (2020), which involves comparison of different trend models using the generalized likelihood ratio test statistic. In most cases, the preferred trend model accounts for observed changes (or lack thereof) in the datasets over time and therefore is believed to be a useful tool for intrepreting water quality changes on the Tongue River over time.

Preferred TSM models for SAR at Birney School and Tongue River Dam both identified increasing trends from the early 2000s to 2010-2012, followed by a decreasing trend from the 2010s to 2020. This pattern is generally consistent with increasing SAR during the period of active CBM development and decreasing SAR during the post-peak CBM development period. In contrast, the preferred SAR trend for the State Line site consists of a single decreasing trend from 2000 to 2020, showing no apparent correlation with changes in CBM activity.

The preferred TSM SC trends in general do not directly correspond to the timing of the area's peak or post CBM development periods. There is no SC trend identified at the Tongue River Dam site and the only SC trend identified at the State Line site is an increasing trend from 2016–2020. Birney School exhibits a slight decreasing SC trend from 2000 to 2006 when CBM activity was high but began to increase in 2006 and continued doing so throughout the period of record even after the end of peak-CBM. Overall, TSM SC trends do not appear to correspond directly with changes in CBM activity, though they are not necessarily inconsistent if a time-lag dynamic exists between CBM activity and impacts to SC values (for instance due to seepage from CBM-discharge ponds).

In addition to the TSM analysis, the Mann-Kendall test was applied to flow-adjusted seasonal SC and SAR data collected during the spring season (March, April, and May), and during the baseflow season (August, September, and October).

The Mann-Kendall analysis identified a total of 5 significant trends ($p < 0.05$) out of 12 site/parameter/season combinations tested. The significant trends included decreasing SAR trends during the baseflow season at State Line and Tongue River Dam and increasing SC trends at Tongue River Dam (spring) and Birney School (spring and baseflow). Mann-Kendall trend analysis on data from specific seasons is generally consistent with TSM results in cases when the Mann-Kendall detected a significant trend. However, a few discrepancies exist between the statistically significant Mann-Kendall trends and preferred TSM trend models; these appear to be attributable to the Mann-Kendall's single monotonic trend limitation or the seasonal-only data sets evaluated by this method.

Future recommended work includes testing of additional TSM models in order to further refine model fits and reduce or eliminate residual trends. Additionally, the TSM's capability to incorporate ancillary trend variables into models could be explored, with potential ancillary variables to test including those associated with CBM production, agricultural output, and coal mining activity.

1.0 Introduction

HydroSolutions Inc (HydroSolutions) was awarded Montana Department of Environmental Quality (DEQ) contract number 221016 (the contract) to complete the Tongue River Trend Analysis project on June 16, 2021. Modification 1 to the contract was executed on January 4, 2022, extending the contract period by two weeks to March 1, 2022.

This report presents the purpose and scope, methods, results, and conclusions of the Tongue River Trend Analysis, along with other details of the project, in fulfillment of the reporting requirements of the contract (Tasks 3 and 4).

1.1 Purpose

DEQ initiated the Tongue River Trend Analysis project (the project) to support DEQ's work on a salinity total maximum daily load (TMDL) being prepared for the Tongue River downstream of Tongue River Dam in southeastern Montana (MT42C001_014; Figure 1). Reaches of the Tongue River in this area are listed as impaired due to excessive levels of salinity.

DEQ's TMDL analysis will include allocation of salinity impairments to both natural and anthropogenic sources, with one potential anthropogenic contributor being ongoing impacts from coal-bed methane (CBM)-produced water. DEQ is relying on a watershed model to determine source allocations for the TMDL analysis. However, DEQ also desires to evaluate trends in specific conductance (SC) and sodium adsorption ratio (SAR) on the Tongue River to supplement the watershed model and potentially provide an additional line of evidence for determining source allocations. Evaluation of potential trends in these data is the primary objective of this project and the focus of this report.

1.2 Scope of Work

The scope of work for the analysis consists of four tasks, which are summarized as follows:

- **Task 1: Data collection and trend analysis selection.** Review electronic SAR and SC data sets provided by DEQ. Assess applicability of the USGS Time Series Model utilized previously on the Tongue River (Sando, et al. 2014) for use on this project. Provide proposed data sets for trend analysis and a description of proposed analysis methods.
- **Task 2: Conduct trend analysis and submit preliminary results.** Conduct flow-adjusted annual and seasonal trend analysis for SC and SAR at the three USGS gage sites identified by DEQ. The seasonal analysis should focus on the March-April and August-October period, representing SC exceedances under rising limb and baseflow conditions, respectively, on the Tongue River. Provide a preliminary summary and interpretation of results and conduct a virtual meeting with DEQ following submittal.
- **Task 3: Prepare and submit draft report.** Submit a complete draft report as outlined by DEQ in electronic format for DEQ to review and edit, along with any statistical code or spreadsheets used to conduct the analysis, in electronic format. Conduct a virtual meeting with DEQ.

- **Task 4: Submit final report.** Prepare a final report that incorporates all modifications of the draft report requested by DEQ. Submit report in Microsoft Word format and include electronic copies of statistical code and spreadsheets used to conduct analysis.

1.3 Study Area

The project study area, as identified by DEQ, is the Tongue River in Big Horn County and Rosebud County in southeastern Montana (Figure 1). The study area consists of a north-northeasterly flowing reach of the Tongue River from the Wyoming state line near Decker, Montana to Birney Day School in Montana. The straight-line distance between the state line and Birney Day School is approximately 34 miles.

More specifically, river discharge and water quality data from three U.S. Geological Survey (USGS) gage sites within the project study area were selected by DEQ for trend evaluation. From up to downstream they include: (1) USGS Site Number 06306300 Tongue River at State Line near Decker, MT (State Line or SL), (2) USGS Site Number 06307500 Tongue River at Tongue River Dam near Decker, MT (Tongue River Dam or TRD), which is immediately below the Tongue River dam, and (3) USGS Site Number 06307616 Tongue River at Birney Day School Bridge near Birney, MT (Birney School or BS). These three gage sites are shown on Figure 1 and summarized on Table 1. The Miles City USGS gage (06308500) was not included in the analysis because it is downstream of the TMDL section (Figure 1).

Table 1. Summary of USGS gages used for project.

USGS Site Name	USGS Site Number	Abbreviated Name Used in this Report
Tongue River at State Line nr Decker MT	06306300	State Line (SL)
Tongue River at Tongue R Dam nr Decker MT	06307500	Tongue River Dam (TRD)
Tongue R at Birney Day School Br nr Birney MT	06307616	Birney School (BS)

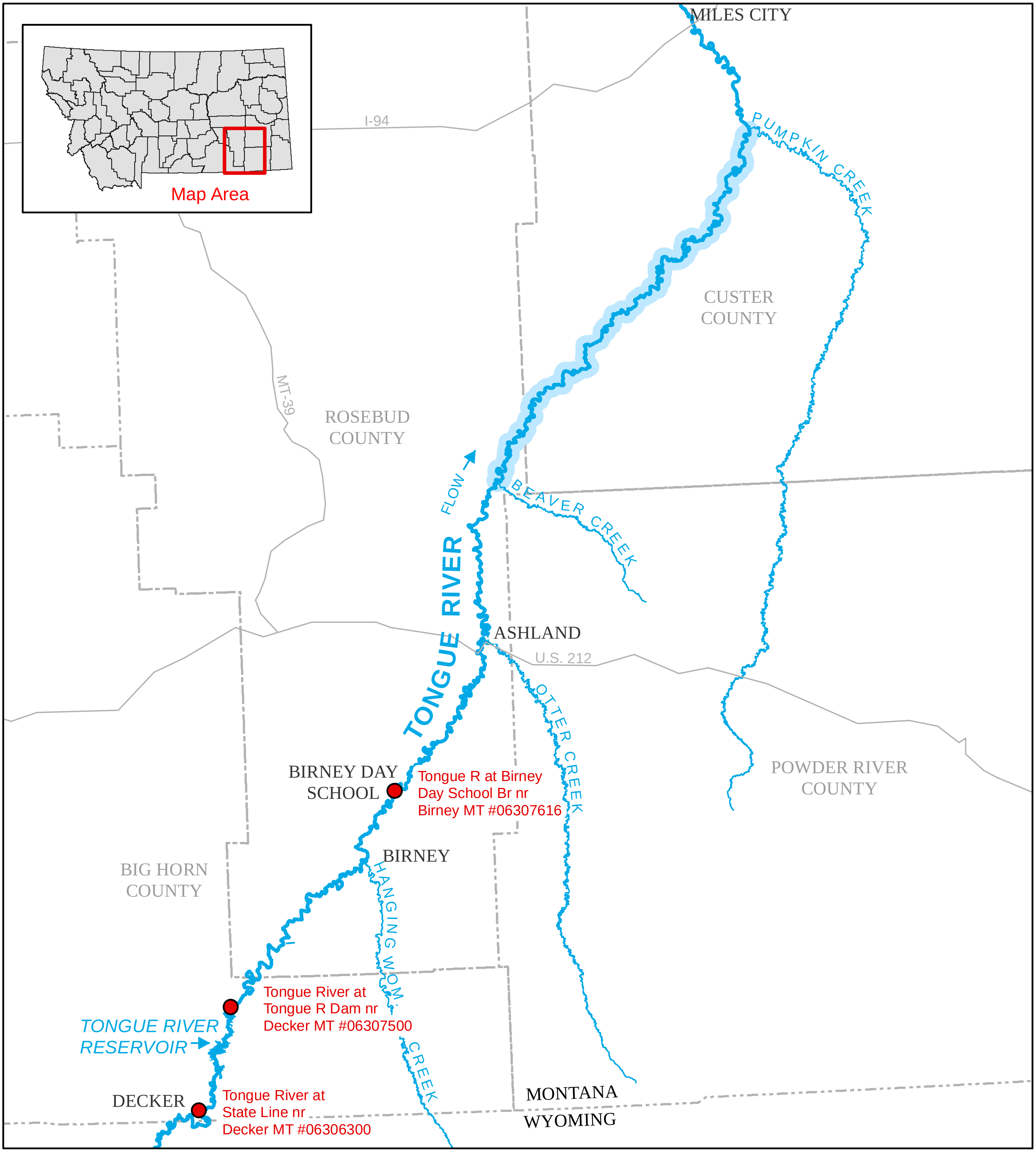

Figure 1. Study Area and Monitoring Locations

Tongue River Trend Analysis
Montana Department of Environmental Quality
Water Quality Planning Bureau

CRS: NAD 1983 StatePlane Montana FIPS 2500
Projection: Lambert Conformal Conic
Revision Date: 2/11/2022
File: TR Trends Figure 1 rev2.mxd

1.4 Previous Investigations

Water quality on the Tongue River has been extensively studied. Much of the previous work has been completed by the USGS, which is summarized at length by Sando et al. (2014). Additionally, the Montana Board of Oil and Gas Conservation funded a monitoring program on the Tongue River called the Tongue River Irrigation Program (TRIP) from 2006 to 2011 to assess potential CBM-related water quality effects on the Tongue River.

Of particular interest to this study is the Tongue River water quality trend analysis work of Sando et al. (2014). The objective of the Sando et al. study was to evaluate flow-adjusted temporal trends in water quality on the Tongue River at 16 sampling sites between 1980 and 2010, with an intent to identify trends that might be attributed to CBM activity. Notably, Sando used an earlier version of the USGS Time-Series Model (TSM) for water quality trend analysis published by Vecchia and Nustad (2020).

The Sando et al. analysis evaluated data from the State Line, Tongue River Dam, and Birney School gage sites, among others. It considered two trend periods: 1986 through 1995 (Period 1, representing the pre-CBM time period) and 2001 through 2010 (Period 2, representing the active-CBM development period). A variety of major ion constituents and water quality parameters were consisdered in the Sando et al. trend study; the SC and SAR trends they identified for the project sites are summarized in Table 2. Statistically significant positive or negative trends for all parameters evaluated at the project sites are shown in Table 3.

Table 2. Specific conductance (SC) and Sodium Adsorption Ratio (SAR) trends (percent change) reported by Sando et al. (2014) for sites used in this study. Statistically significant ($p<0.01$) trends shown in red.

Site	Period 1 SC	Period 2 SC	Period 1 SAR	Period 2 SAR
State Line	**-17**	+5	+2	+7
Tongue River Dam	-16	+1	-16	+38
Birney School	-15	-2	-27	+46

Period 1 = 1986–1995 (pre-CBM period), Period 2 = 2001–2010 (active CBM period).
Red+bold = statistically significant trend (at p <0.01); gray = trend not statistically significant.
Reference: Sando et al. (2014) Table 2, p. 33.

Table 3. Count of statistically significant (p <0.01) positive or negative trends for all parameters evaluated by Sando et al. (2014) by site and period. Value in each cell represents count of statistically significant trends out of 11 water quality parameters evaluated for each site/period.

Site	Period 1		Period 2	
	+	–	+	–
State Line	0	1	1	0
Tongue River Dam	0	7	3	0
Birney School	0	5	3	0

Period 1 = 1986–1995 (pre-CBM period), Period 2 = 2001–2010 (active CBM period).
+ denotes positive trend, − denotes negative trend.
Reference: Sando et al. (2014) Table 2, p. 33.

For SC and SAR at the three sites of interest, Sando et al. (2014) only identified one statistically significant trend during the pre- and active-CBM periods (decreasing SC at State Line pre-CBM; Table 2). However, when all parameters evaluated by Sando et al. are considered, there were 13 total significant negative trends and zero significant positive trends identified during the pre-CBM period and 7 significant positive trends and zero significant negative trends during the active-CBM period (Table 3).

Ultimately, Sando et al. (2014) conclude that there are generally small significant or non-significant decreases for most constituents during Period 1. However, they state that the TSM trend results do not permit confident conclusions vis á vis CBM impacts during Period 2, because significant trends were relatively infrequent and inconsistent, and confounding factors such as irrigation and coal mining activities may have affected water quality at the Tongue River Dam and Birney School sites.

2.0 Methods

This section details the methodology of each of the key elements of the trend analysis employed for the project. The workflow generally consisted of input data cleanup, exploratory data analysis (EDA), TSM model analysis and interpretation, and Mann-Kendall analysis of flow-adjusted concentrations during seasonal periods of interest.

All data pre-processing, analysis, and trend modeling was completed using the R language for statistical computing (R Core Team 2019) within the R Studio integrated development environment (R Studio Team 2021). Scripts to complete these tasks are included as electronic attachments to this report in both R markdown files (for convenient editing or execution) as well as .html format R notebook files (for convenient viewing of code and output).

2.1 Input Data Cleanup and EDA

DEQ provided HydroSolutions with Microsoft Excel format spreadsheet documents containing discharge and water quality data from the USGS State Line, Tongue River Dam, and Birney School gage stations. Two spreadsheets were provided for each site, one containing discharge measurements with continuously recorded SC and SAR measurements made at the gage, and the other containing discrete water quality sampling data that were manually collected during sampling events at the sites. DEQ obtained the discharge and continuously recorded measurements from the USGS National Water Information System (NWIS) website and the discrete measurements from the National Water Quality Monitoring Council Water Quality Portal website. Raw data are provided in Electronic Attachment EA-1.

Complete annotated R code used to convert these raw data into datasets ready for the TSM is contained in electronic attachments EA-2, EA-3, and EA-4.

The initial cleanup and EDA process is documented in Electronic Attachment EA-2 and summarized as follows:

- Read continuously recorded mean daily discharge (USGS parameter-statistic code 00060_00003), mean SC (USGS 00095_00003), and mean SAR (USGS 90856_00003) data into R.
- Read discretely sampled laboratory analyzed SC (Pcode 90095) and SAR (Pcode 931) data into R.
- Review general characteristics of the data, including the period of record and remark codes present.
- Join discrete and continuous data tables together. Populate “final” SC and SAR data columns with the value to be used in the TSM analysis. Initially, for Task 1, based on discussions with DEQ, the “final” columns were populated with a continuous SC or SAR value if one existed and only filled in with a discrete value if continuous data were lacking on a date.
- Datasets were truncated (to the nearest full calendar year) to only include the water quality period of record for each site (e.g., years with only streamflow but no water quality measurements were dropped).
- A final TSM input data table was created containing date, average daily discharge, discharge code, SC value, SC code/remark, SAR value, and SAR code/remark. These tables were exported from R as .csv files for DEQ review.
- Final datasets were evaluated to see if TSM data density assumptions were met (at least 10 calendar years with one or more water quality observations for each parameter during all three-month periods e.g., January-March, February-April, March-May…October-December).
- Datasets were plotted and visually inspected.

Following review of the initial data cleanup and EDA, DEQ indicated a preference for using discrete SAR data as opposed to the combination of continuous and discrete SAR data provided in the initial TSM input datasets, on the basis that discrete sampled (laboratory-determined) SAR would provide a more independent measure than SAR calculated from continuous data. Therefore, HydroSolutions assessed the suitability of the discrete datasets with respect to TSM data assumptions and plotted the results for visual examination using the code contained in EA-3.

Upon determining discrete SAR data sufficiently met TSM data assumptions, at DEQ's request the SAR observation and SAR code/remark columns of the final TSM input datasets were modified to contain the discrete SAR data only. The resulting datasets were again plotted for visual inspection. The R code used to complete this modification to the final datasets is provided in Electronic Attachment EA-4.

Final datasets for TSM input, as described above, are included in .csv format as Electronic Attachments EA-5, EA-6, and EA-7. In summary, the final datasets assembled for input into the TSM consist of the following (actual column name given in square brackets):

- Observation date [DATE]
- Mean daily discharge measurement (cubic feet per second; USGS 00060_00003) [Q_mean]
- Continuously recorded mean SC measurement (USGS 00095_00003) if available; discrete laboratory SC measurements (Pcode 90095) are used only if available on dates that continuous measurements are missing. SC measurements are reported in microSiemens per centimeter [TSM_SC].
- Discrete SAR measurements (Pcode 931; unitless) [TSM_SAR].
- Measurement qualification code/remark for daily discharge [Q_cd], SC [TSM_SC_cd], and SAR [TSM_SAR_cd].

2.2 Time Series Model

The USGS TSM is a water quality trend analysis method developed by the USGS. The theory underpinning the TSM, and its practical implementation, are described in detail by Vecchia and Nustad (2020). The TSM is made available by the USGS as an R programming language script called R-QWTREND (Vecchia and Nustad 2020), which is freely available on the USGS website.

2.2.1 Overview

Using continuous discharge data and water quality sample data, the TSM calculates the flow-related variability of the water quality data, filters the data using a periodic autoregressive moving average (PARMA) model (which helps to reduce the effects of autocorrelation), and ultimately solves for the coefficients required to fit a trend to the input data. A key difference between the TSM method and other trend analysis methods is that the TSM partitions the effects of streamflow variability into interannual, seasonal, and short-term time components, resulting in a more detailed correction for streamflow variability compared to other approaches (Sando, et al. 2014). At sites with continuous or near-continuous streamflow data, the TSM provides superior handling of variable sampling frequency, serial correlation, and periods without water quality data compared to other trend analysis methods (Sando, et al. 2014).

2.2.2 TSM Data Requirements and Assumptions

USGS documentation for the R-QWTREND package for TSM analysis provides the following general guidance regarding data requirements for successful application of the TSM (emphasis added; Vecchia and Nustad 2020, p. 11):

> *The statistical methods previously described are based upon two general assumptions: (1) that the data can be modeled using the general framework described in the “Time-Series Model” section of this report and (2) that the data available to fit the model are sufficient to allow the asymptotic (large-sample) properties of Gaussian maximum likelihood estimation to be applied. Whether or not a particular dataset is sufficient to obtain reliable estimates of trend coefficients and p-values, annual flow-weighted average concentration, annual flux, and other quantities using R–QWTREND depend on a host of factors, including the number of observations, record length, sampling design (distribution of samples among different years, seasons, and flow conditions), and the complexity of the trend model. Although* ***there are no minimum data requirements that are guaranteed to provide reliable results for every possible water-quality constituent and sampling location****, a few general recommendations are provided to lead to reliable results for most applications:*
>
> > *1. At least 10 separate calendar years with 1 or more observations (water-quality samples) in each of the following 3-month windows: January–March, February–April, March–May, April–June, May–July, June August, July–September, August–October, September–November, and October–December.*
> >
> > *2. A total of at least 60 observations.*
> >
> > *3. At most 25-percent censored data.*
> >
> > *4. Minus 2 times the logarithm of the likelihood function (−2ln[Lik]; eq. 15) has a well-defined minimum (positive definite Hessian matrix) with respect to the model parameters.*
> >
> > *5. The model assumptions are reasonable, judging by examination of diagnostic model output (see example applications later in this report for suggested diagnostic output and model verification).*
>
> *These requirements ensure that observations are reasonably spread out among multiple (10+) years and among sliding 3-month seasons within each year, starting with January–March and ending with October December.*

In addition to the requirements above, streamflow data should be daily with only a limited number of missing values (Vecchia and Nustad 2020).

2.2.3 Suitability for Project

The TSM is well-suited to the evaluation of temporal water quality trends at project sites over periods of years to decades. The proposed project sites have continuous streamflow data and thus benefit from TSM advantages discussed above, and review of the input data sets demonstrates that they generally meet the recommended assumptions for the TSM. Furthermore, the TSM method has been applied to the same project sites previously by Sando et al. (2014) over similar decadal timescales. Therefore, based on the characteristics of the assembled data sets (described in the Section 3.1), and the guidance of Vecchia and Nustad (2020), the TSM was determined to be the best overall trend analysis approach for all sites.

2.2.4 Method of Implementation

R-QWTREND was used for TSM analysis of SC and SAR at the project sites. The general approach outlined in Vecchia and Nustad (2020) was followed, which consisted of:

- Preparing input data frames for R-QWTREND in specified format using final data sets (Electronic Attachments EA-5, EA-6, and EA-7). R code used for preparation of final TSM input data is included in Electronic Attachment EA-8. Commands for execution of TSM model runs using R-QWTREND are provided along with model results in Table 5.
- Preparing data for the model by running the `prepQWdata()` routine on the input data frames for each site. Review preliminary plot output from prepQWdata and check for outliers or other irreguarities in the data.
- Removing any outliers identified by the R-QWTREND screening procedure and re-running `prepQWdata()` on the updated data set.
- On the output of `prepQWdata()`, running the maximum likelihood estimation routine `runQWmodel()` to fit different trend models.
    - Three to five models were run on each site-parameter combination. At a minimum, the models run consisted of a no-trend (null) model, a single monotonic trend model over the entire period of record, and a two-period piecewise monotonic trend model. The piecewise monotonic trend model was divided into two periods of time (period of record dependent) falling within 2000 through 2009 and 2010 through 2020 (inclusive), representing high-CBM activity times and reduced-CBM activity times, respectively. Additional models were run in some instances based on review of runQWmodel output plots, particularly if visually discernable residual trends were apparent in the flow-adjusted, detrended, PARMA filtered concentration time-series plots output by each model run.
    - Trend periods in the TSM are described as a half-open interval of decimal years (first year inclusive, last year exclusive). A decimal year expresses a date as a decimal fraction of its year. For instance, January 1, 2020 is equivalent to 2020.0 and July 1, 2020 is equivalent 2020.5. Thus, a trend written as 2000x2010 in TSM notation describes the period spanning from January 1, 2000 (2000.0) up until (but not including) January 1, 2010 (2010.0)
    - The best model was selected based on numerical convergence, reasonableness and statistical significance of fitted trends, and comparison of models to each other using the generalized likelihood ratio (GLR) test statistic (see Appendix A for example GLR calculation).
    - Model diagnostic output was reviewed for discrepencies or anomalies that could suggest an invalid model.

For determination of a preferred model, this study follows the approach of Vecchia and Nustad (2020), which focuses on comparision of models to the null model and more complex models using the GLR test statistic, with lower GLR test statistic p-values being indicative of a preferred model. For comparison of multiple models to each other, a GLR test statistic p-value of <0.01 is recommended by Vecchia and Nustad (2020) to avoid selecting overly complex models, though they suggest that in general even when GLR p-values are not <0.01, lower p-values are a useful guide to selecting a preferred model. Vecchia and Nustad also incorporate other considerations into selection of a preferred model, such as individual trend p-values and visual examination of model output to assess residual trends, which are adopted in this analysis as well.

2.3 Mann-Kendall Analysis

DEQ has a specific interest in year-to-year trends during certain seasons, specifically early spring (rising limb of the hydrograph) when SC exceedances are known to occur and late summer/fall when streamflow is low (baseflow). The TSM described previously is poorly suited to this specific question because it is optimized to identify long-term trends using the maximum amount of available data and not for evaluating trends using subsets of a time series, such as for specific seasons only. Therefore, with the approval of DEQ, and similar to the approach of Clark (2012), the non-parametric Mann-Kendall trend test along with the Theil-Sen robust line (Helsel, et al. 2020) were selected to test for trends over time in SC and SAR during specific seasons.

The Mann-Kendall test essentially determines if the central (median) value of a dataset is changing over time in a monotonic fashion. For surface water quality trend analysis, the Mann-Kendall test is typically run after flow-related variability has been removed from a dataset. Data need not be normally distributed, but there must be no serial correlation in the concentration values for the alpha level of the test to be valid (Helsel, et al. 2020).

Based on the above criteria, the TSM output variable “fapfdat” was selected as the basis for Mann-Kendall input datasets, because it consists of a time series of concentration data that has been flow-adjusted with serial correlation reduced/removed (i.e., PARMA filtered). The fapfdat data for each site/parameter combination (taken from the output of the null model) were further broken into two separate time series, one including only data from March, April, and May (spring season), and another containing only data from August, September, and October (late summer/fall or baseflow season)[1]. The final dataset for Mann-Kendall analysis was created by calculating the median value for each season on a yearly basis.

Using these seasonal median data, the Mann-Kendall test was run and a Theil-Sen robust line calculated for each site/parameter/season combination in order to test for the presence of long-term trends between the targeted seasons. Mann-Kendall trends were judged statistically significant if the 2-sided p-value was less than 0.05, because this represents a commonly used confidence level with the Mann-Kendall test and is the same confidence level used by Clark (2012) for Tongue River trend analyses based on the seasonal Kendall test.

Mann-Kendal analyses and Theil-Sen robust line determination utilized the rkt package for R (Marchetto 2021). R code used for Mann-Kendall analysis is included in Electronic Attachment EA-9.

[1] Compared to the original seasons laid out in the scope of work, the spring season was expanded to include May based on discussion with DEQ.

3.0 Results

This section presents the results of data set EDA and preparation, TSM analysis, and Mann-Kendall analysis of project data.

3.1 TSM Model Input Data

Characteristics of the data sets selected for TSM analysis are summarized in Table 4. The complete input data sets are included in Electronic Attachments EA-5, EA-6, and EA-7. Based on the characteristics shown in Table 4, it was determined that the project data adequately met the recommended criteria for application of the TSM (Vecchia and Nustad 2020; Section 2.2.2). Data were not culled based on measurement qualification or remark codes because there were no codes that indicated any data points were likely to be invalid.

Furthermore, the TSM provides outlier screening and as well as color coding of observations by remark code on output plots as a further visual check for anomalies. TSM outlier screening led to the removal of a single SAR data point from one site and between 1 and 5 SC data points from each of the three sites. Thus, outlier screening resulted in removal of about 0 to 0.6 percent of SAR data at each site and about 0.04 to 0.1 percent of SC data at each site.

Table 4. Summary of TSM input data characteristics.

	Birney School	**State Line**	**Tongue River Dam**
SC analysis period [a]	4/3/2000–9/21/2016	1/5/2000–12/16/2020	1/19/2000–10/20/2020
SC obs. count	2,350	5,142	7,671
SAR analysis period [a]	1/7/2004–9/21/2016	1/5/2000–12/16/2020	1/20/2004–6/24/2020
SAR obs. count	168	261	165
Missing discharge values during analysis period	0	0	0
SC: start of three-month windows with zero observations	1/2002 2/2002 1/2003 7/2003	1/2014	6/2000 10/2001 7/2000 7/2003 8/2001 9/2001
SAR: start of three-month windows with zero observations	--	1/2014 4/2020 1/2018 5/2020 1/2019 6/2020 7/2020	1/2018 1/2019 1/2020 7/2020
Measurement qualification and/or remark codes from NWIS and Water Quality Portal represented in dataset [b]	A A:e Accepted Preliminary No code given	A A:[4] A:e P P:e Ssn P Accepted Preliminary No code given	A A:[4] A:e P P:[4] Ssn P:[4] Accepted Preliminary No code given

[a] Data sets were expanded to include flow data for entirety of first and last year within these ranges

[b] NWIS data codes: A approved for publication, P provisional data subject to revision, e value has been estimated, 4 statistic computed from less than expected number of instantaneous values for the period, Ssn parameter monitored seasonally. Water Quality Portal data codes: Accepted--meets QA/QC criteria, Preliminary--subject to revision.

3.2 TSM Results

Plots showing TSM flow-adjusted and PARMA filtered flow-adjusted data points overlain on raw observations were prepared to illustrate the effect of the TSM adjustments to the data. An example from the Tongue River Dam site is provided on Figure 2 and plots from all three project sites are included in Appendix B. These plots illustrate that the TSM flow adjustment tends to reduce the magnitude of the seasonal peaks and valleys present in the SC and SAR time series data, and in most cases the addition of the TSM's PARMA filtering noticeably reduces this variability further.

Results of preferred TSM model runs are presented in Table 5, and results from all TSM model runs are included in Appendix C. Complete graphical output from all TSM model runs is contained in Appendix D. Full output for all model runs, including tabular data in .csv and .rds format and graphics in .pdf format, is contained in a zipped file provided as Electronic Attachment EA-10.

Plots showing flow-adjusted, PARMA filtered data and the fitted trend of the preferred model for each site/parameter combination are shown on Figure 3 through Figure 5. These plots graphically illustrate the overall trend identified by the preferred TSM models overlain on flow-adjusted, PARMA filtered data points. Figure 4 through Figure 6 illustrate the direction and magnitude of the preferred model trends over time. Figure 7 through Figure 9 show residual trends (if any) in the PARMA filtered and detrended data, which can be used for qualitative evaluation of model fits.

SAR trends identified in the preferred models for the three sites are as follows:

- State Line: decrease of about 10 percent from 2000 to 2020 (p=0.03)
- Tongue River Dam: An increase of about 18 percent during 2000 to 2010 (p=0.02) followed by a decrease of 15 percent from 2010 to 2016 (p=0.007) and a further decrease of 5.8 percent from 2016 to 2020 (p=0.43)
- Birney School: An increase of about 16 percent from 2004 to 2012 (p=0.04) followed by a decrease of 16 percent from 2012 to 2016 (p=0.01).

SC trends identified in the preferred models for the three sites are as follows:

- State Line: Increase of 8.8 percent from 2016 to 2020 (p=0.02)
- Tongue River Dam: No trend
- Birney School: 5.6 percent decrease 2000 to 2006 (p=0.22); 17 percent increase 2006 to 2016 (p=0.0004)

These results are discussed in Section 4.1.

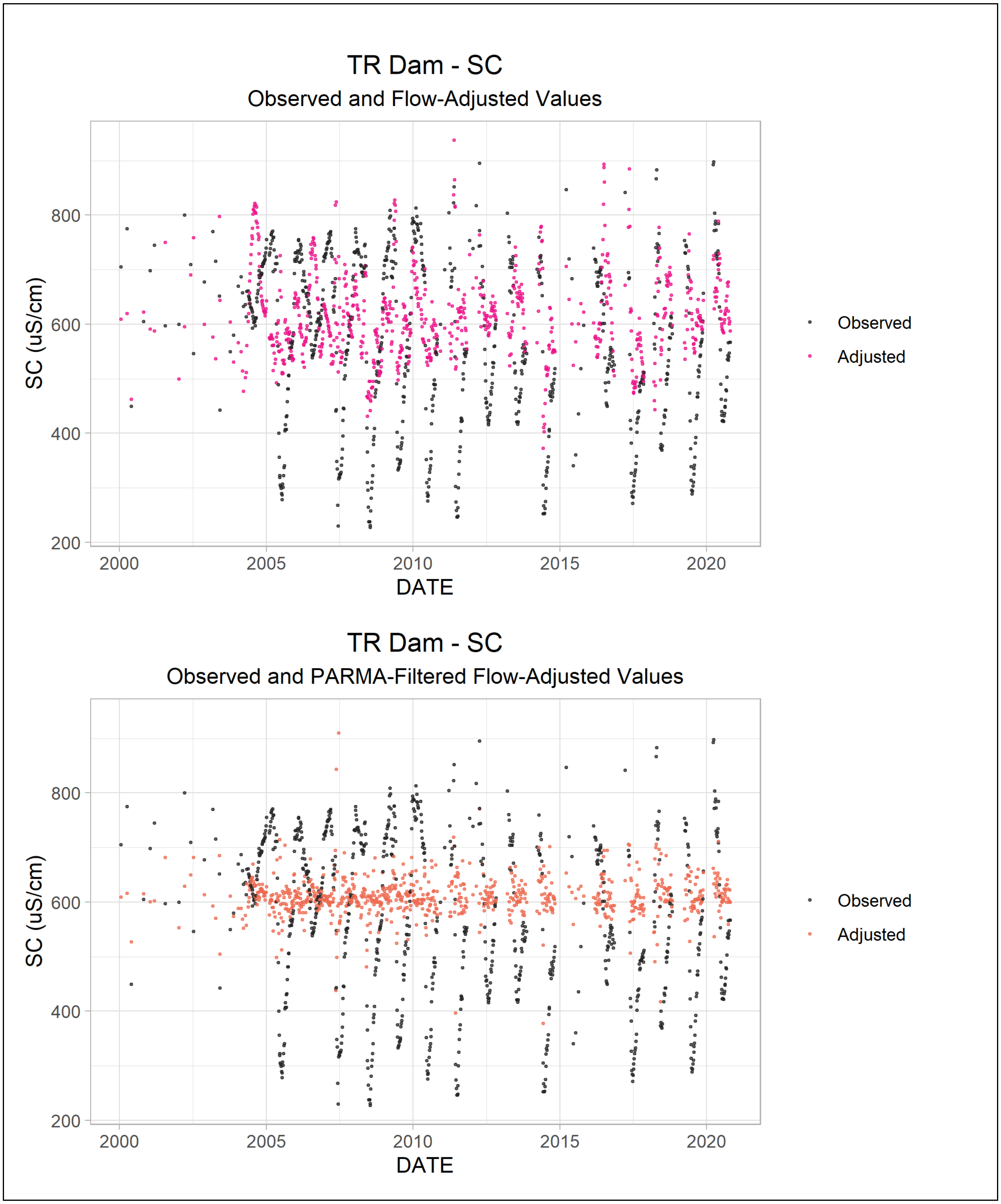

Figure 2. Plots illustrating effect of TSM flow adjustment and PARMA filtering on raw observed data (black points) for SC at Tongue River Dam. Top: flow-adjustment only, bottom: flow-adjustment and PARMA filtering. See Appendix B for other sites.

Table 5. Preferred time series models and trend results. See Appendix C for complete results of all models.

Site/ Parameter[a]	Function Call[b]	Run suffix[c]	Monotonic Trend(s)[d]	Trend (percent)[e]	Trend p-value[f]	GLR_{NULL}[g]	Compa-rison[h]	GLR_{1-2}[i]	Residual trends[k]
State Line SAR	`runQWmodel(SL_QWP, "sar", monxx=c("2000x2020"), exlev=c(0.8, 1.2, 1.6), runname="_M0")`	_M0	2000x2020	-9.97	0.0316	0.0313	-	-	flat '05-'15 but downward trend at start and upward trend at end
State Line SC	`runQWmodel(SL_QWP, "sc", monxx=c("2016x2020"), runname="_M2")`	_M2	2016x2020	8.77	0.019	0.0096	M2 – M1	1	None
Tongue River Dam SAR	`runQWmodel(TRD_QWP, "sar", monxx=c("2004x2010", "2010x2016", “2016x2020), modnum=2, exlev=c(0.8, 1.2, 1.6), runname="_M2")`	_M2	2004x2010 2010x2016 2016x2020	17.54 -15.12 -5.85	0.0221 0.00694 0.430	0.00426	M1 – M2	0.0301	Slightly wavy but flatter than M1
Tongue River Dam SC	`runQWmodel(TRD_QWP, "sc", exlev=c(500,750,1000), runname="_null")`	_null	-	-	-	-	-	-	Possible upward trend 2000-2020
Birney School SAR	`runQWmodel(BS_QWP, "sar", monxx=c("2004x2012", "2012x2016"), exlev=c(0.8, 1.2, 1.6), runname="_M1")`	_M1	2004x2012 2012x2016	16.49 -16.13	0.0396 0.0118	0.0365	M0 – M1	0.0108	Relatively flat with slight concve shape
Birney School SC	`runQWmodel(BS_QWP, "sc", monxx=c("2000x2006", "2006x2016"), exlev=c(500,750,1000), runname="_M2")`	_M2	2000x2006 2006x2016	-5.55 17.33	0.223 0.00042	1.98e-4	M0 – M2	0.0154	Nearly flat.

[a] Site/parameter combination. SL=State Line, BS=Birney School, TRD=Tongue River Dam, SC=specific conductance, SAR=sodium adsorption ration. All output file names contain indication of site name, parameter, and run suffix.

[b] Function call and arguments used to invoke R-QWTREND runQWmodel function for specified model

[c] Suffix appended to model output file names associated with a particular model run

[d] Description of (piecewise) monotonic trend(s) used in model. “2000x2020” indicates a single monotonic trend from January 1, 2000 up until (but not including) January 1, 2020. Multiple trends listed indicates a model using piecewise monotonic trends.

[e] Percent change in trend over trend period (+ for upward trend, - for downward trend)

[f] p-value for individual model trends.

[g] GLR statistic for trend model versus the null model. Models with lower values of this parameter are generally preferred. A significant p-value for the GLR statistic indicates the null hypothesis can be rejected (null hypothesis is that all coefficients of the tested model are zero, e.g. there's no trend).

[h] Indication of which two non-null models of differing complexity are being compared using GLR statistic.

[i] GLR statistic resulting from comparison of two non-null models. A significant value indicates the more complex of the two models is preferred.

[k] Visual/qualitative assessment for any remaining trend in flow-adjusted, detrended, and PARMA filtered data (model output pdf page 4). Minimal to no trend on this plot suggests a good overall model fit.

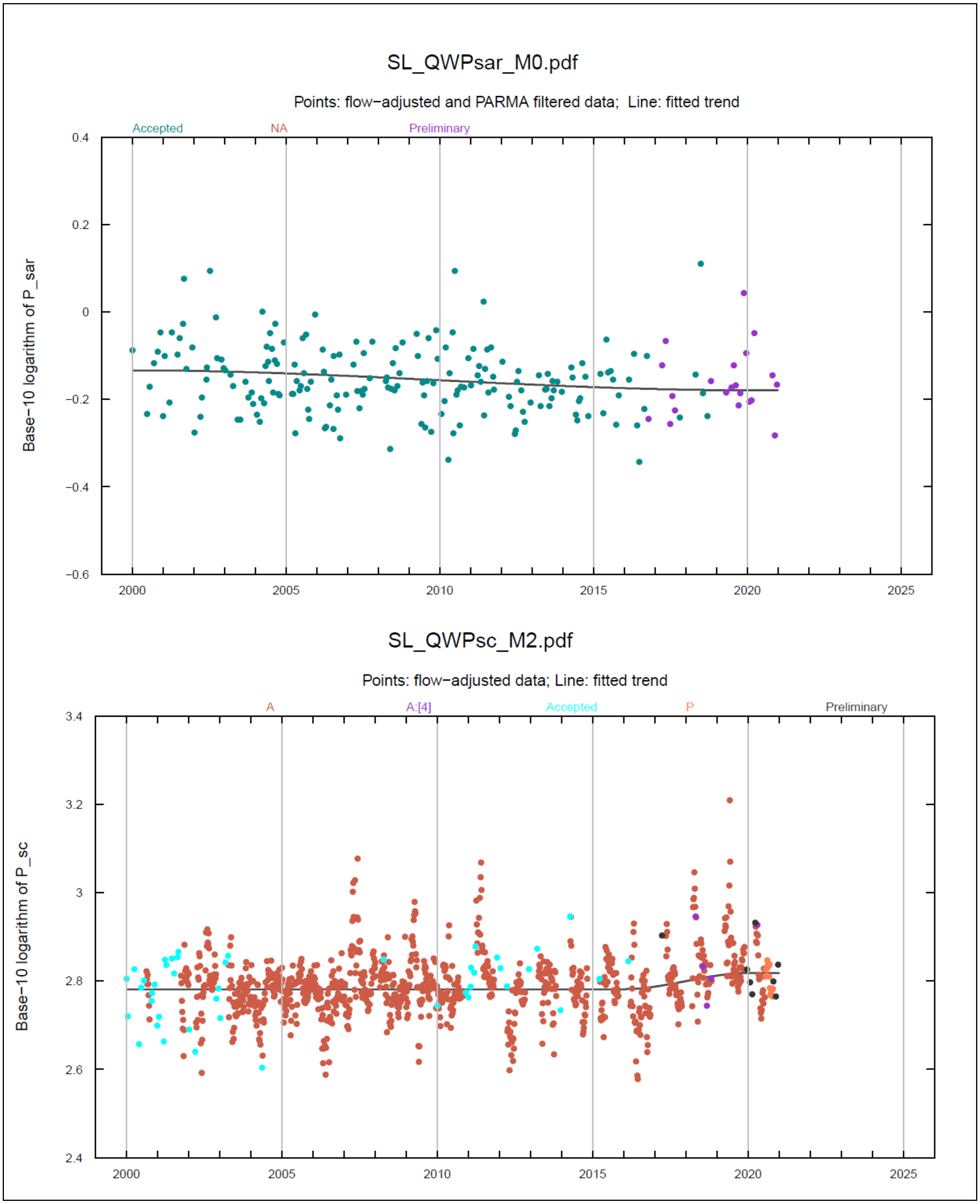

Figure 3. State Line preferred models with fitted trend. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

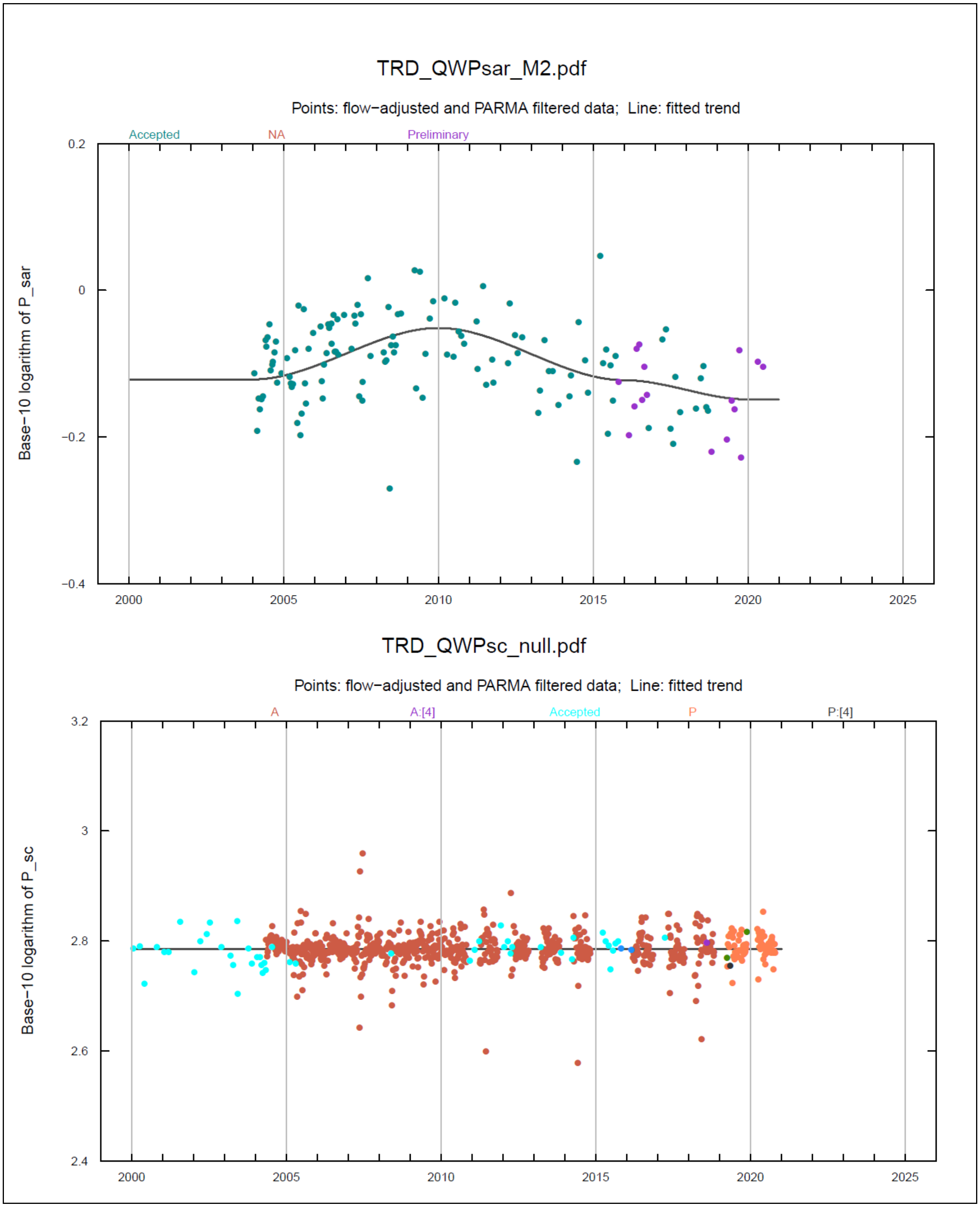

Figure 4. Tongue River Dam preferred models with fitted trend. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

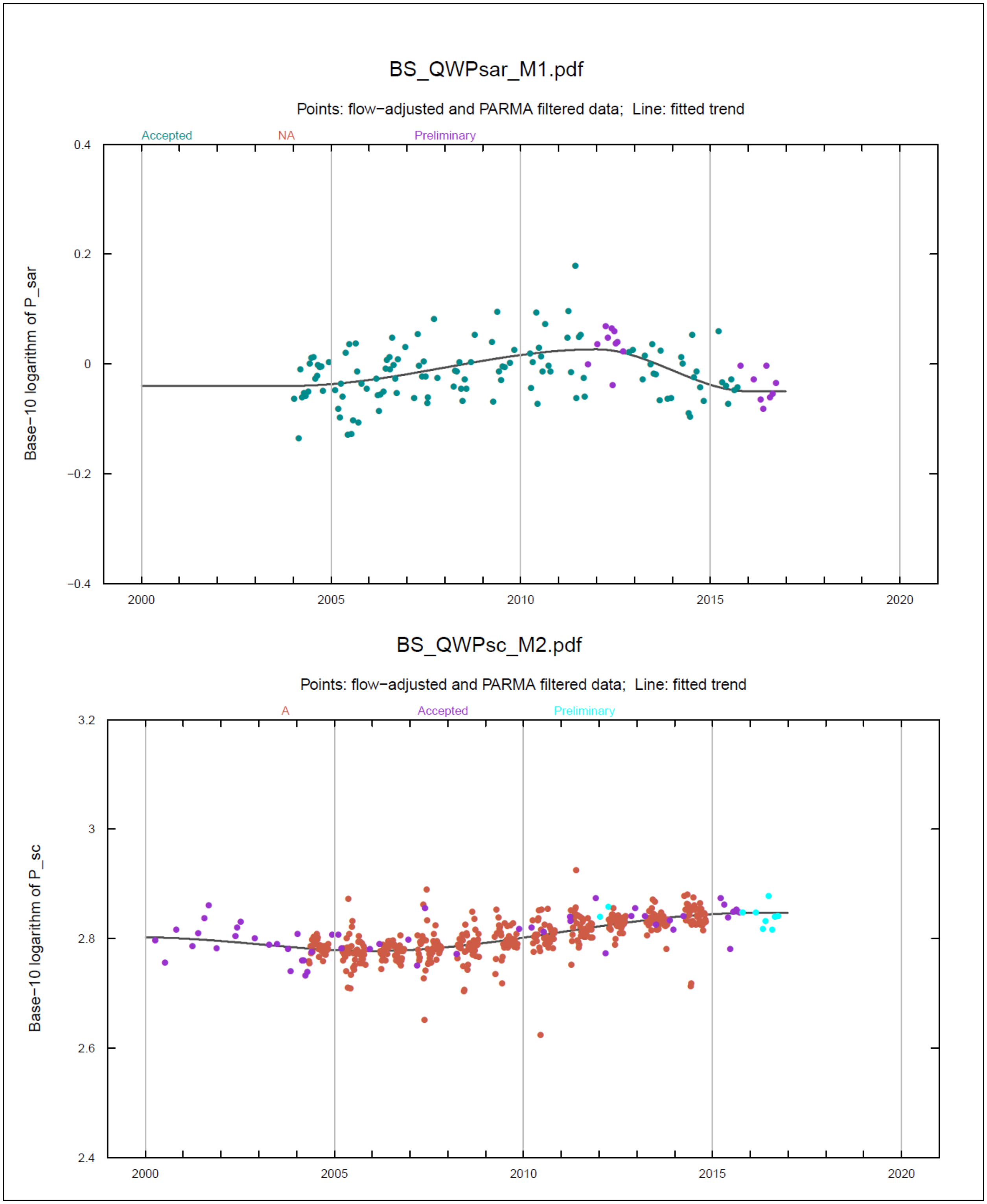

Figure 5. Birney School preferred models with fitted trend. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

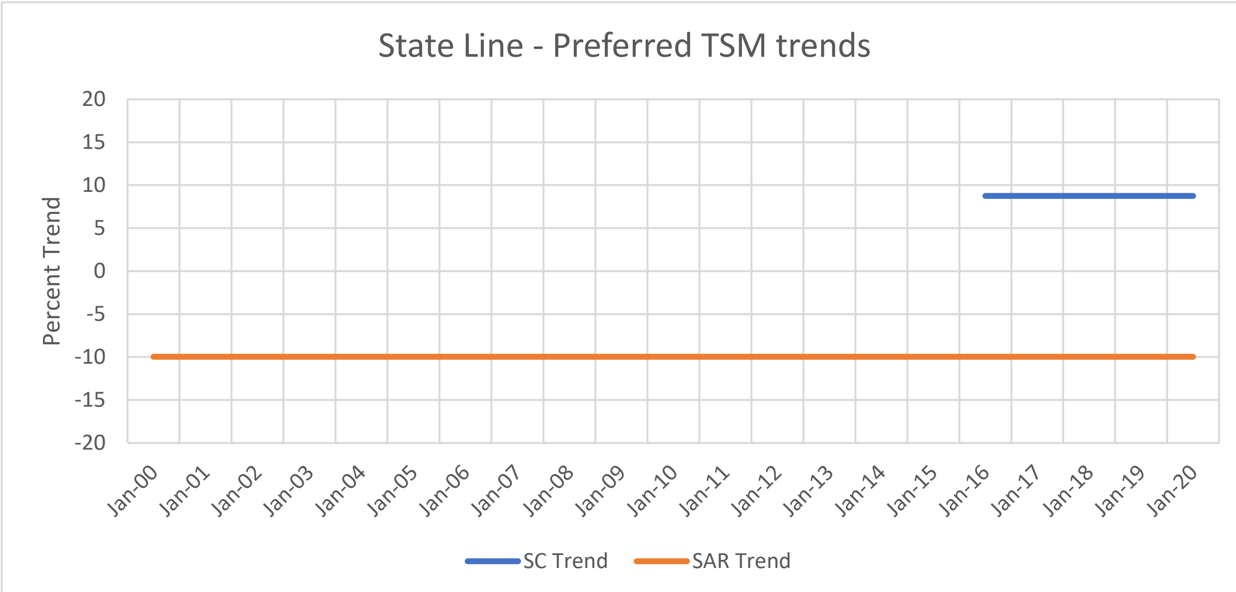

Figure 6. Illustration of magnitude and direction of SC and SAR trends at State Line over time.

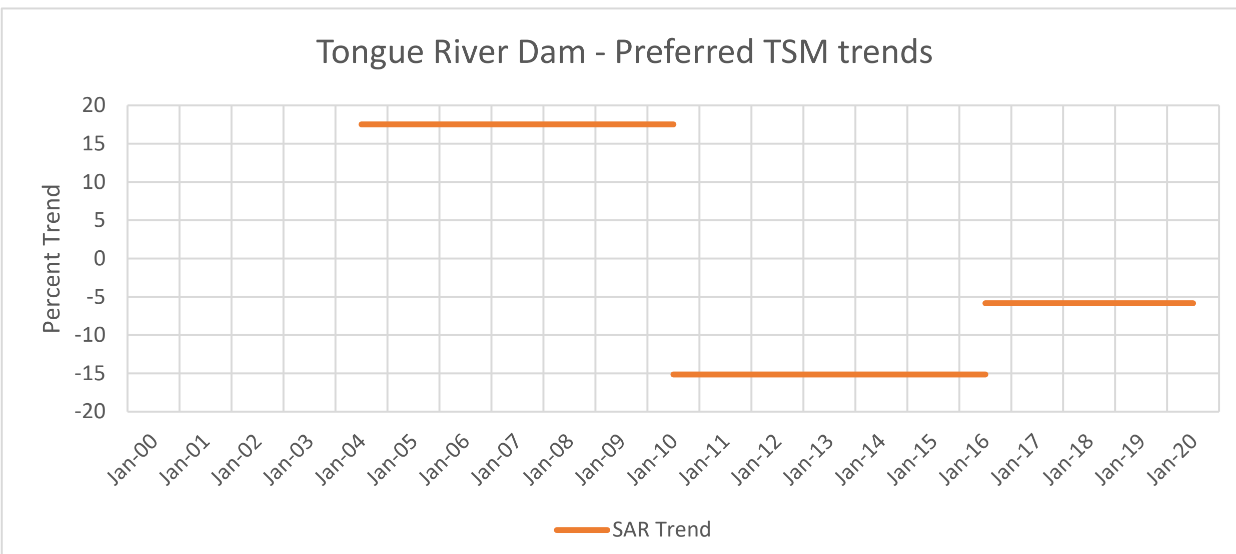

Figure 7. Illustration of magnitude and direction of SAR trend at Tongue River Dam over time. No SC trend was detected at this site.

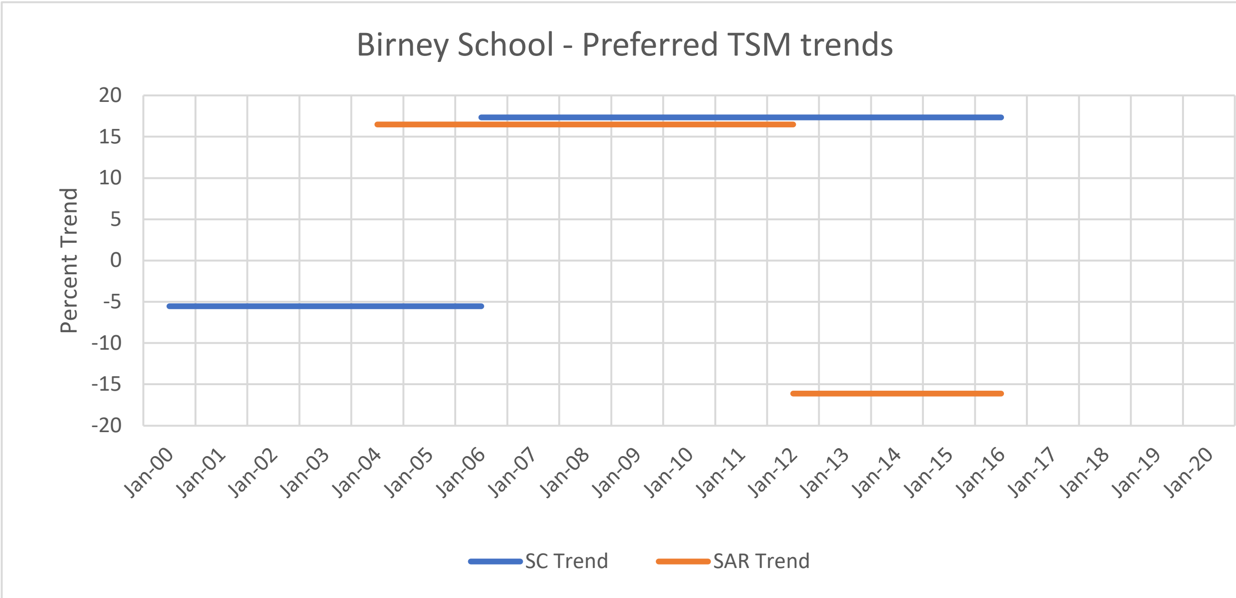

Figure 8. Illustration of magnitude and direction of SC and SAR trends at Birney School over time.

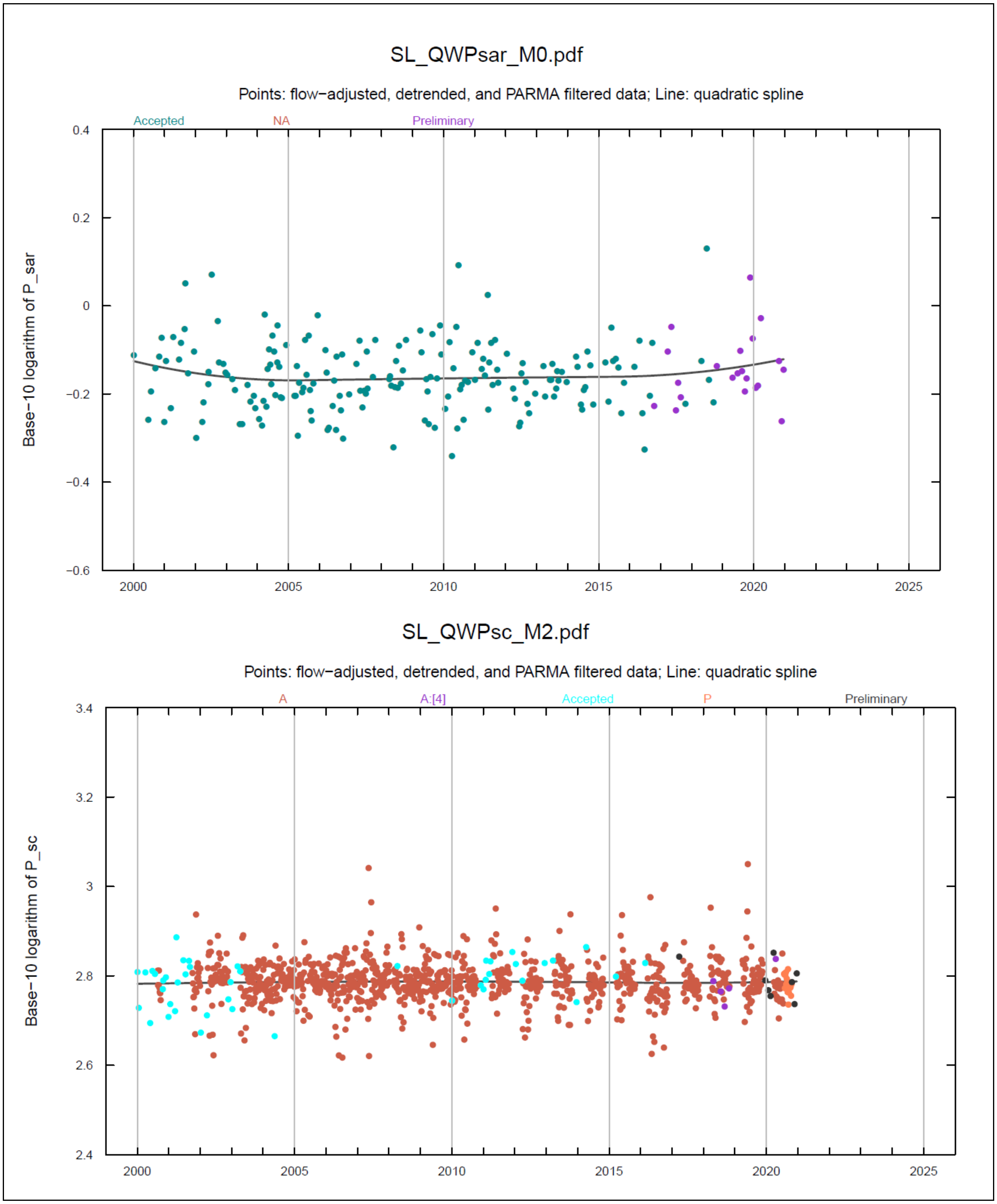

Figure 9. Residual trend in flow-adjusted, detrended, and PARMA filtered data (black line) in State Line preferred models. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

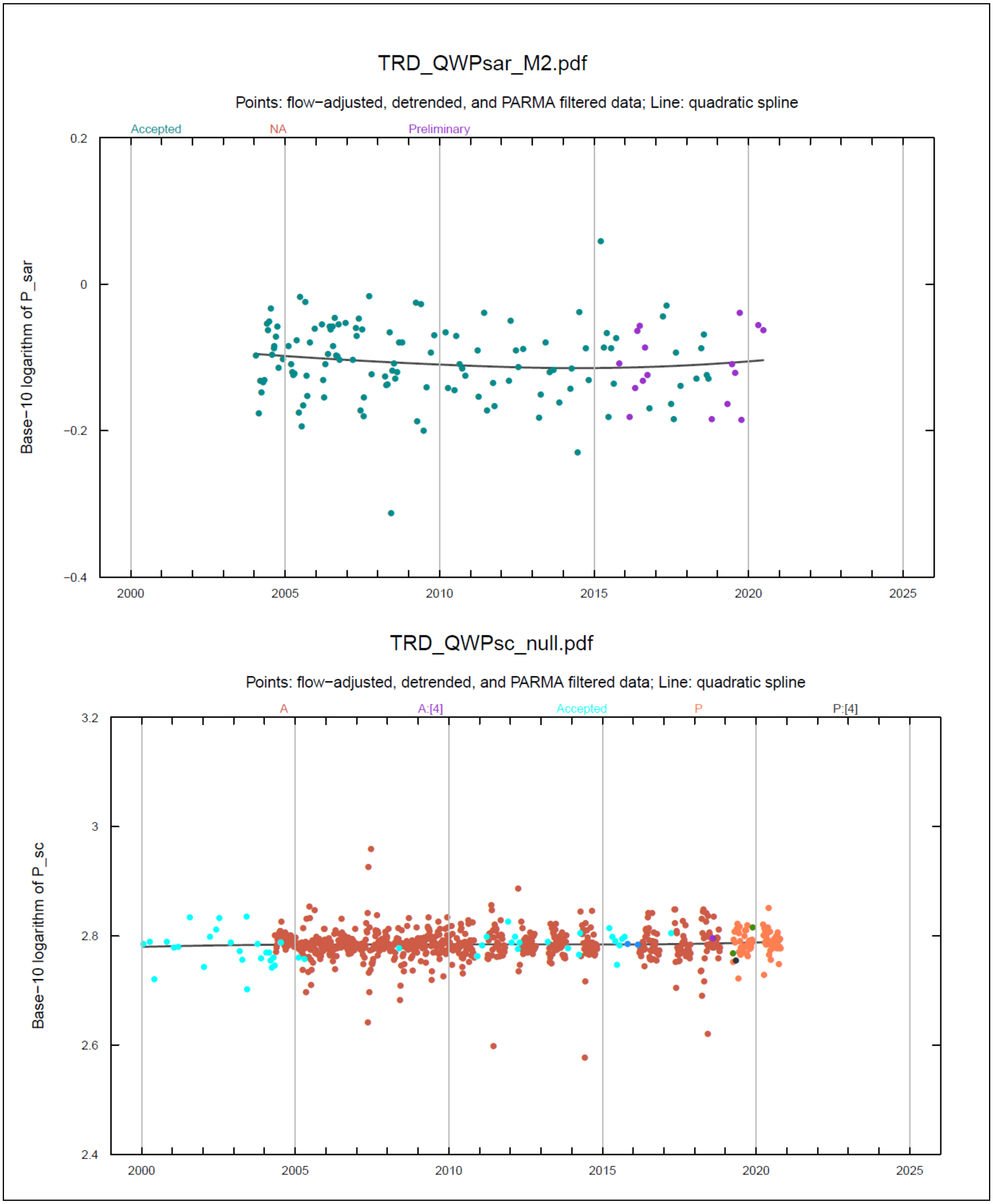

Figure 10. Residual trend in flow-adjusted, detrended, and PARMA filtered data (black line) in Tongue River Dam preferred models. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

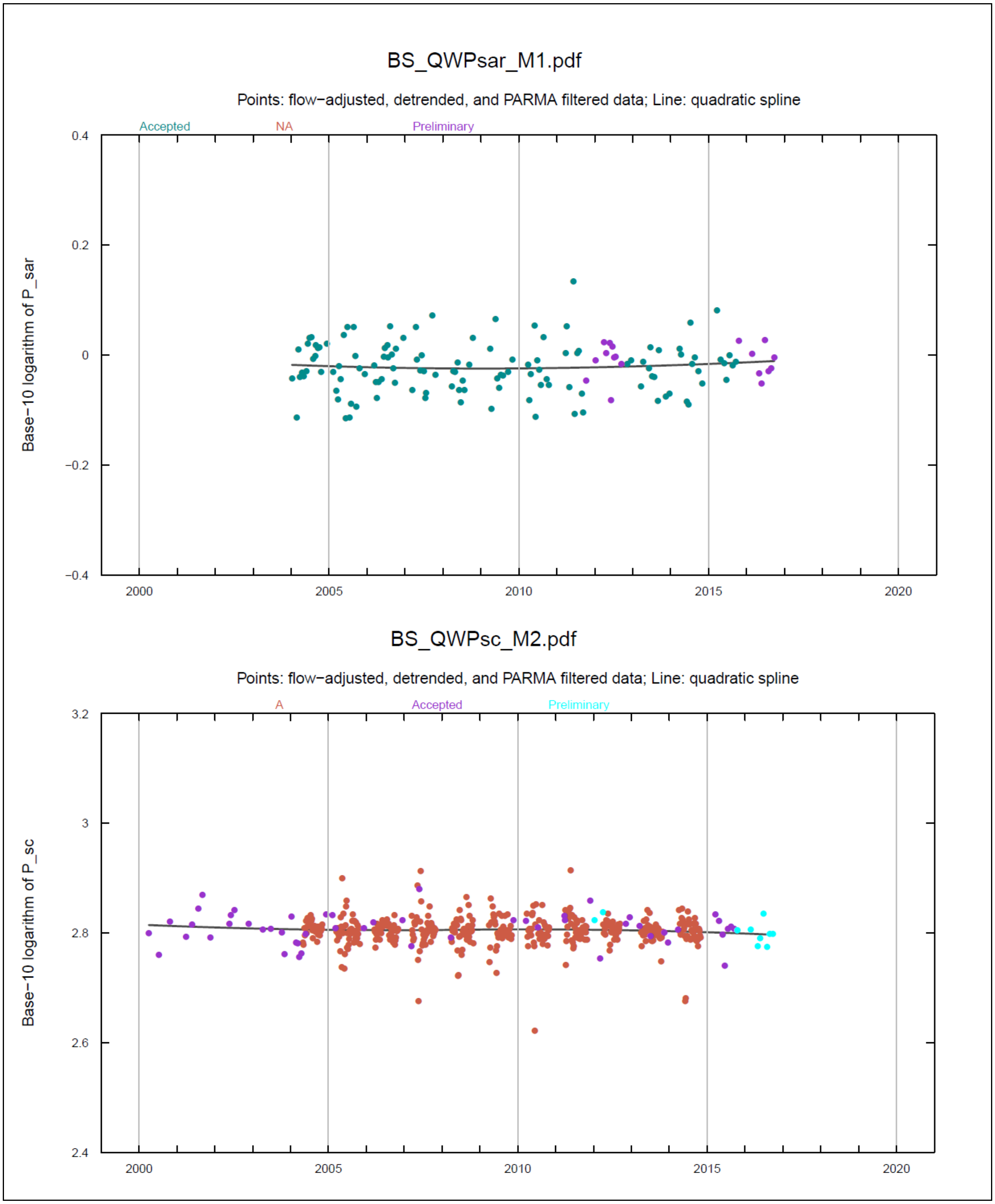

Figure 11. Residual trends in flow-adjusted, detrended, and PARMA filtered data (black line) in Birney School preferred models. P_sar is SAR (top) and P_sc is SC (bottom). Points colored by remark code (see Table 4 for explanation).

3.3 Mann-Kendall Results

Results of Mann-Kendall trend analyses are shown in Table 6. Twelve parameter/site/season combinations were tested, resulting in the detection of five statistically significant ($p<0.05$) monotonic trends (highlighted in yellow). Time-series plots of seasonal medians with Theil-Sen trend lines overlain are provided for each site/parameter/season combination in Appendix E. Mann-Kendall results are discussed in Section 4.2.

Table 6. Mann-Kendall trend analysis results.

Site	Para-meter	Season	n	2-sided p-value	Kendall's S Statistic	Theil-Sen's Slope	Slope Intercept
SL	SAR	Spring	20	0.315	32	0.00233	-3.98
	SAR	Low Water	21	0.0103	-86	-0.00836	17.5
	SC	Spring	21	0.381	30	0.648	-693
	SC	Low Water	21	0.566	20	0.186	228
TRD	SAR	Spring	17	0.343	-24	-0.00495	10.8
	SAR	Low Water	16	0.00139	-72	-0.0119	24.7
	SC	Spring	21	5.66E-04	115	2.39	-4198
	SC	Low Water	19	0.400	-25	-0.279	1172
BS	SAR	Spring	13	0.428	14	0.00797	-15.0
	SAR	Low Water	13	0.0576	-32	-0.00879	18.7
	SC	Spring	17	0.00448	70	6.93	-13272
	SC	Low Water	16	0.00777	60	7.72	-14870
Site: BS Birney School, SL State Line, TRD Tongue River Dam n: count of years represented Theil Sen's slope (trend): in parameter units per year Yellow highlight indicates significance at an alpha level of <0.05							

There were 5 statistically significant season-to-season trends identified out of 12 site/parameter/season combinations analyzed (2-sided p-value <0.05), including:

- Low water SAR at State Line and Tongue River Dam (decreasing)
- Spring SC at both Tongue River Dam and Birney School (increasing)
- Low water SC at Birney School (increasing)

These trends are illustrated on Figure 12.

The two low water SAR trends at State Line and Tongue River Dam are consistent at approximately -0.01 SAR units per year. Additionally, the low water SAR trend at Birney School is very close to being significant (p=0.0576) and also exhibits a trend of about -0.01 SAR units per year. Spring SC trends at Tongue River Dam and Birney School are both positive, at 2.39

and 6.93 µS/cm per year, respectively. The low water SC trend at Birney School is 7.72 µS/cm per year, similar in magnitude and direction to the site's spring SC trend.

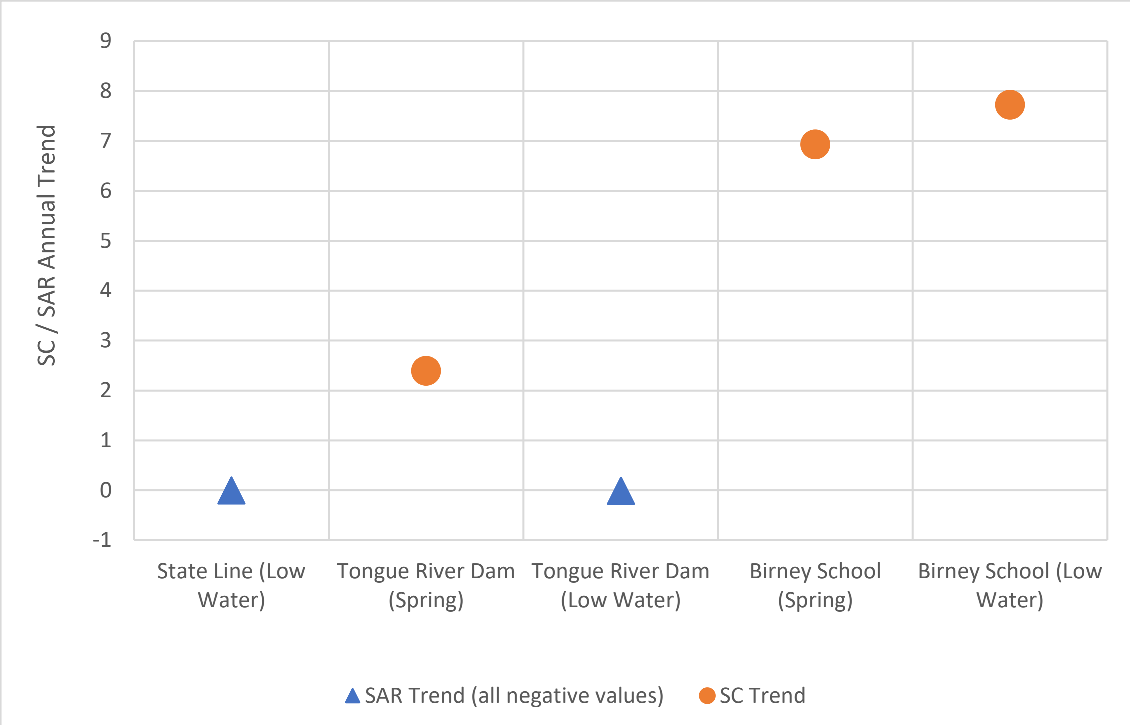

Figure 12. Summary of statistically significant ($p<0.05$) Mann-Kendall trends during low water and spring seasons.

4.0 Discussion

This section presents a discussion of the TSM and Mann-Kendall trend analysis results.

4.1 TSM

The basis for the selection of the preferred TSM models is presented in this section, followed by a discussion of the SAR and SC trends identified by the preferred models.

Similar to work by Sando et al. (2014; Section 1.2), this TSM analysis identified few trends that meet a significance level (alpha) of 0.01. However, in following the Vecchia and Nustad (2020) approach for identification of preferred models, useful inferences about water quality trends may still be drawn from the analysis, as described below.

4.1.1 Preferred Model Selection

Rationale for the selection of each preferred model (Table 5) is discussed below. Note that all preferred models do not necessarily have individual trend or GLR p-values that are statistically significant at an alpha level of 0.01 or less. Rather, in many cases, the preferred model is simply the model that best fits the data compared to the other tested models based on quantitative and qualitative evaluation of the TSM results. Thus, interpretation must be made with caution.

- State Line SAR M0 Of the different models tested, this model has the lowest GLR p-value compared to the null model. Furthermore, neither of the more complex models tested were preferred over this model. The residual trend (Figure 9) is similar to that of the null model (Appendix D), however, a reasonably low p-value (~0.03) for the trend suggests this model is close to capturing a significant trend and should be preferred over the null (no trend) model.
- State Line SC M2 This model is also nearly significant (p=0.02) and has the lowest GLR p-value (0.0096) when compared to the null model. The more complex model M1 is not preferred over this model, and there are no apparent residual trends with this model (Figure 9), suggesting it fits the observed data well.
- Tongue River Dam SAR M2 This model has a very small GLR p-value versus the null model of 0.004, a reasonably low GLR p-value of 0.03 when compared against simpler model M1, and the smallest apparent residual trend compared to the other tested models (Figure 4, Appendix D).
- Tongue River Dam SC Null Non-null tested models had trend p-values and GLR p-values compared to the null model of 0.07 to 0.44, none of which are suggestive of a statistically significant trend being detected by these models. Therefore, the null model, which has a barely perceptible residual trend, is selected as the preferred model.
- Birney School SAR M1 Residual trends for the null model, this model, and model M0 are all similar (Figure 11; Appendix D). However, this model has a much lower GLR p-value (0.037) when tested against the null model compared to M0 (0.729). This model also has a GLR p-value of 0.0108 compared to the simpler M0 model suggesting it is preferable. Additionally, piecewise trend p-values are relatively low, ranging from 0.01 to 0.04.
- Birney School SC M2 This model has a very low GLR p-value when compared to the null model (1.98×10^{-4}), a relatively low GLR value when compared to simpler model M0 (0.015), and the least apparent residual trend of any Birney School SC models.

4.1.2 TSM SAR Trends

Tongue River Dam and Birney School, the two downstream sites (Figure 1), exhibit a similar pattern whereby SAR values increased from the early 2000s to 2010-2012, and then followed a decreasing trend from the 2010s on. The increases and decreases are similar in magnitude and timing, with the trend inflection points occurring around or slightly after the time that CBM activity began waning in the area. The SAR trend at the State Line site, in contrast, appears to have been decreasing both during and following the period of peak CBM activity in the area.

4.1.3 TSM SC Trends

No trend was identified for SC at the Tongue River Dam site. Similarly, at the State Line site, there is no trend evident from 2000 to 2016, which encompasses both active- and post-CBM periods in the area. The preferred State Line SC model did, however, identify an upward trend from 2016 to 2020.

At Birney School, the SC trend was decreasing modestly (5.6 percent) during the early part of the analysis period (2000 to 2006) when CBM activity was high and only began to increase in 2006, continuing to do so through the end of the period or record. This increasing trend spans both active- and post-CBM time in the area. Overall, these preferred SC trend models do not appear to directly correspond to the timing of the area's peak CBM or post CBM development periods. However, they are not necessarily inconsistent if a time-lag dynamic exists between CBM activity and impacts to SC values (for instance due to seepage from CBM-discharge ponds).

4.1.4 Residual Trends

Notes regarding possible residual trends following TSM model application are included in Table 5. These observations are based on visual evaluation of TSM flow-adjusted, PARMA filtered, and detrended data points as shown on Figure 9 through Figure 11 and in Appendix D for non-preferred models. Residual trends for all the preferred models are minimal, although they generally appear to be slightly more prominent in the SAR models compared to the SC models. The presence of these residual trends suggests in some cases that an improved model fit may be attainable by testing additional models. Such models may include additional or reconfigured piecewise monotonic trends, step trends, or potential ancillary trend variables.

4.2 Mann-Kendall

Mann-Kendall trends are generally consistent with those determined using the TSM although a few discrepancies exist. Some variation between the Mann-Kendall and TSM trend results is not unexpected because the Mann-Kendall tests were run on a subset of seasonal data in order to look only for trends between certain seasons of the year as opposed to the entire period of record supplied to the TSM. Furthermore, the Mann-Kendall's ability to test only for a single monotonic trend means it is inherently less capable of handling complex piecewise trends than the TSM. Limitations notwithstanding, the Mann-Kendall results are more often than not in general agreement with the TSM results and indicate that several statistically significant year-over-year trends are present within the high water and low water seasons that were evaluated.

Low water season SAR values at State Line and Tongue River Dam have a significant, slightly decreasing Mann-Kendall trend over the period of record. Birney School has a nearly significant decreasing SAR trend of similar magnitude during this season as well (p=0.06). These decreasing trends contrast with the increasing trends detected by the TSM prior to 2010–2012 at Tongue River Dam and Birney School. Notably, visual examination of the Mann-Kendall plots for Tongue River Dam and Birney School low water SAR (Appendix E) does suggest an increase in SAR values before 2010 followed by a decrease, which is consistent with the TSM results. However, this subtlety cannot be captured by the Mann-Kendall analysis or Theil-Sen trend lines due to the monotonic limitation of these procedures; instead, the most dominant overarching monotonic trend (downward in this case) is detected by Mann-Kendall. Therefore, in this situation, the TSM model should supplant the Mann-Kendall due to its ability to model the apparent piecewise monotonic trends within the data.

In contrast, the Mann-Kendall test detected a significant decreasing low-water SAR trend at the State Line site, which is consistent with the preferred TSM SAR trend for this site. Thus, in this case, where only a single monotonic trend is evident, the TSM and Mann-Kendall analysis are in general agreement.

Additionally, the Mann-Kendall test detected three small but statistically significant increasing SC trends, two during the spring season (Tongue River Dam and Birney School) and one during the low water season (Birney School). The detection of significant upward Mann-Kendall trends in SC at Birney School is generally consistent with the predominant trend direction in the preferred TSM model for Birney School.

However, the significant Mann-Kendall trend for SC at Tongue River Dam during the spring season does not agree with the no trend preferred TSM model for this site. This discrepancy may be related to the period of record versus seasonal only data sets evaluated by the TSM and Mann-Kendall test, respectively. In this case, the Mann-Kendall test, being focused only on seasonal data, may have been better able to detect a subtle SC trend, especially if it is more prominent between spring seasons.

5.0 Summary and Conclusions

Preferred TSM trend models were selected following the approach of Vecchia and Nustad (2020), which involves comparison of different potential trend models using the GLR test statistic. Few trends were ultimately detected by the TSM analysis at a significance level of 0.01. However, in most cases, the preferred trend models selected reasonably account for observed changes (or lack thereof) in the datasets over time and are thus a useful tool for intrepreting water quality changes on the Tongue River over time. The existence of modest residual trends following application of some of the preferred models suggests that in these cases, further model testing could result in improved model fits.

Preferred TSM models for SAR at Birney School and Tongue River Dam both consisted of two-piecewise monotonic trends with one increasing from the early 2000s to 2010-2012, followed by a decreasing trend from the 2010s on. This pattern is generally consistent with increasing SAR during the period of active CBM activity and decreasing SAR during the post-CBM period. The preferred SAR trend for the State Line site is distinct from these trends, consisting of a single decreasing trend from 2000 to 2020 that shows no apparent correlation with changes in CBM activity.

Preferred TSM SC trends do not appear to directly correspond to the timing of the area's peak CBM or post CBM development periods. The no trend (null) model was the preferred model for the Tongue River Dam site; the State Line site exhibits no trend from 2000 to 2016 but shows an increasing trend from 2016 to 2020. Birney School exhibits a slight decreasing SC trend from 2000 to 2006 when CBM activity was high but an increase from 2006 through 2016. The latter part of this increasing period is well after the end of peak-CBM. Overall, TSM SC trends do not appear to correspond directly with changes in CBM activity, though they are not necessarily inconsistent with a CBM impact to SC if a time-lag dynamic exists between CBM activity and impacts to SC values.

The Mann-Kendall analysis of seasonal data identified a total of 5 significant trends out of 12 site/parameter/season combinations tested. The significant trends included decreasing SAR trends during the low water season at State Line and Tongue River Dam and increasing SC trends at Tongue River Dam (spring) and Birney School (spring and baseflow).

Mann-Kendall trend analysis on data from specific seasons is generally consistent with TSM results in cases when the Mann-Kendall detected a statistically significant trend. However, a few discrepancies exist between the significant Mann-Kendall trends and preferred TSM trend models. These appear to be attributable to the Mann-Kendall's single monotonic trend limitation or the seasonal-only dataset evaluated with the Mann-Kendall test. Overall, the significant Mann-Kendal seasonal trends tend to support the TSM preferred model results, though the TSM results are generally considered most reliable due to the large amount of data utilized and robustness of the TSM method.

6.0 Recommendations for Future Work

The preferred TSM models presented in this report provide satisfactory fits to observed data and are considered a useful tool for intrepreting water quality changes on the Tongue River over time. However, as noted, small residual trends appear to be present in some instances, which suggests that the testing and comparison of additional time series models could further refine the trend fits.

Additionally, future work could leverage the TSM's capability to include user-defined ancillary trend variables into models. Such ancillary variables can be used to more directly establish attribution of changes in water quality over time. For instance, CBM-produced water discharge volumes over time could be incorporated into a model as an ancillary variable to more directly test the relationship between CBM production and Tongue River water quality. The effects of agricultural practices and/or coal mining activity on Tongue River water quality could also potentially be tested using an ancillary variable. Research would be required to identify suitable variables to represent these exogenous factors, but possibilities include irrigation application volumes and crop or coal production records.

7.0 Works Cited

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Appendix A – Example calculation of generalized likelihood ratio

Appendix A

Generalized Likelihood Ratio (GLR) Test Statistic

The following provides the equations and an example calculation for the GLR test statistic adapted directly from Vecchia and Nustad (2020 p. 6 and 28-29). Refer to this paper for additional information regarding the GLR test statistic. No R functions exist for direct calculation of the GLR test statistic, so hand calculation is required. R (or a lookup table) may be used at the end of the process to look up the chi-squared distribution function of the GLR test statistic for determination of the p-value.

GLR test statistic (GLR)

$$G_{1\sim2} = \left(-2\ln\left[LIK1_{J-K}\right]\right) - \left(-2\ln\left[[LIK2_{J}\right]\right)$$

$$P_{1\sim2} = Prob[X_K > G_{1\sim2}]$$

Where:

$G_{1\sim2}$	is the GLR statistic for testing if models 1 and 2 are equivalent
$LIK1_{J-K}$	is the maximum of the likelihood function for model 1
$J-K$	is the number of trend coefficients for model 1
$LIK2_{J}$	is the maximum of the likelihood function for model 2
J	is the number of grend coefficients for model 2
$P_{1\sim2}$	is the p-value
X_K	is the chi-squared random variable with K degrees of freedom

Example

Model 1 (Null model):

-2lnLik = -478.35

Degrees of freedom (df): 0

Model 2 (2 trend model):

-2lnLik = -483.33

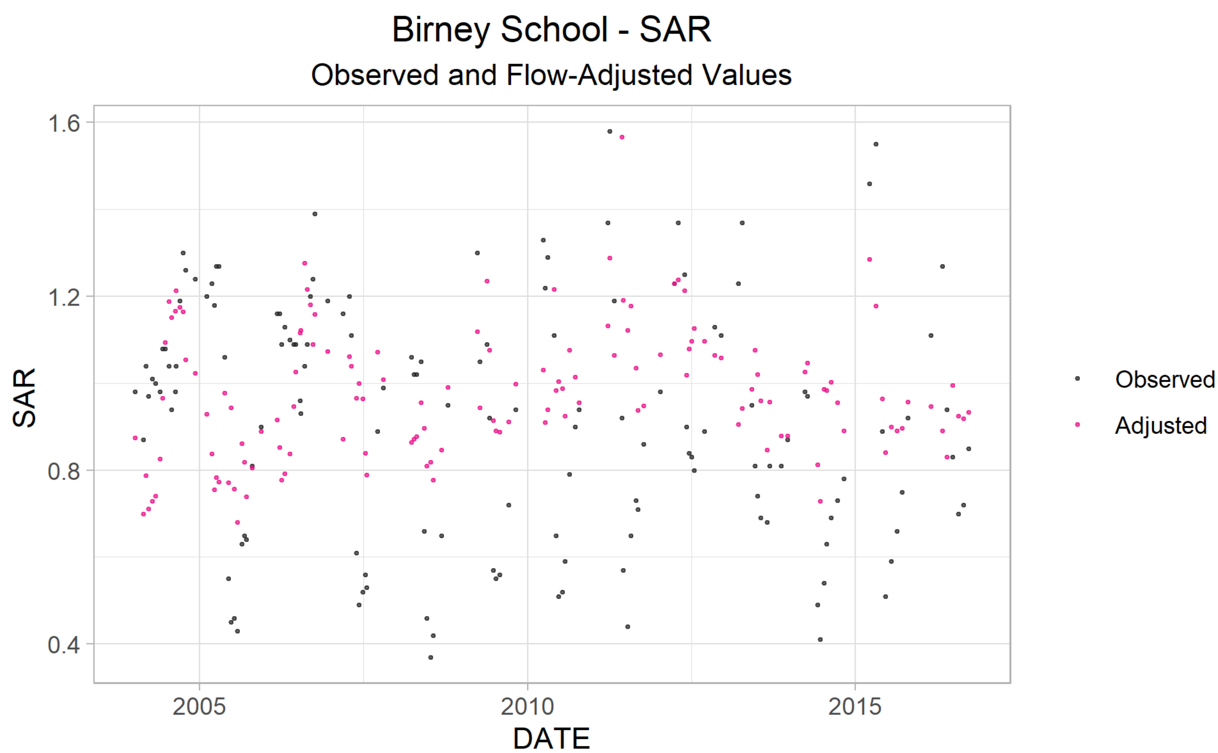
Degrees of freedom: 2

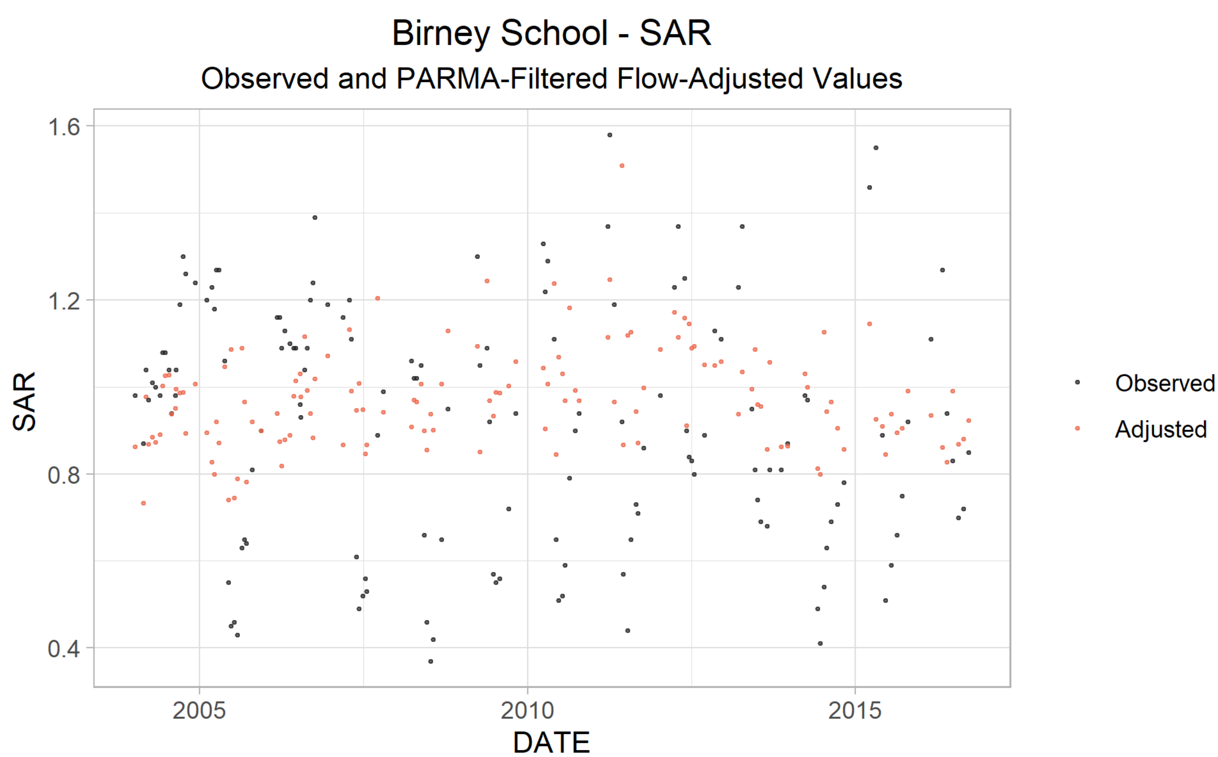
$$G_{1\sim2} = (-478.35) - (-483.33) = 4.98$$

$$P_{1\sim2} = 1 - pchisq(4.98, df = 2) = 0.083 \text{ *}$$

*the *pchisq()* function in R or a lookup table may be used to determine the chi-squared distribution function

Appendix B – Plots showing TSM flow adjustment and PARMA filtering





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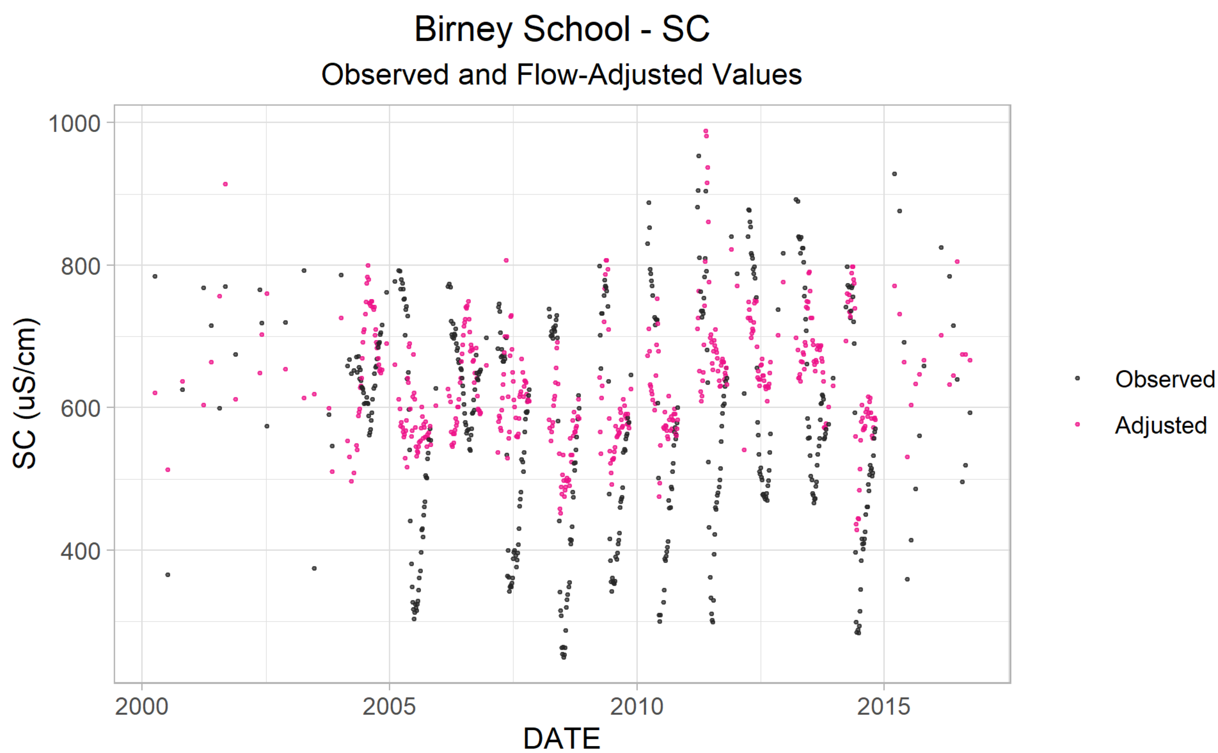
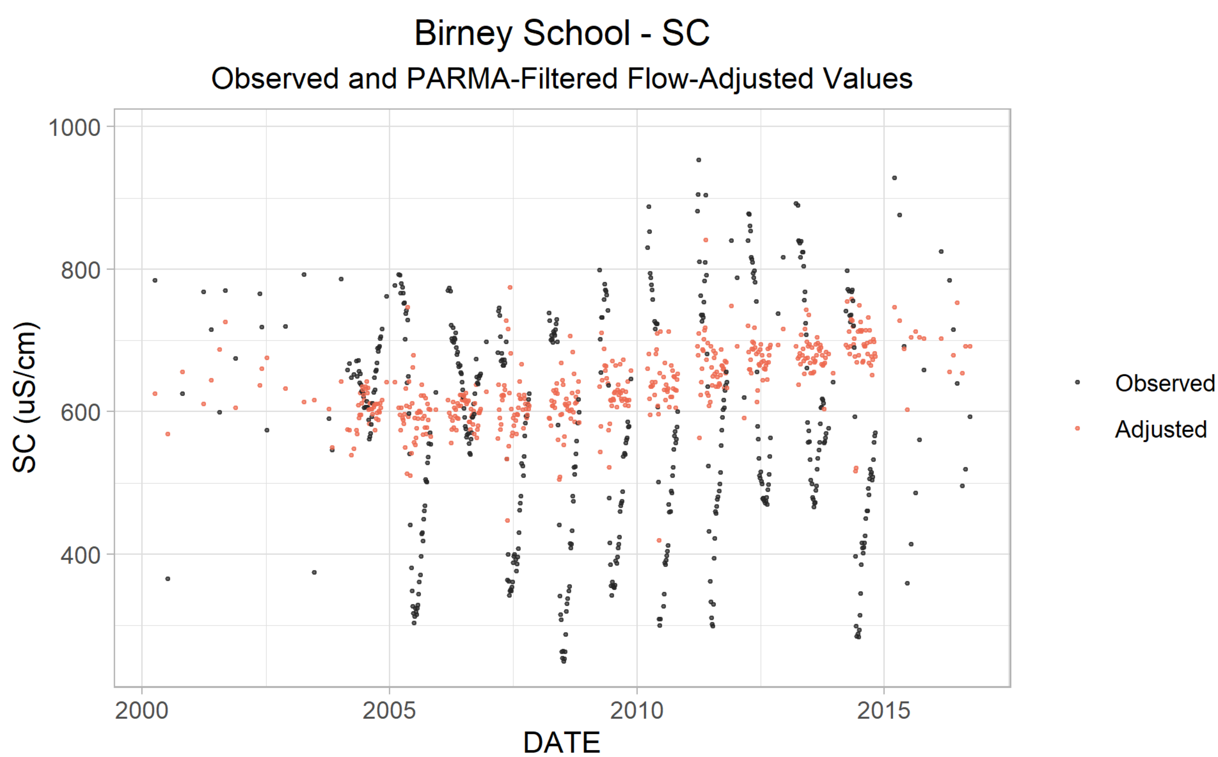
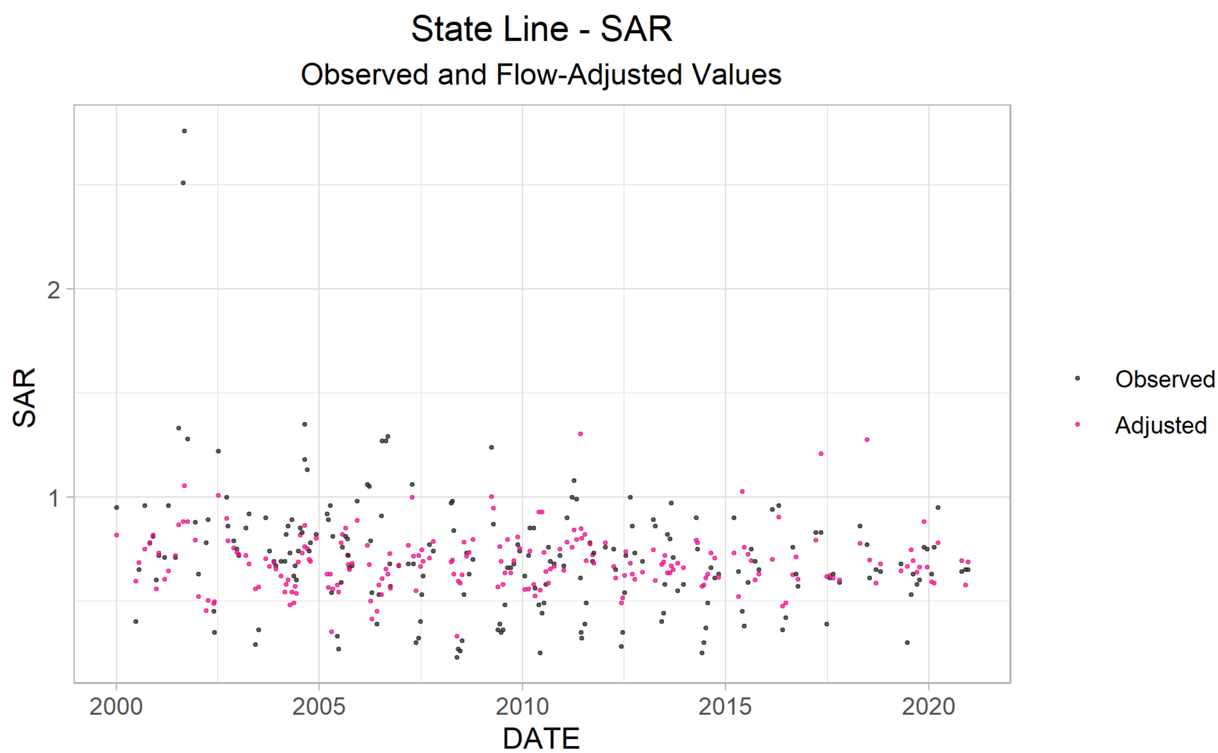
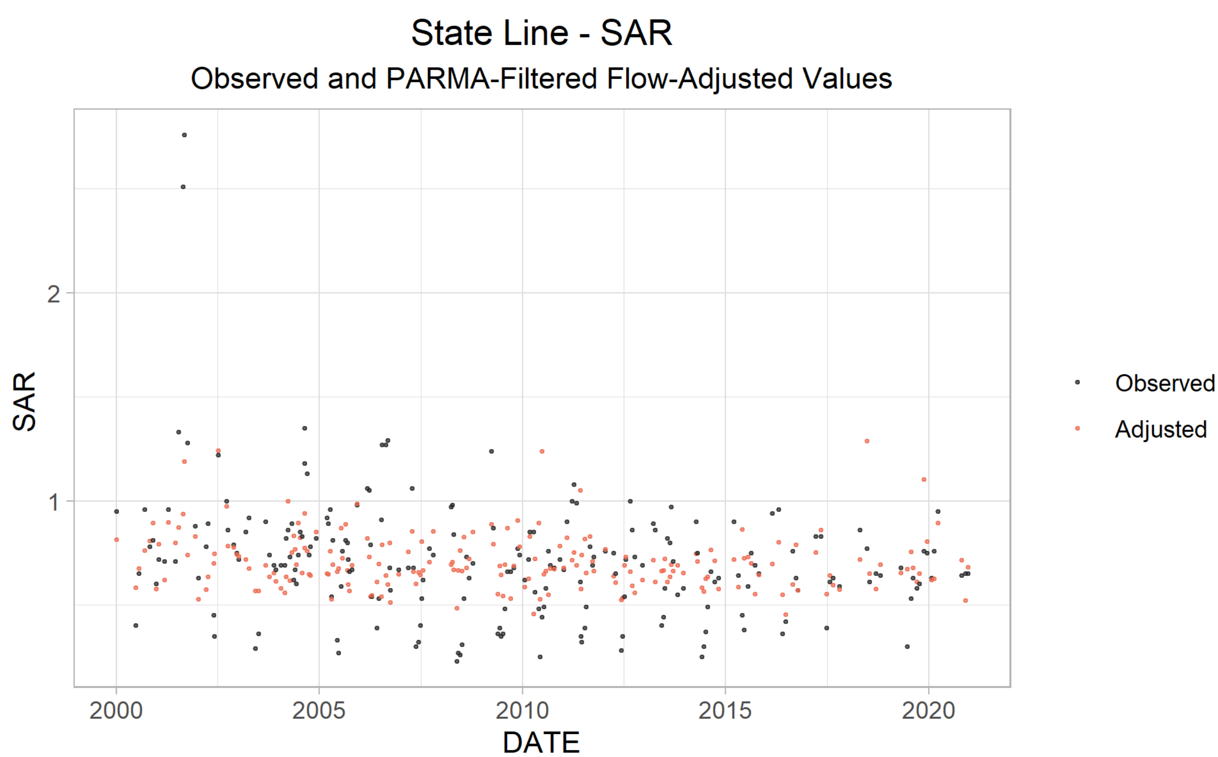


Birney School - SC
Observed and Flow-Adjusted Values
SC (uS/cm)
1000
800
600
400
2000
2005
2010
2015
DATE
Observed
Adjusted

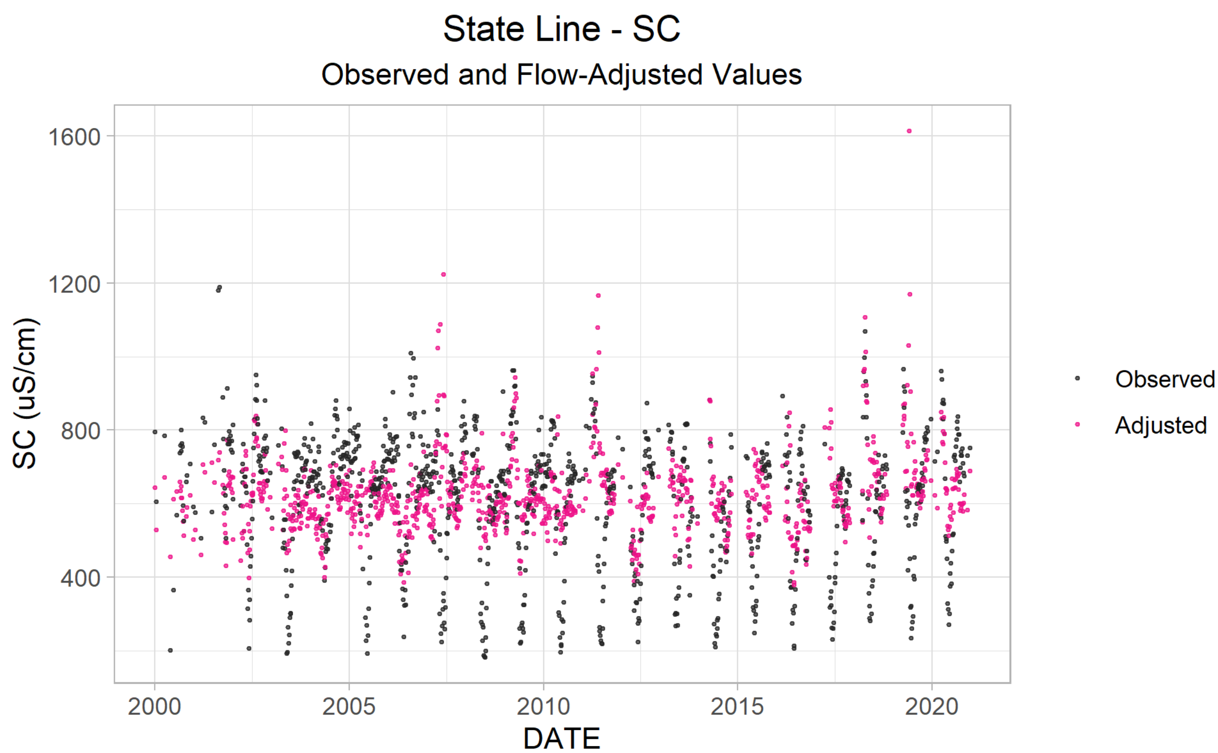


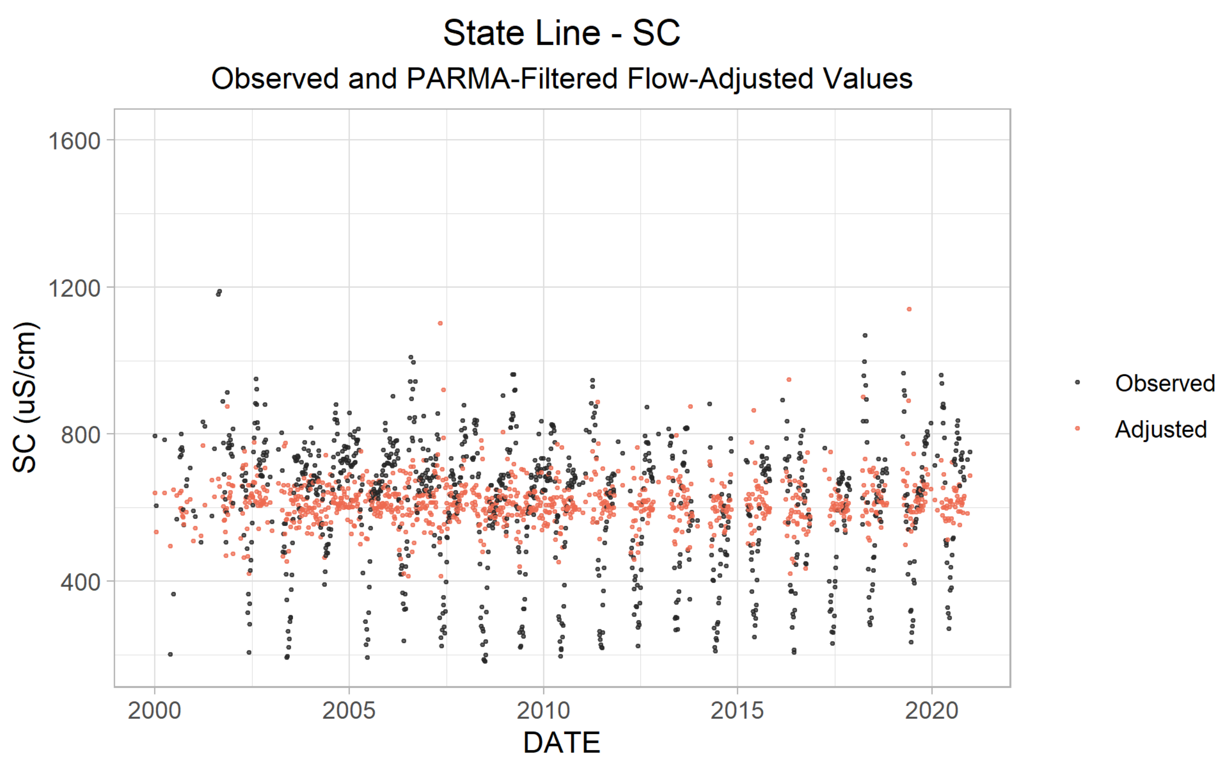
Birney School - SC
Observed and PARMA-Filtered Flow-Adjusted Values
SC (uS/cm)
1000
800
600
400
2000
2005
2010
2015
DATE
Observed
Adjusted



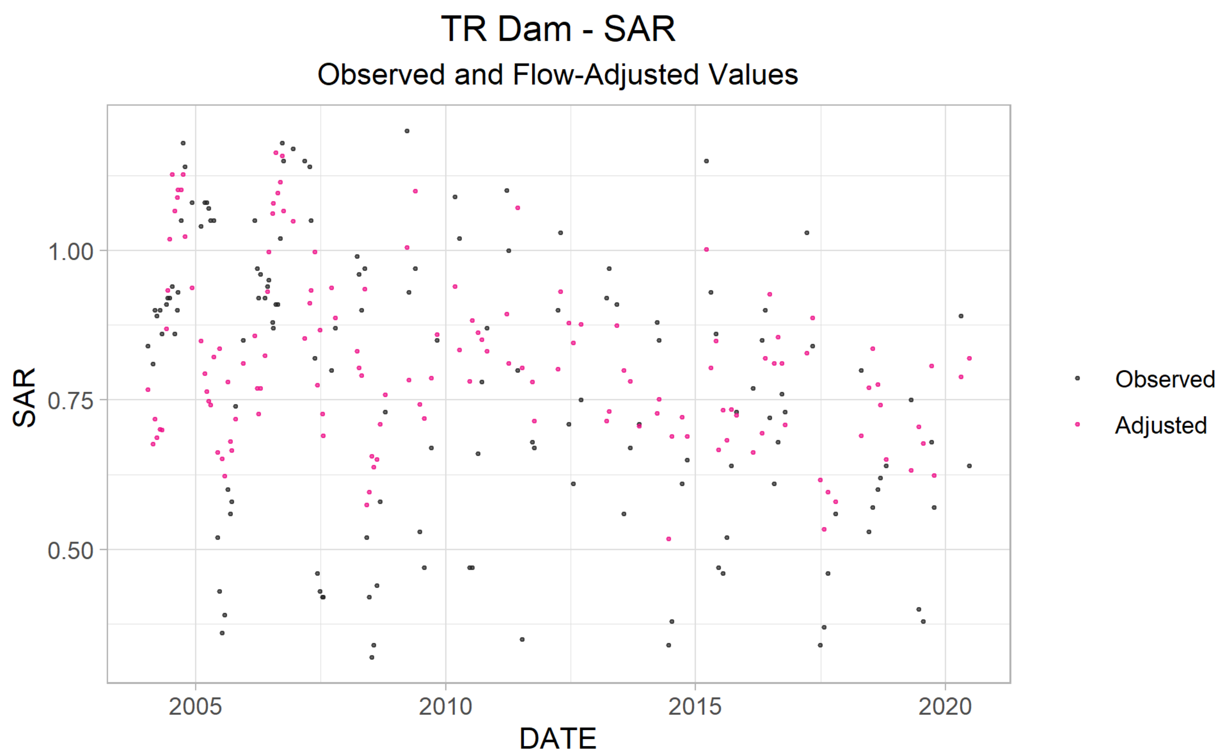


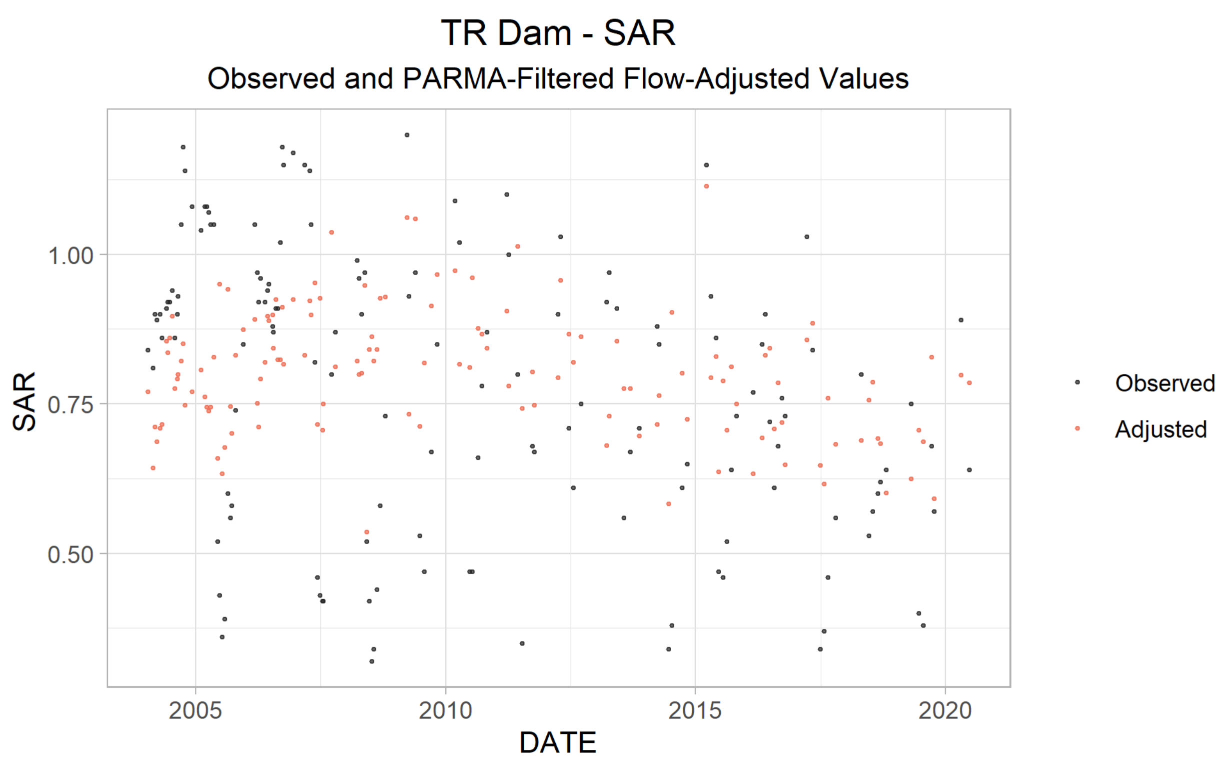
HydroSolutions



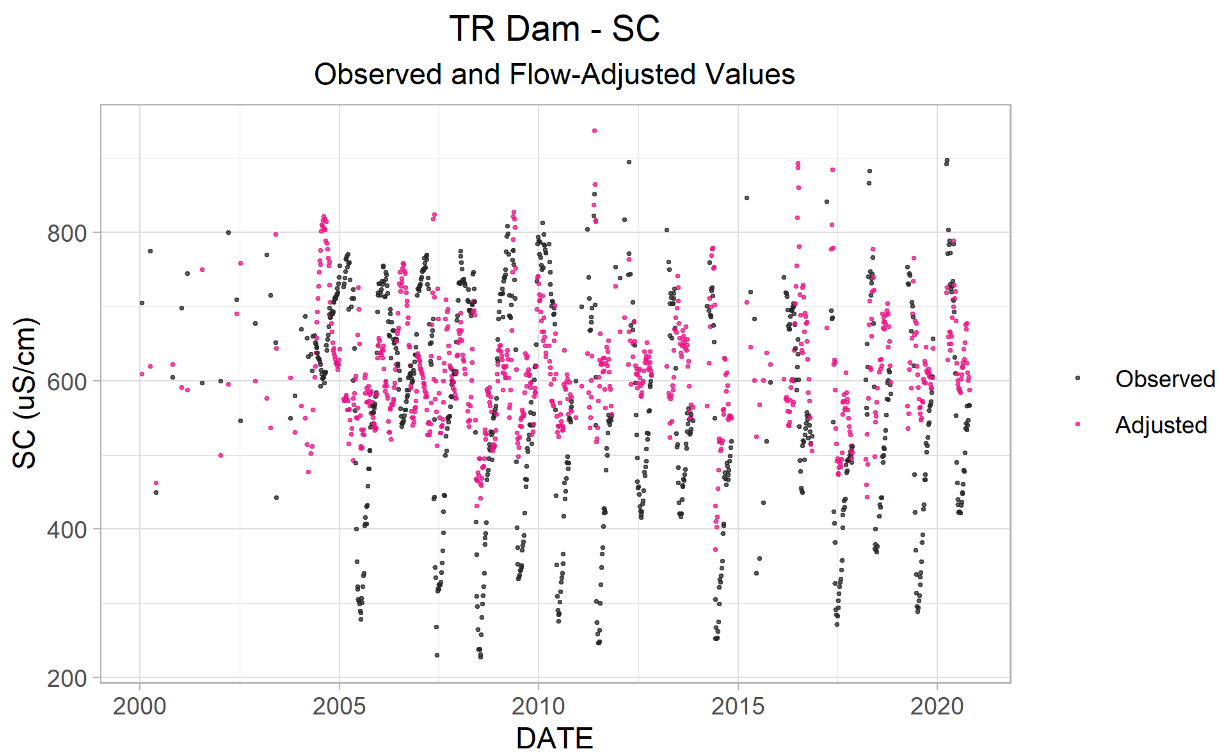


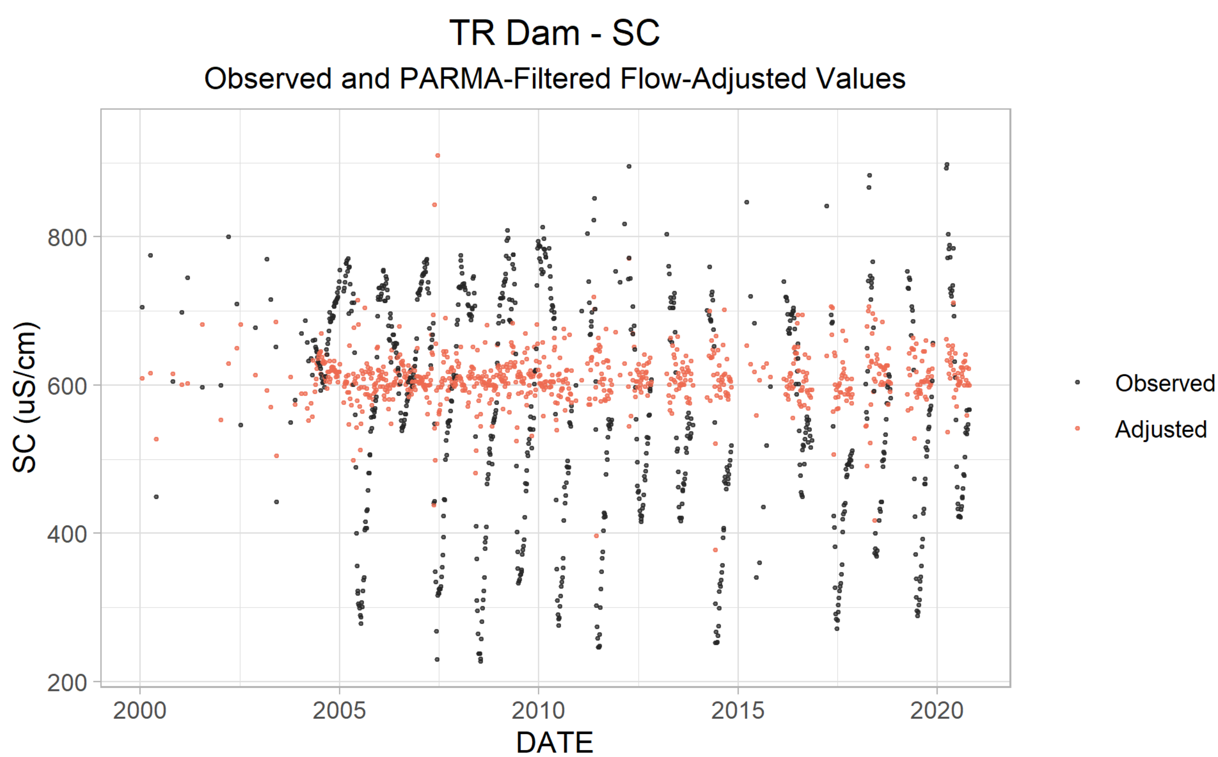
HydroSolutions





HydroSolutions


TR Dam - SC
Observed and Flow-Adjusted Values
SC (uS/cm)
200
400
600
800
2000
2005
2010
2015
2020
DATE
Observed
Adjusted


TR Dam - SC
Observed and PARMA-Filtered Flow-Adjusted Values
SC (uS/cm)
200
400
600
800
2000
2005
2010
2015
2020
DATE
Observed
Adjusted

Appendix C – Time Series Model Results

Note: Preferred models highlighted in yellow.

Site/ Parameter[a]	Function Call[b]	Run suffix[c]	Monotonic Trend(s)[d]	Trend (percent)[e]	Trend p-value[f]	GLR_{NULL}[g]	Compa-rison[h]	GLR_{1-2}[i]	Residual trends[k]
SL (SAR)	`runQWmodel(SL_QWP, "sar", runname="_null")`	_null	-	-	-	-	-	-	2000-2004 (-); 2018-2020 (+)
	`runQWmodel(SL_QWP, "sar", monxx=c("2000x2020"), exlev=c(0.8, 1.2, 1.6), runname="_M0")`	_M0	2000x2020	-9.97	0.0316	0.0313	-	-	flat '05-'15 but downward trend at start and upward trend at end
	`runQWmodel(SL_QWP, "sar", monxx=c("2000x2010", "2010x2020"), exlev=c(0.8, 1.2, 1.6), runname="_M1")`	_M1	2000x2010	-11.1	0.0291	0.0587	M0 – M1	0.310	slight (-) 2000-2004; (+) 2018-2020
			2010x2020	-2.84	0.459				
	`runQWmodel(SL_QWP, "sar", monxx=c("2000x2005", "2005x2018", "2018x2020"), exlev=c(0.8, 1.2, 1.6), runname="_M2")`	_M2	2000x2005	-10.75	0.590	1	M0 – M2	1	slight (+) 2000-2018; slight (-) 2018-2020
			2005x2018	-9.57	0.0391				
			2018x2020	6.1	0.295				
	`runQWmodel(SL_QWP, "sar", monxx=c("2000x2004", "2004x2020"), exlev=c(0.8, 1.2, 1.6), runname="_M3")`	_M3	2000x2004	-10.42	0.0841	1	-	-	slight (+) 2000-2018; (+) 2018-2020
			2004x2020	-8.04	0.0742				
SL (SC)	`runQWmodel(SL_QWP, "sc", exlev=c(500,750,1000), runname="_null")`	_null	-	-	-	-	-	-	Very slight (+) 2000-2020
	`runQWmodel(SL_QWP, "sc", monxx=c("2000x2020"), exlev=c(500, 750, 1000), runname="_M0")`	_M0	2000x2020	6.17	0.128	0.114	-	-	Very slight (+) 2017-2020

Site/ Parameter[a]	Function Call[b]	Run suffix[c]	Monotonic Trend(s)[d]	Trend (percent)[e]	Trend p-value[f]	GLR_{NULL}[g]	Compa-rison[h]	$GLR_{1\text{-}2}$[i]	Residual trends[k]
SL (SC)	`runQWmodel(SL_QWP, "sc", monxx=c("2000x2010", "2010x2020"), exlev=c(500, 750, 1000), runname="_M1")`	_M1	2000x2010 2010x2020	3.75 3.9	0.346 0.244	0.197	M0 – M1	0.387	Very slight (-) 2000-2017, slight (+) 2017-2020
	`runQWmodel(SL_QWP, "sc", monxx=c("2016x2020"), runname="_M2")`	_M2	2016x2020	8.77	0.019	0.0096	M2 – M1	1	None
BS (SAR)	`runQWmodel(BS_QWP, "sar", exlev=c(0.8, 1.2, 1.6), runname="null")`	_null	-	-	-	-	-	-	slight (-) 2012.5-2016
	`runQWmodel(BS_QWP, "sar", monxx=c("2004x2016"), exlev=c(0.8, 1.2, 1.6), runname="_M0")`	_M0	2004x2016	-2.23	0.727	0.729	-	-	Faint sine curve shape
	`runQWmodel(BS_QWP, "sar", monxx=c("2004x2010", "2010x2016"), modnum = 1, exlev=c(0.8, 1.2, 1.6), runname="_M1")`	*none*	2004x2010 2010x2016	-	-	-	-	-	-
	`runQWmodel(BS_QWP, "sar", monxx=c("2004x2012", "2012x2016"), exlev=c(0.8, 1.2, 1.6), runname="_M1")`	_M1	2004x2012 2012x2016	16.49 -16.13	0.0396 0.0118	0.0365	M0 – M1	0.0108	Relatively flat with slight concve shape

Site/ Parameter[a]	Function Call[b]	Run suffix[c]	Monotonic Trend(s)[d]	Trend (percent)[e]	Trend p-value[f]	GLR_{NULL}[g]	Compa-rison[h]	$GLR_{1\text{-}2}$[i]	Residual trends[k]
BS (SC)	`runQWmodel(BS_QWP, "sc", exlev=c(500,750,1000), runname="_null")`	_null	-	-	-	-	-	-	slight (-) 2000-2007, very slight (+) 2007-2016
	`runQWmodel(BS_QWP, "sc", monxx=c("2000x2016"), exlev=c(500,750,1000), runname="_M0")`	_M0	2000x2016	15.56	4.78e-4	8.27e-4	-	-	2000-2006 (-)
	`runQWmodel(BS_QWP, "sc", monxx=c("2000x2010", "2010x2016"), exlev=c(500,750,1000), runname="_M1")`	_M1	2000x2010	2.9	0.550	0.00900	M0 – M1	1	2000-2006 (-), 2014.5x2016 (-)
			2010x2016	9.98	0.0280				
	`runQWmodel(BS_QWP, "sc", monxx=c("2000x2006", "2006x2016"), exlev=c(500,750,1000), runname="_M2")`	_M2	2000x2006	-5.55	0.223	1.98e-4	M0 – M2	0.0154	Nearly flat.
			2006x2016	17.33	0.00042				
TRD (SAR)	`runQWmodel(TRD_QWP, "sar", exlev=c(0.8, 1.2, 1.6), modnum=2, runname="_null")`	_null	-	-	-	-	-	-	2004-2008 (+), 2008-2020 (-)
	`runQWmodel(TRD_QWP, "sar", monxx=c("2004x2020"), modnum=2, exlev=c(0.8, 1.2, 1.6), runname="_M0")`	_M0	2004x2020	-13.5	0.0385	0.0295	-	-	Slight humped shape peaking in 2010
	`runQWmodel(TRD_QWP, "sar", monxx=c("2004x2010", "2010x2020"), modnum=2, exlev=c(0.8, 1.2, 1.6), runname="_M1")`	_M1	2004x2010	21.93	0.00064	0.0144	M0 – M1	0.0531	A little wavy, upward trend 2016-2020
			2010x2020	-19.63	0.00025				

Site/ Parameter[a]	Function Call[b]	Run suffix[c]	Monotonic Trend(s)[d]	Trend (percent)[e]	Trend p-value[f]	GLR_{NULL}[g]	Compa-rison[h]	GLR_{1-2}[i]	Residual trends[k]
TRD (SAR)	`runQWmodel(TRD_QWP, "sar", monxx=c("2004x2010", "2010x2016", “2016x2020), modnum=2, exlev=c(0.8, 1.2, 1.6), runname="_M2")`	_M2	2004x2010	17.54	0.0221	0.00426	M1 – M2	0.0301	Slightly wavy but flatter than M1
			2010x2016	-15.12	0.00694				
			2016x2020	-5.85	0.430				
TRD (SC)	`runQWmodel(TRD_QWP, "sc", exlev=c(500,750,1000), runname="_null")`	_null	-	-	-	-	-	-	Barely preceptible upward trend 2000-2020
	`runQWmodel(TRD_QWP, "sc", monxx=c("2000x2020"), exlev=c(500,750,1000), runname="_M0")`	_M0	2000x2020	6.49	0.0912	0.0710	-	-	Flat/slightly wavy
	`runQWmodel(TRD_QWP, "sc", monxx=c("2000x2010", "2010x2020"), exlev=c(500,750,1000), runname="_M1")`	_M1	2000x2010	3.49	0.438	0.242	M0 – M1	1	barely perceptible downward trend, slightly concave
			2010x2020	3.66	0.218				
	`runQWmodel(TRD_QWP, "sc", monxx=c("2016x2020"), runname="_M2")`	_M2	2016x2020	4.76	0.167	0.145	M2 – M1	0.396	None perceptable.

[a] Site/parameter combination. SL=State Line, BS=Birney School, TRD=Tongue River Dam, SC=specific conductance, SAR=sodium adsorption ration. All output file names contain indication of site name, parameter, and run suffix.

[b] Function call and arguments used to invoke R-QWTREND runQWmodel function for specified model

[c] Suffix appended to model output file names associated with a particular model run

[d] Description of (piecewise) monotonic trend(s) used in model. “2000x2020” indicates a single monotonic trend from January 1, 2000 up until (but not including) January 1, 2020. Multiple trends listed indicates a model using piecewise monotonic trends.

[e] Percent change in trend over trend period (+ for upward trend, - for downward trend)

[f] p-value for individual model trends.

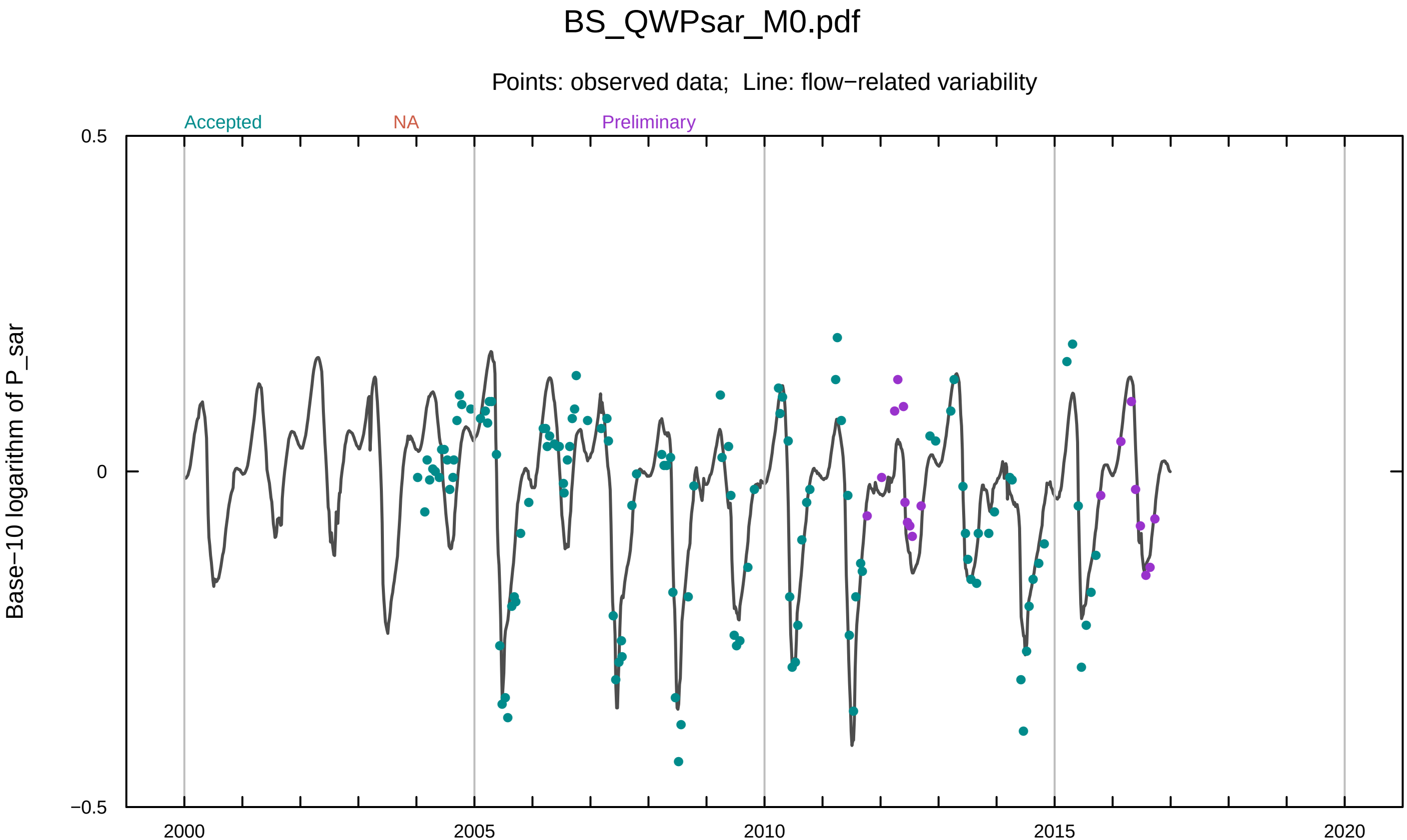
[g] GLR statistic for trend model versus the null model. Models with lower values of this parameter are generally preferred. A significant p-value for the GLR statistic indicates the null hypothesis can be rejected (null hypothesis is that all coefficients of the tested model are zero, e.g. there’s no trend).

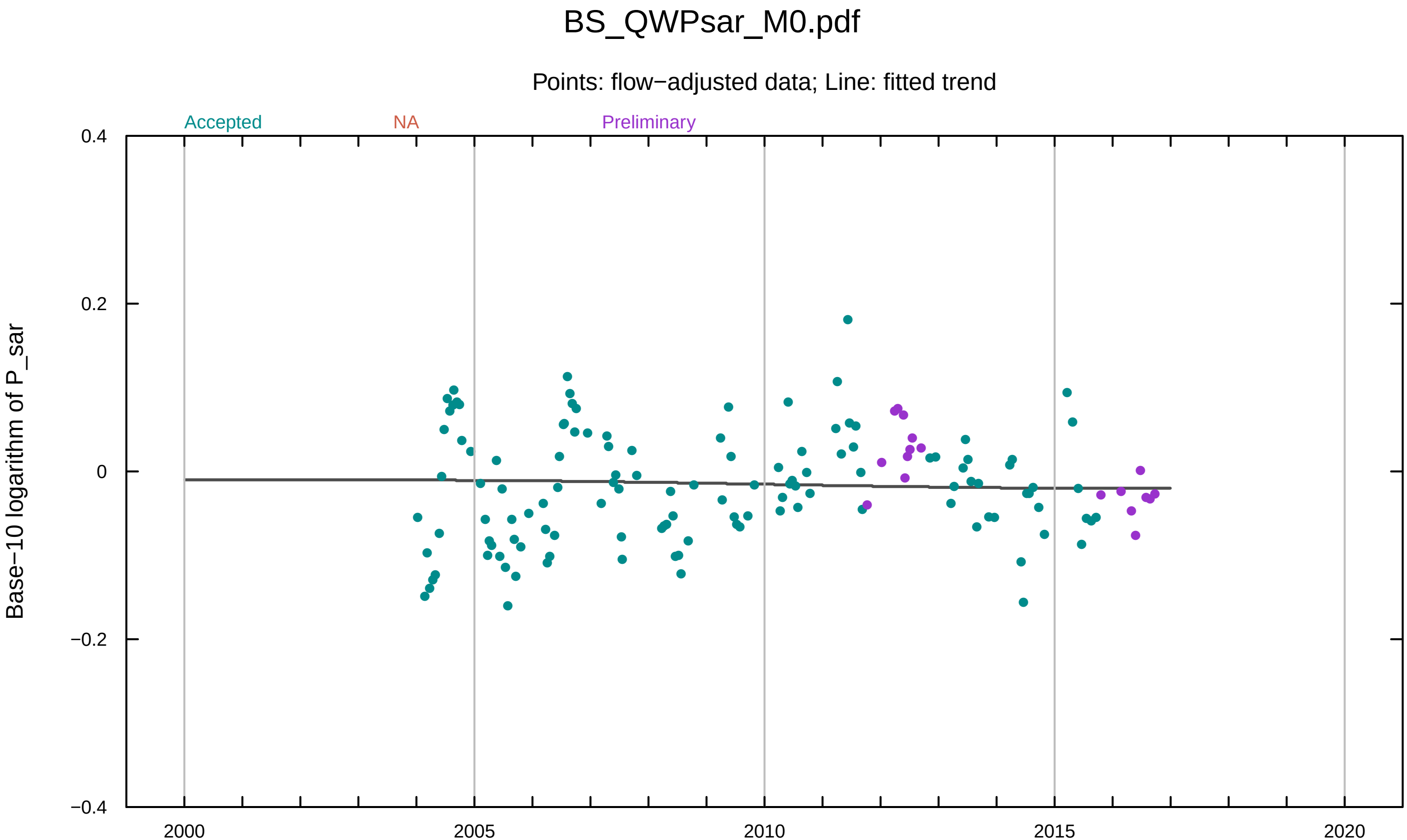
[h] Indication of which two non-null models of differing complexity are being compared using GLR statistic.

[i] GLR statistic resulting from comparison of two non-null models. A significant value indicates the more complex of the two models is preferred.

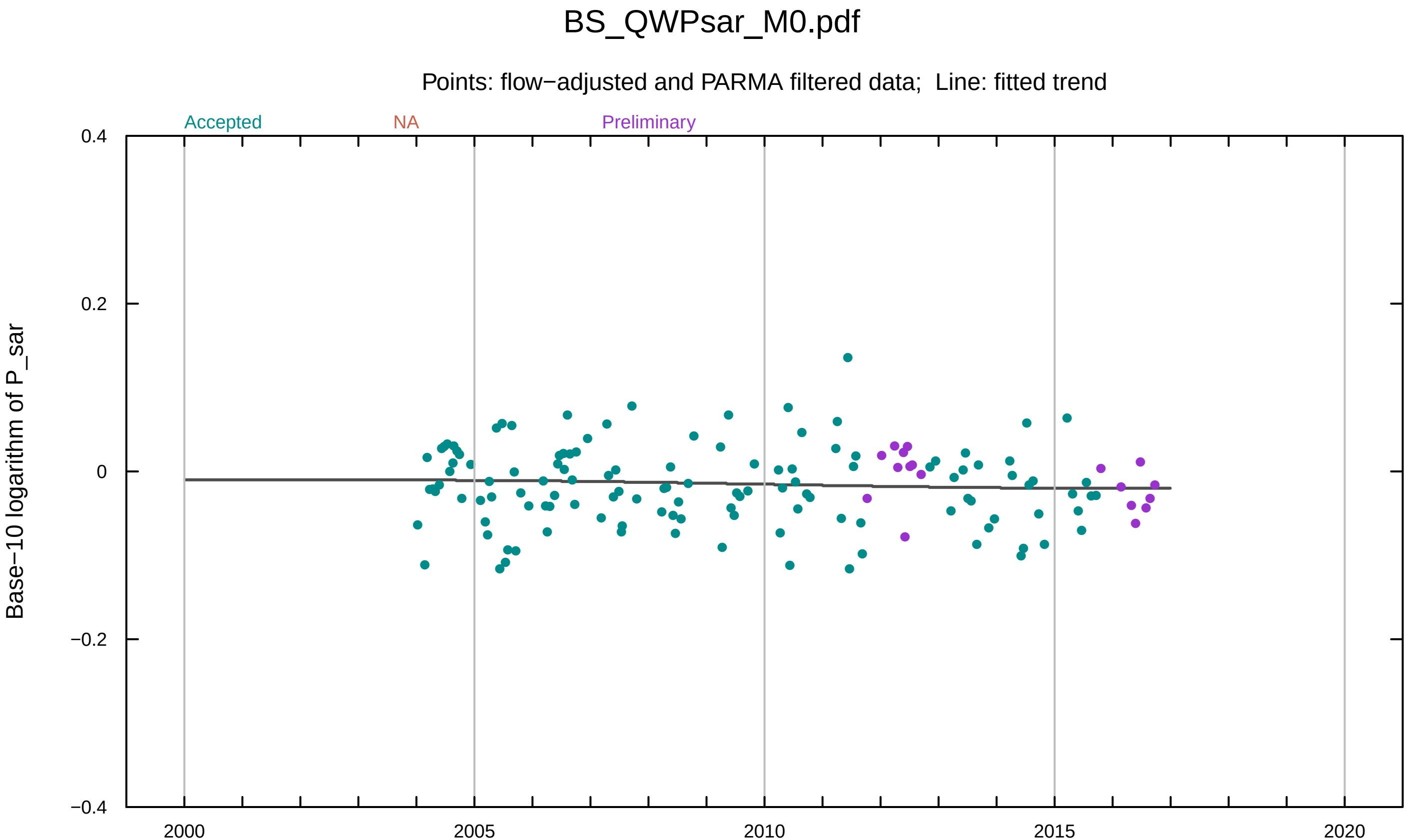
[k] Visual/qualitative assessment for any remaining trend in flow-adjusted, detrended, and PARMA filtered data (model output pdf page 4). Minimal to no trend on this plot suggests a good overall model fit.

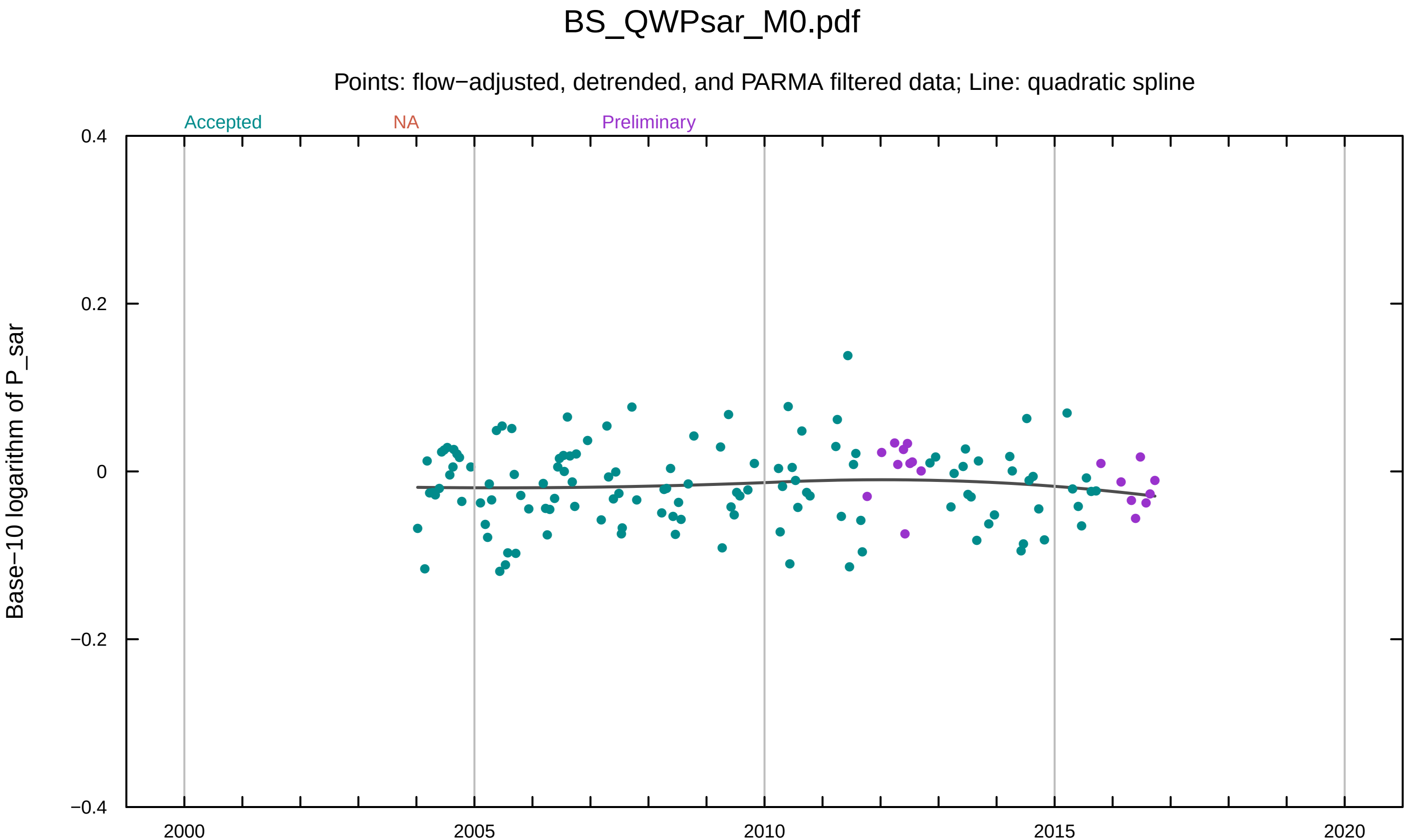
Appendix D – Complete TSM/R-QWTREND Graphical Output

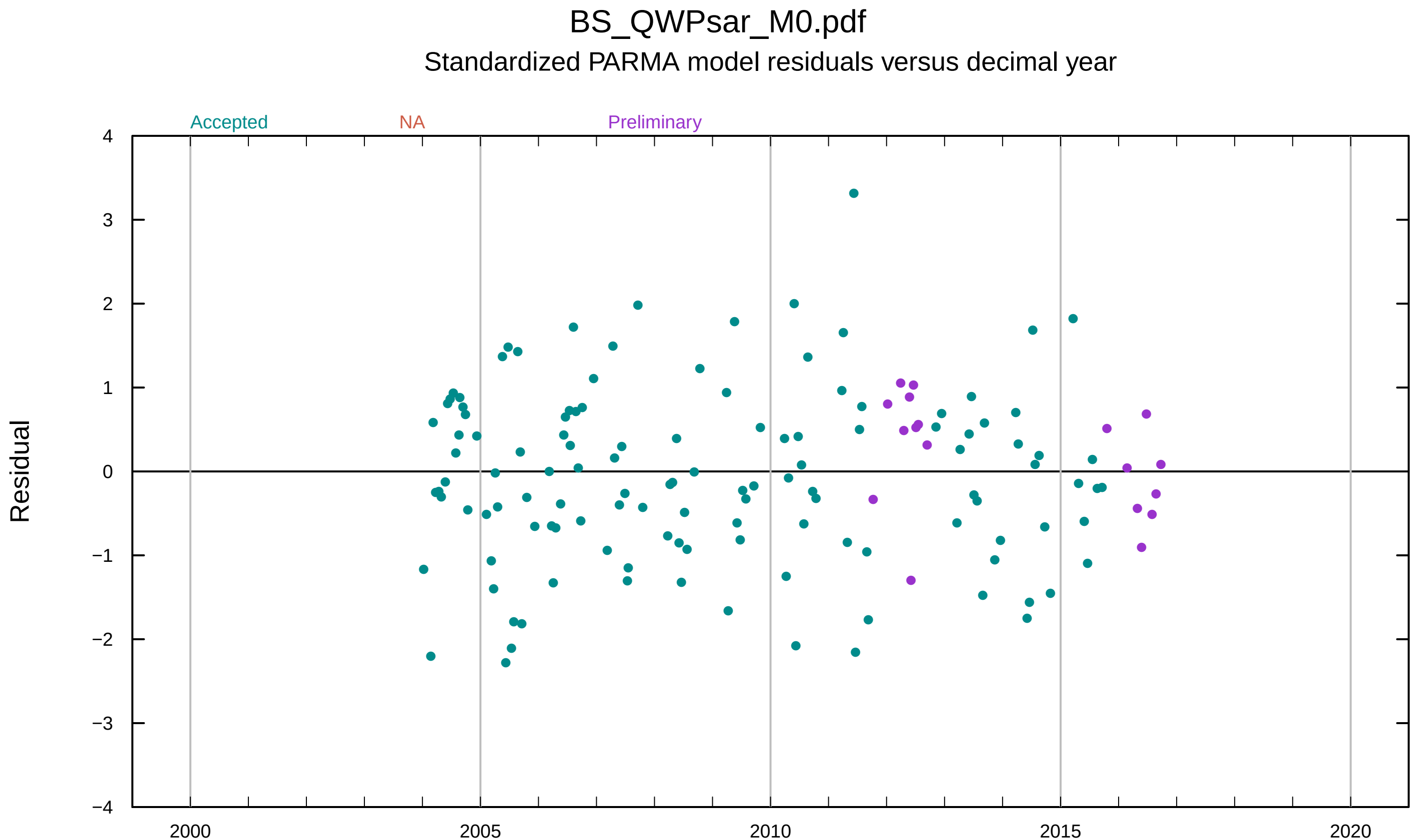

BS_QWPsar_M0.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
0.5
0
−0.5
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020

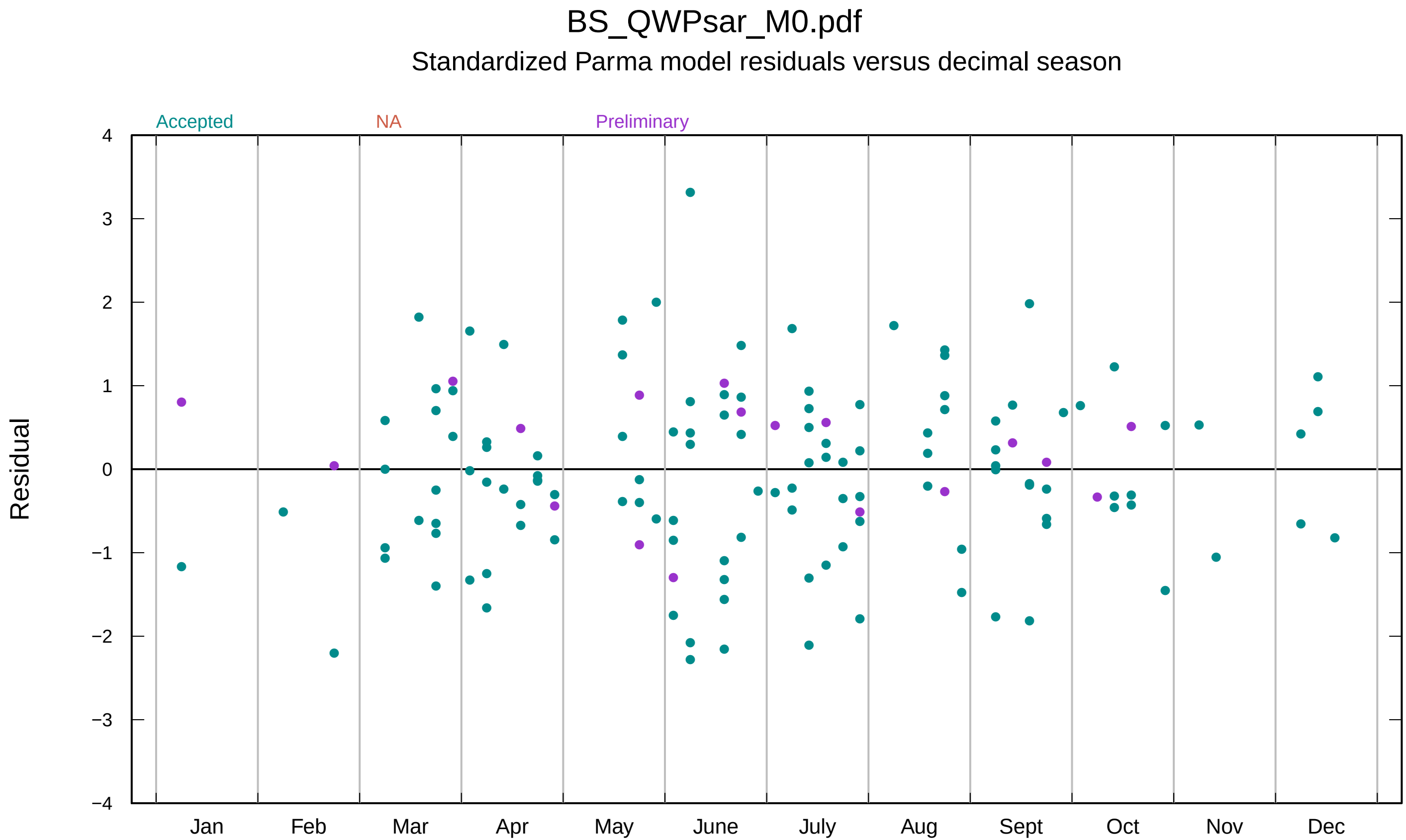


BS_QWPsar_M0.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020

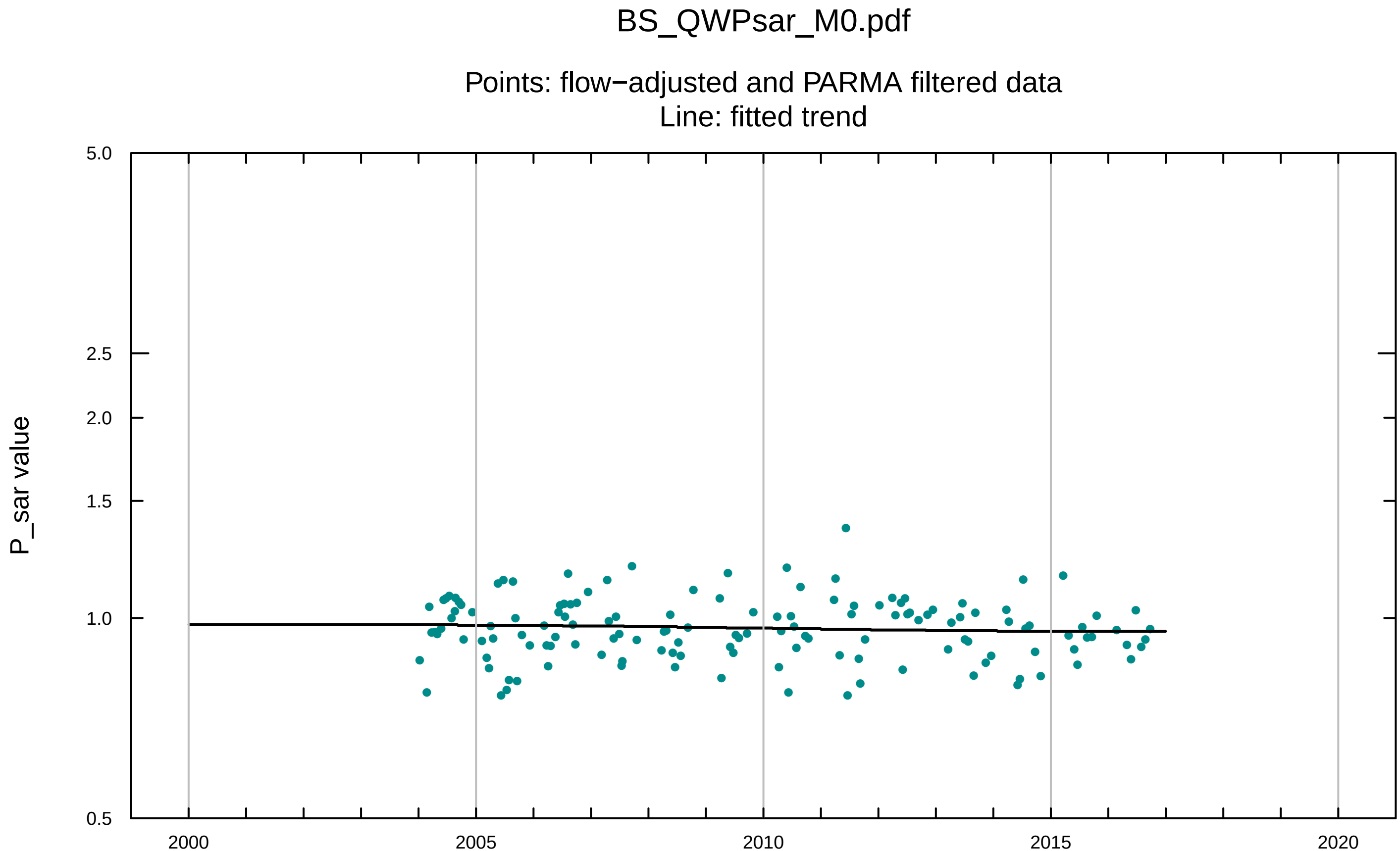

BS_QWPsar_M0.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020

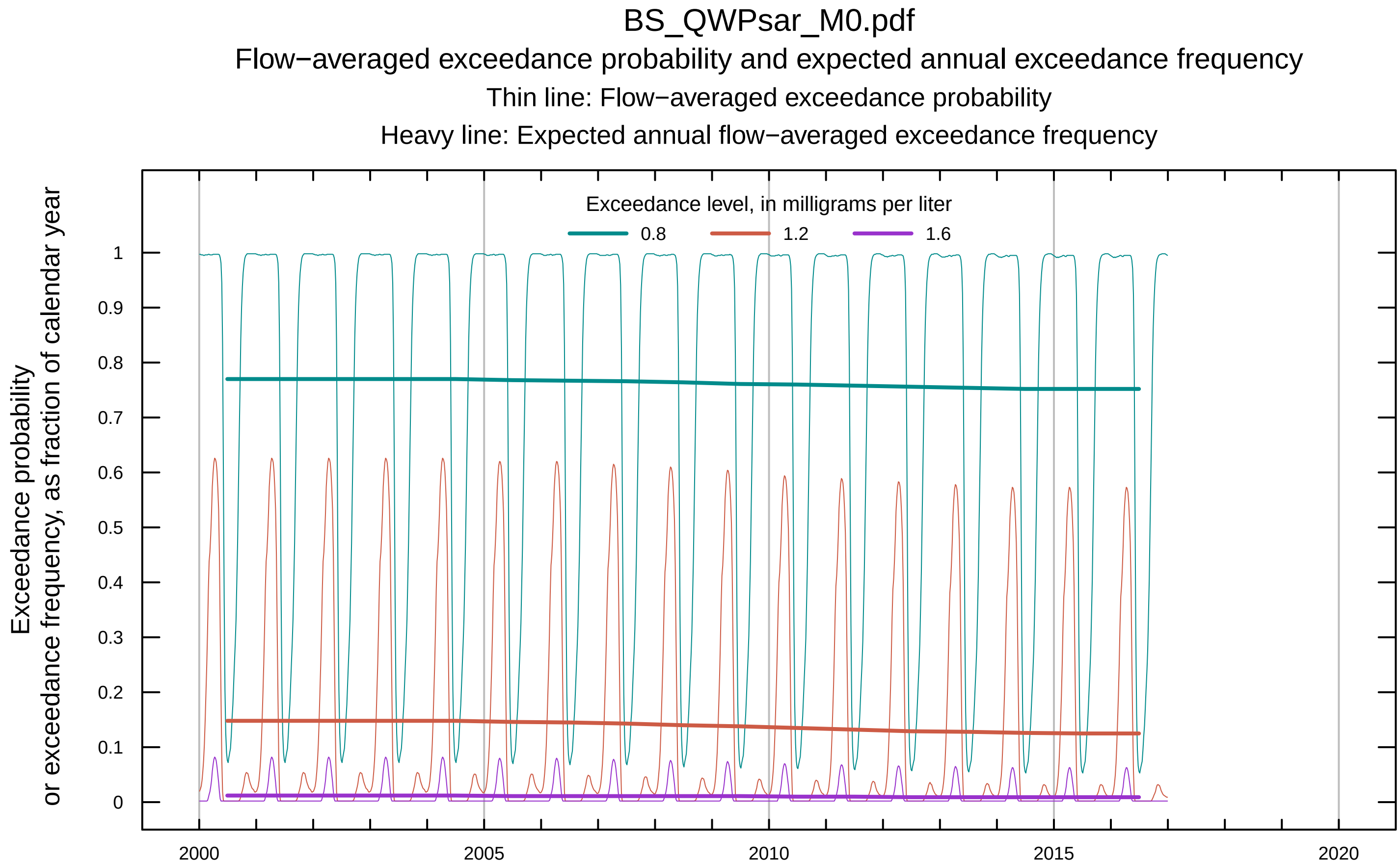

BS_QWPsar_M0.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020

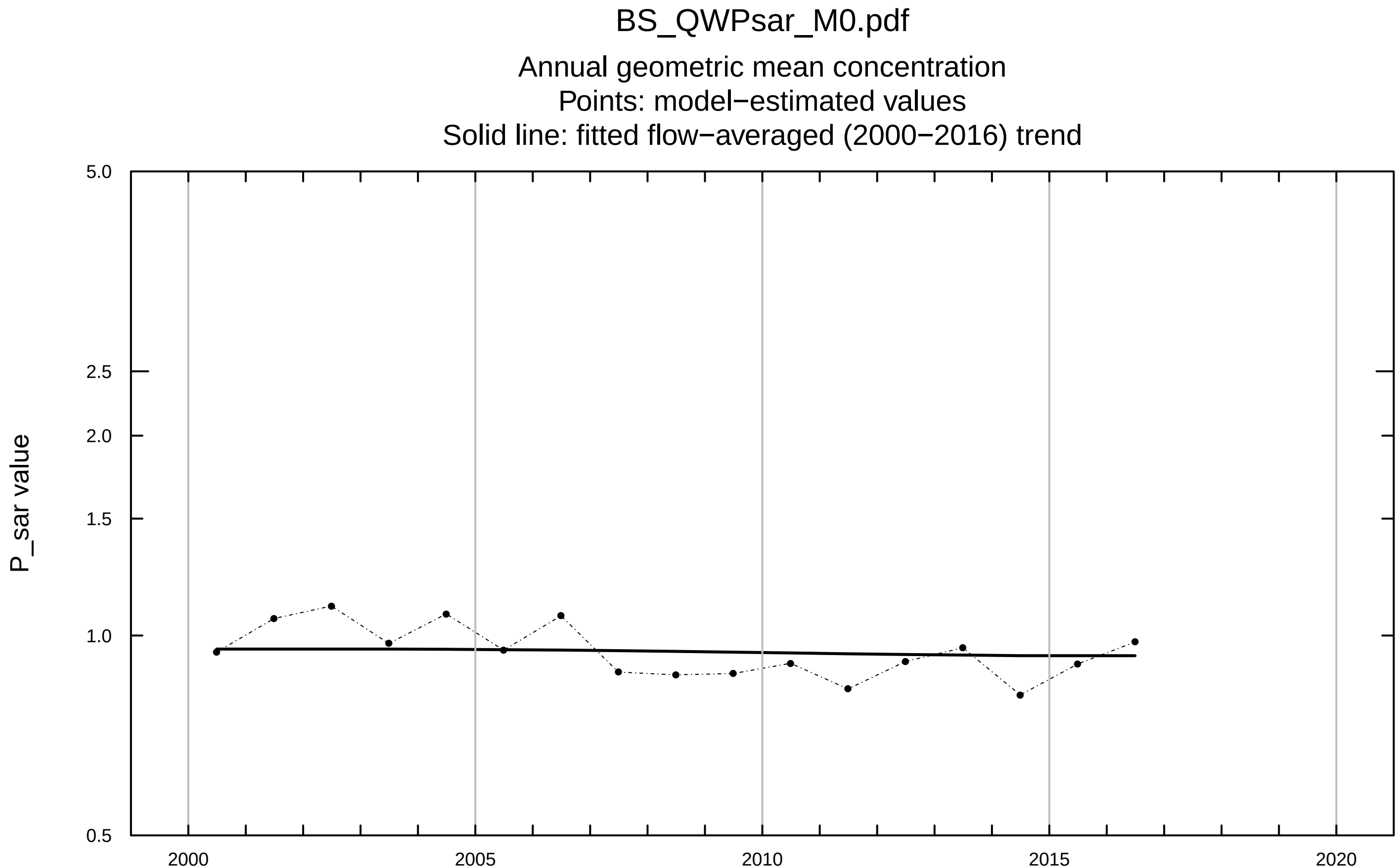

BS_QWPsar_M0.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020

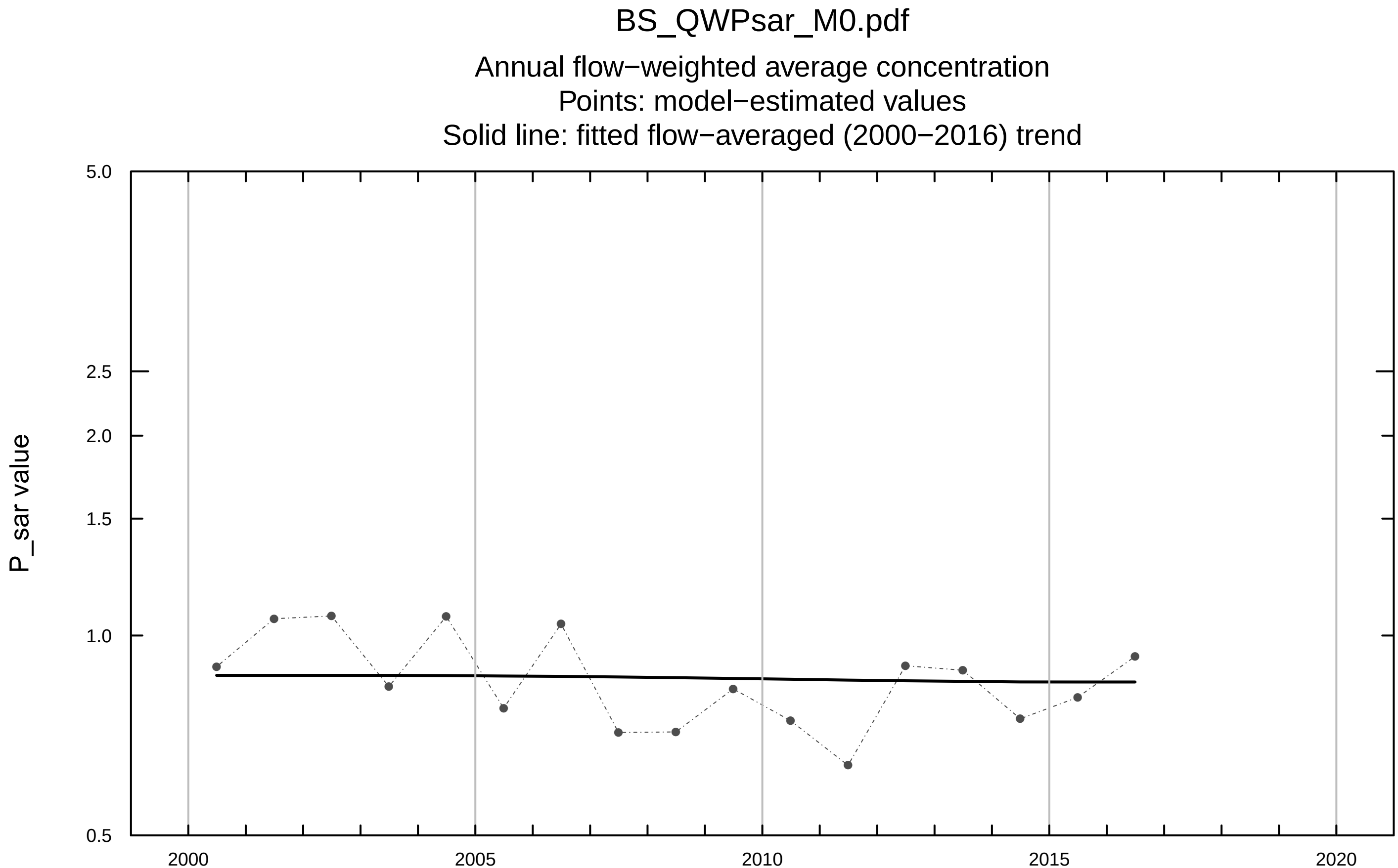


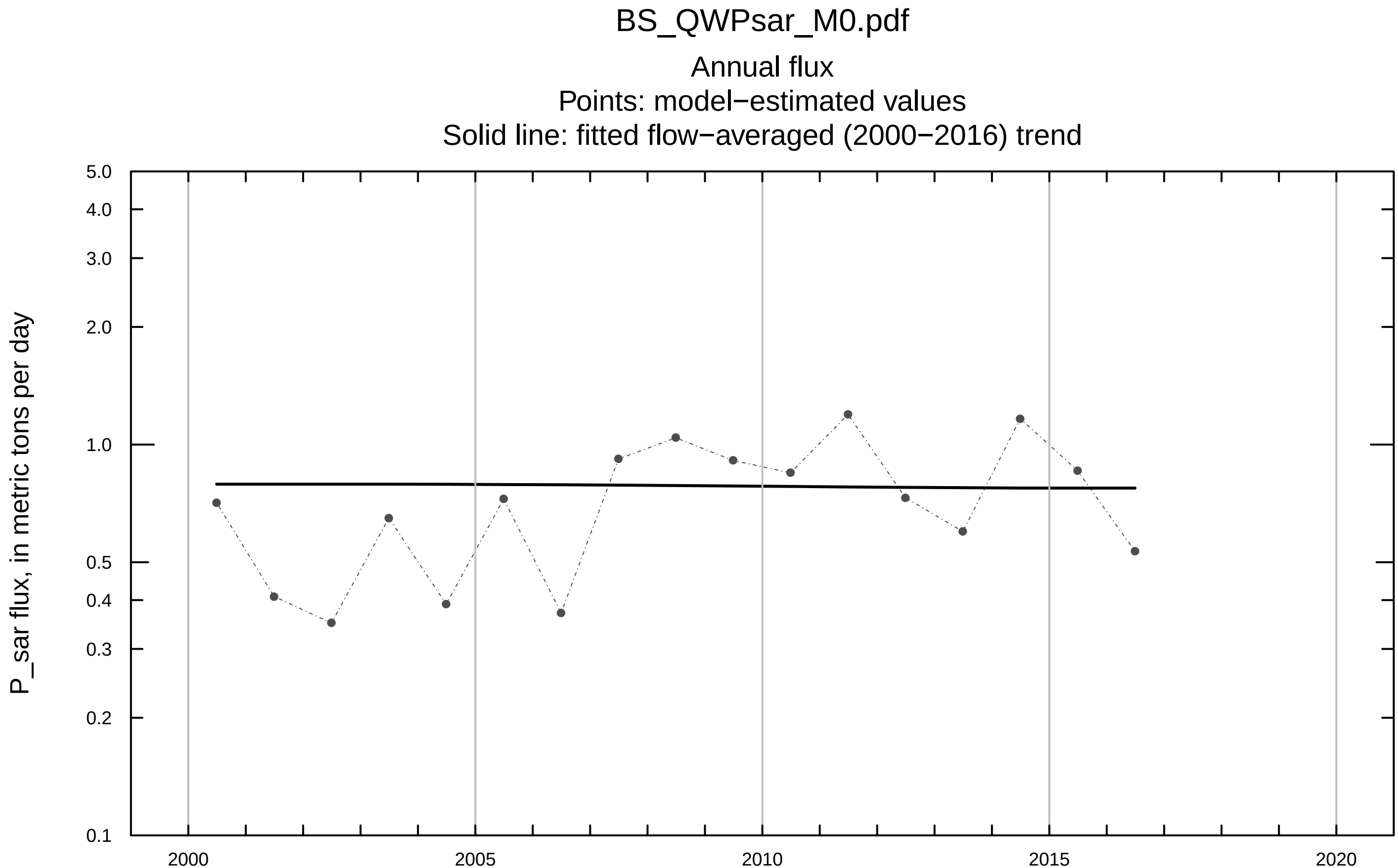
BS_QWPsar_M0.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec


BS_QWPsar_M0.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020


BS_QWPsar_M0.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020

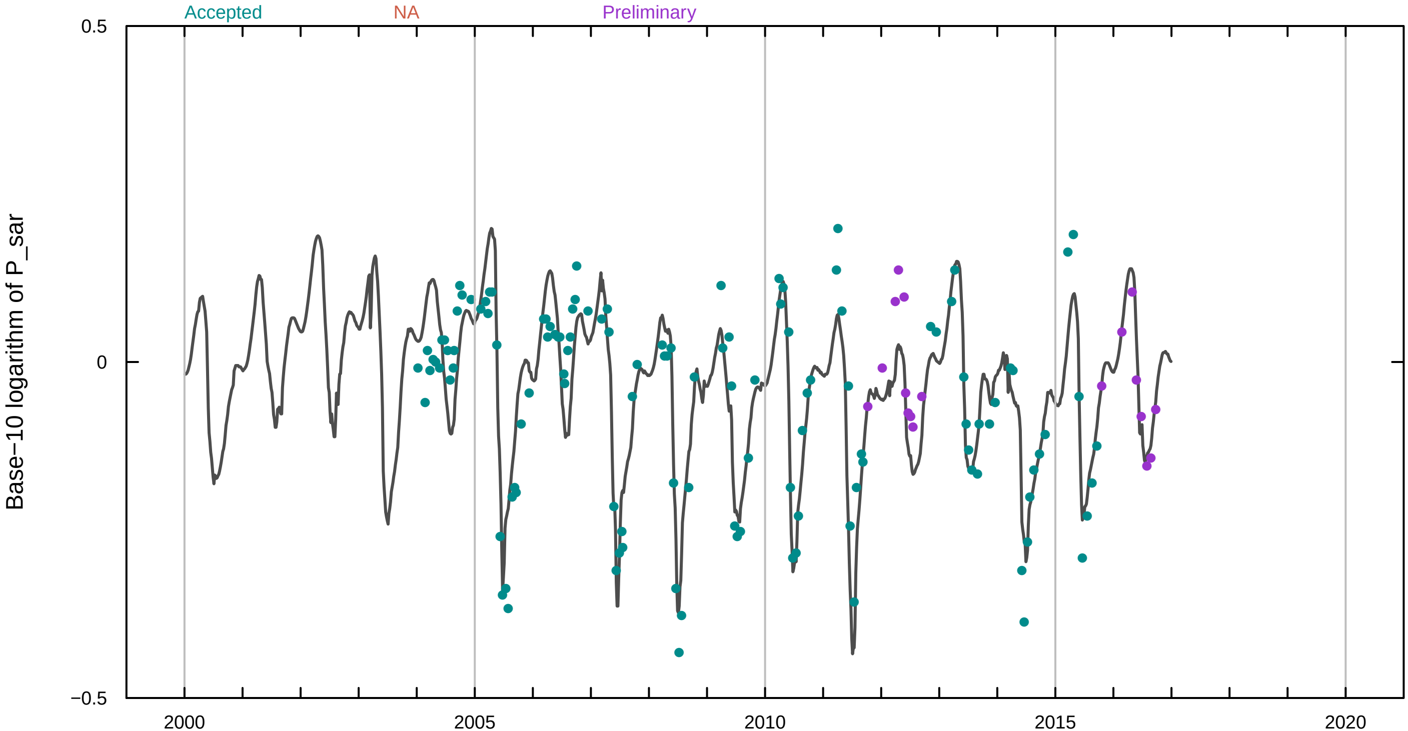

BS_QWPsar_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020

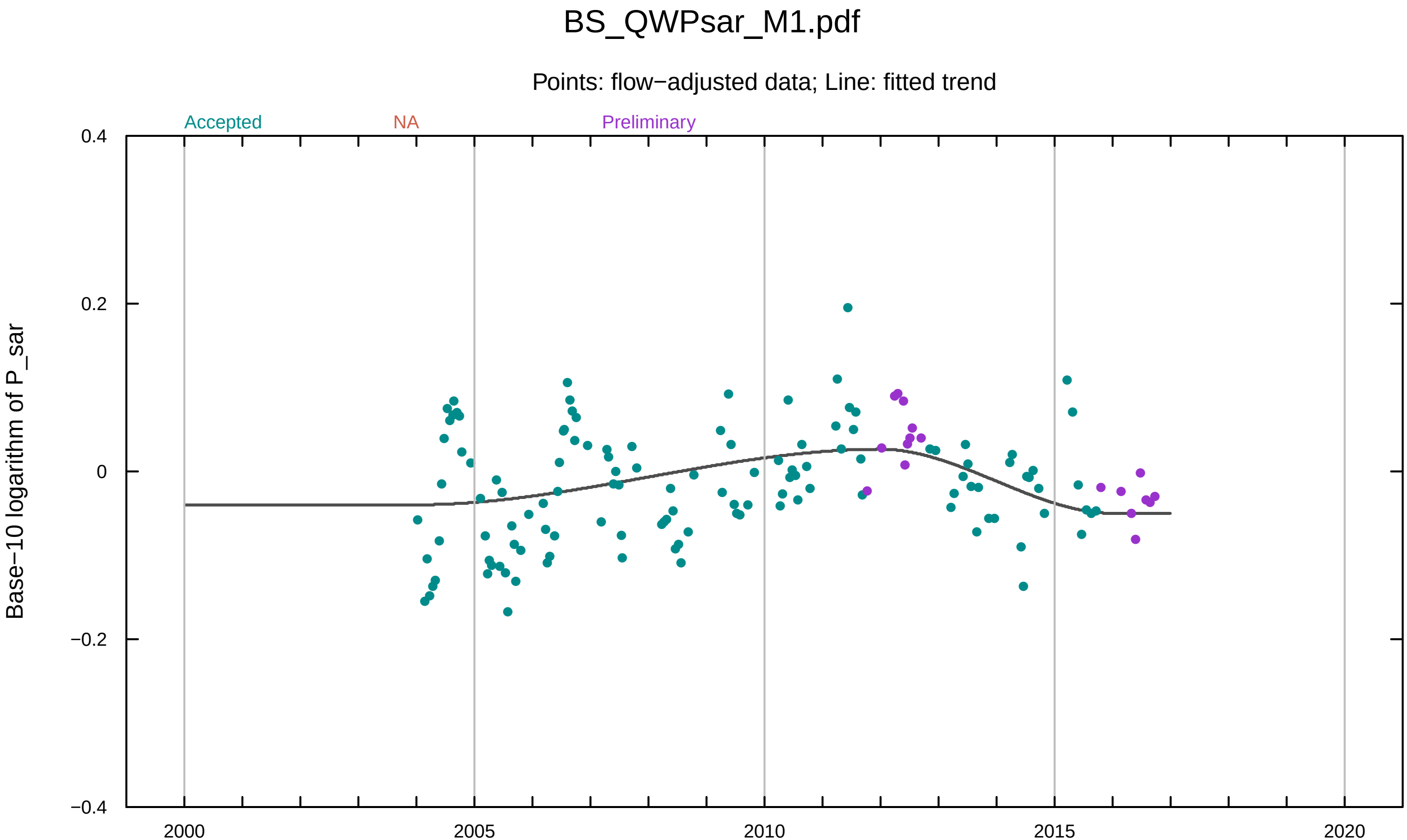

BS_QWPsar_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020

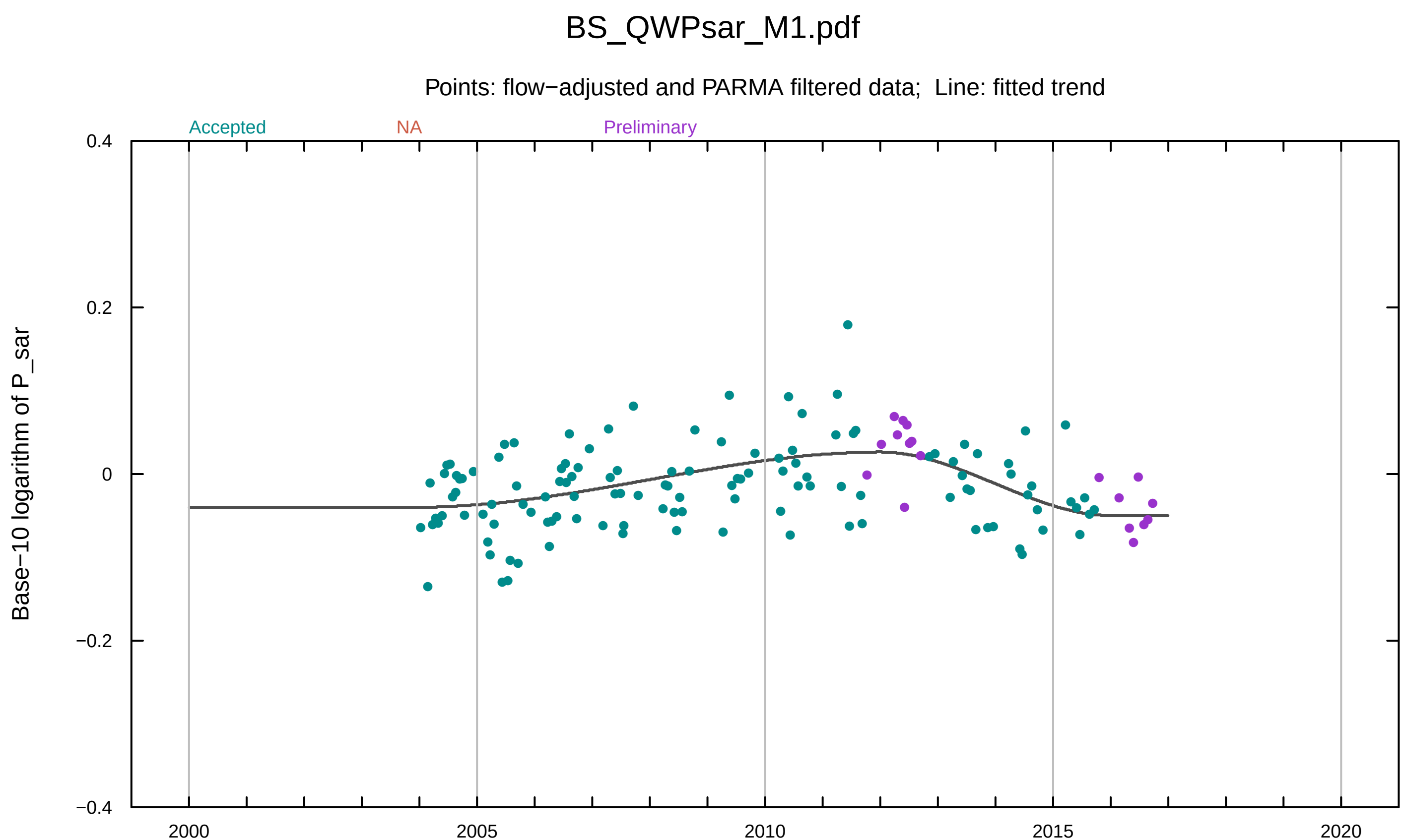

BS_QWPsar_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020

BS_QWPsar_M1.pdf

Points: observed data; Line: flow−related variability



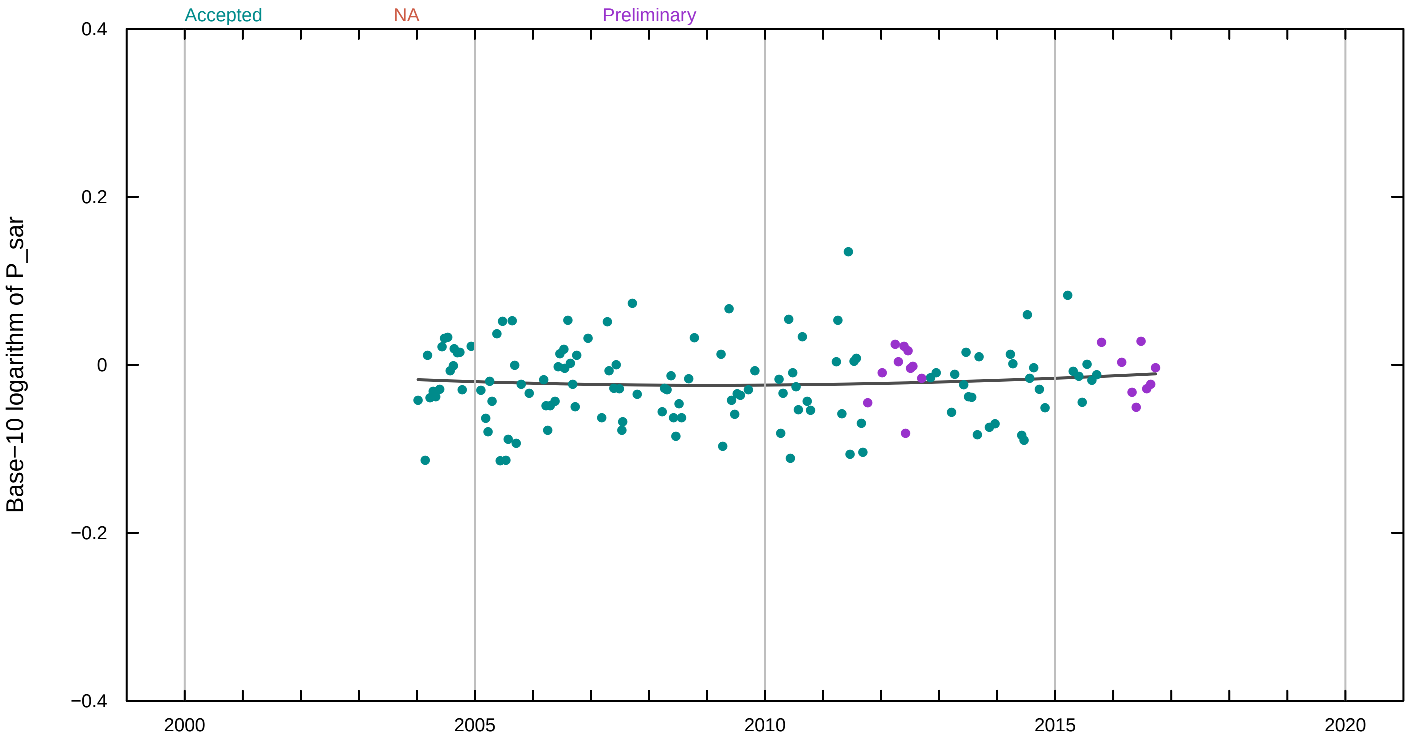

BS_QWPsar_M1.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020

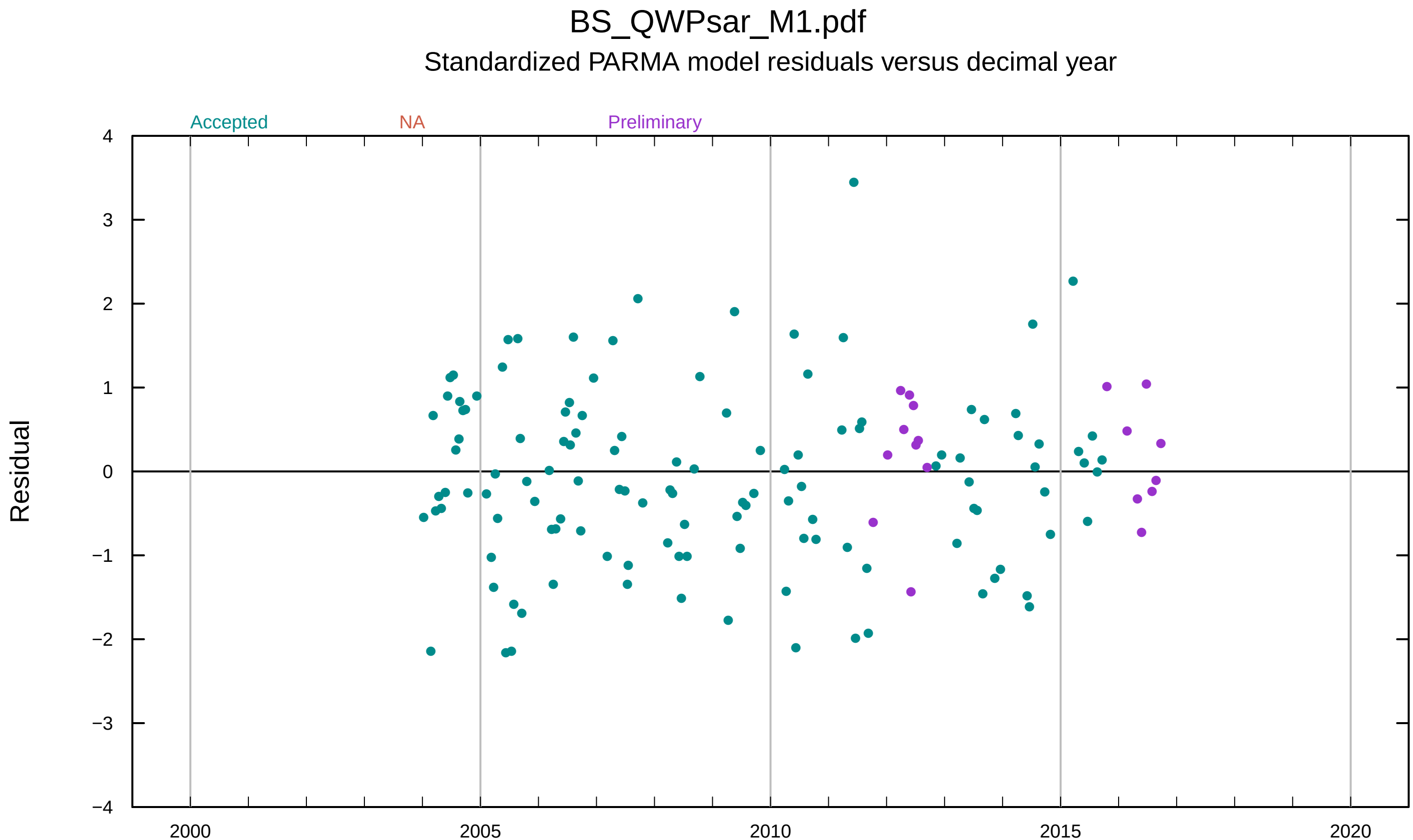


BS_QWPsar_M1.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020

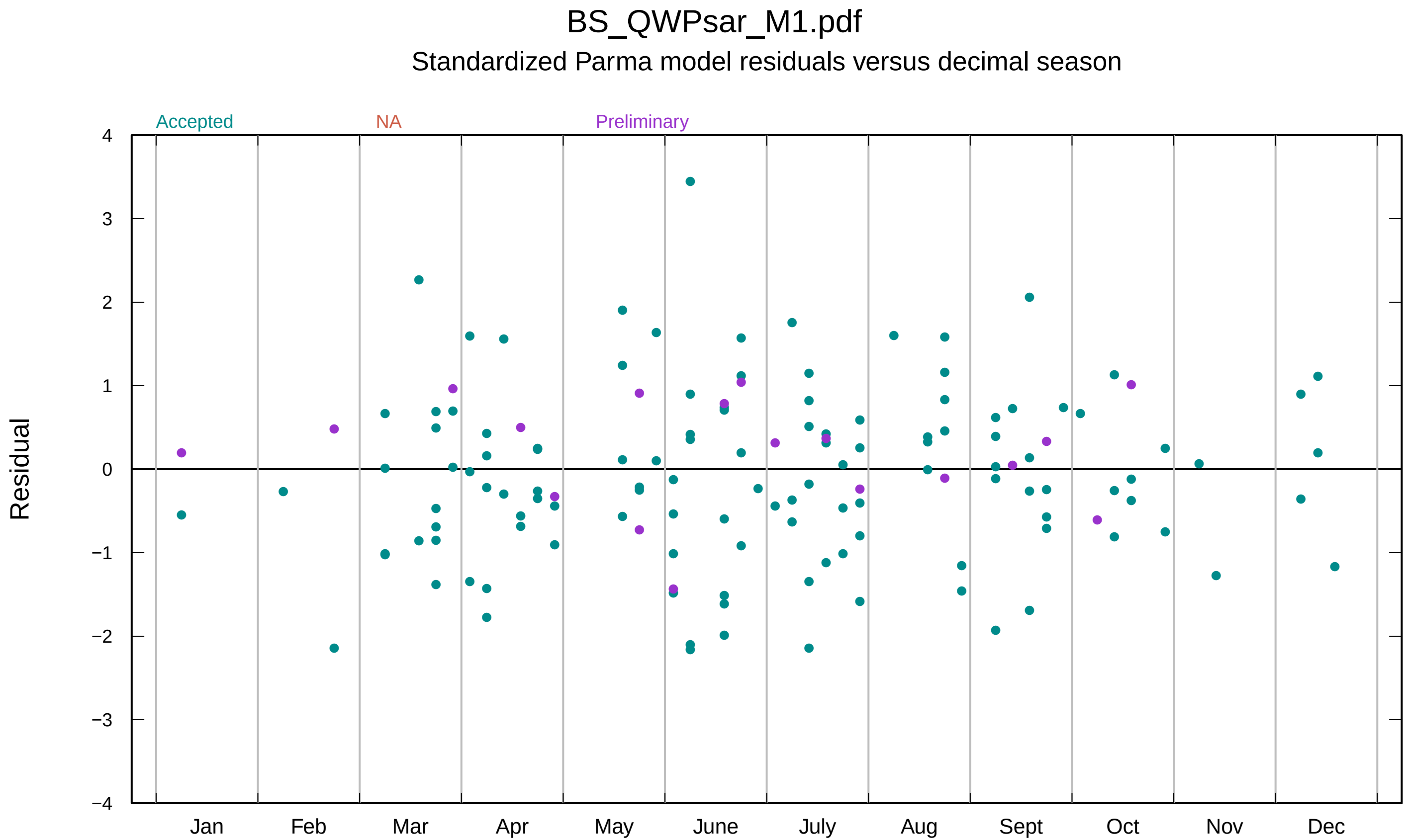
BS_QWPsar_M1.pdf

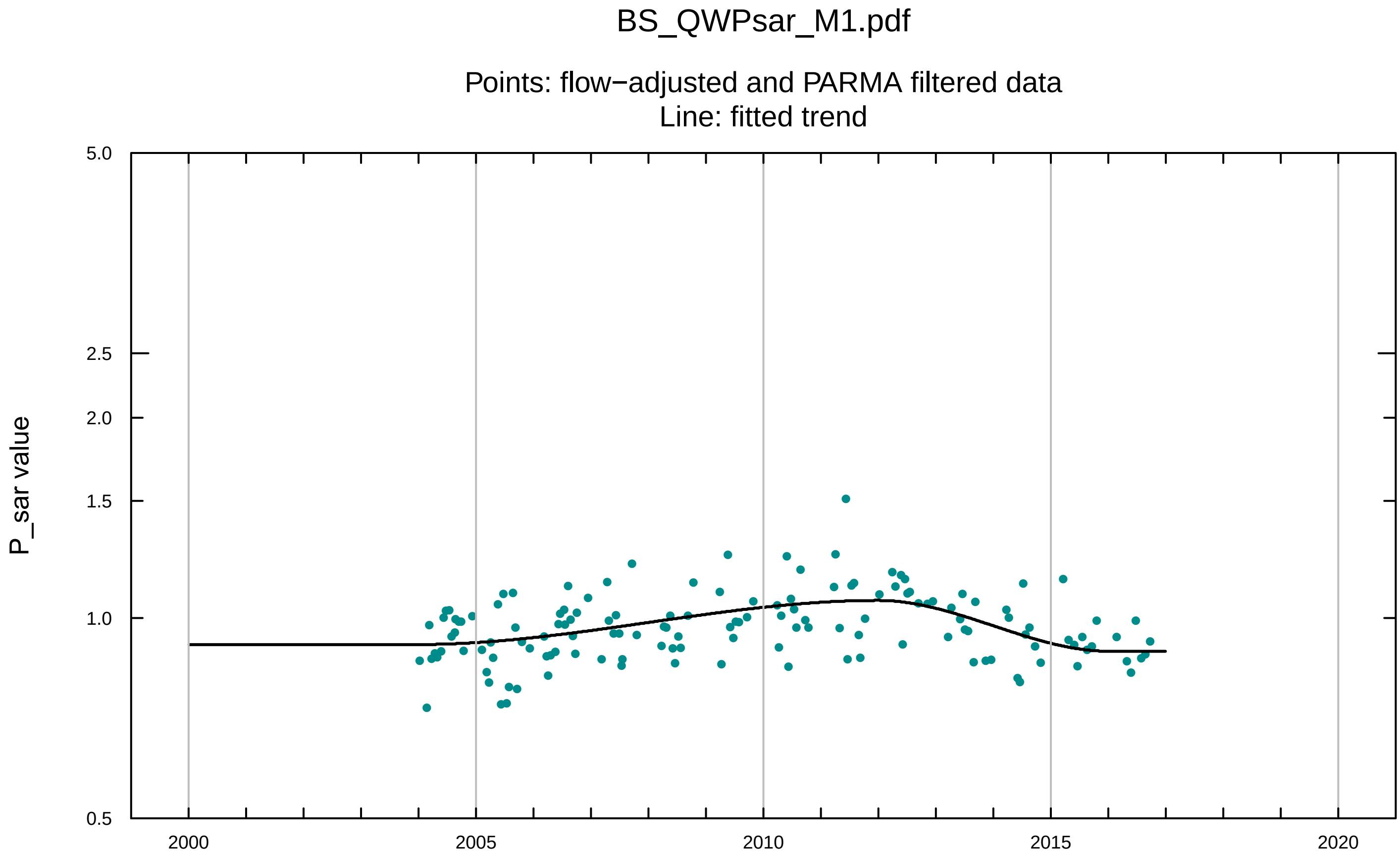
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline

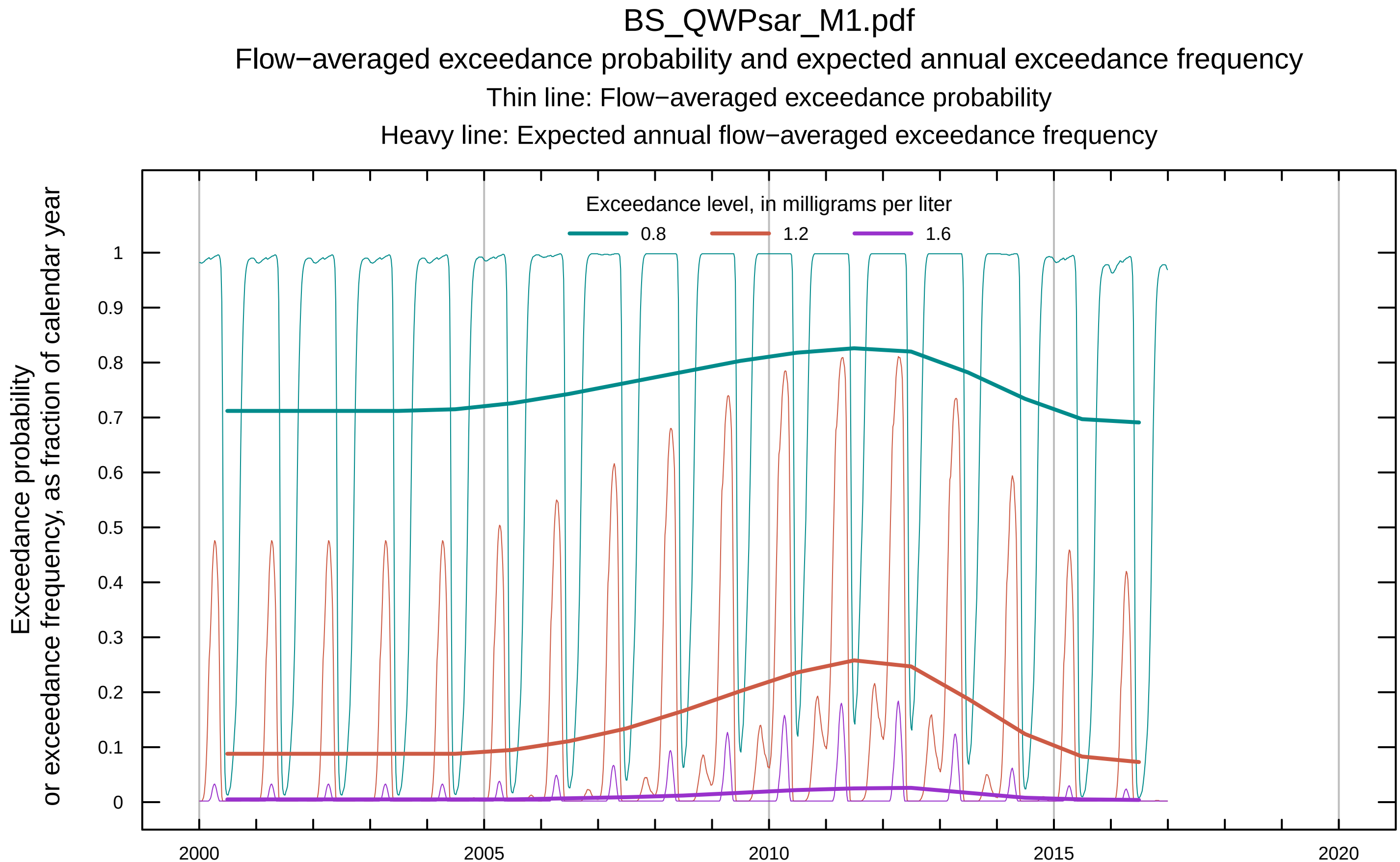




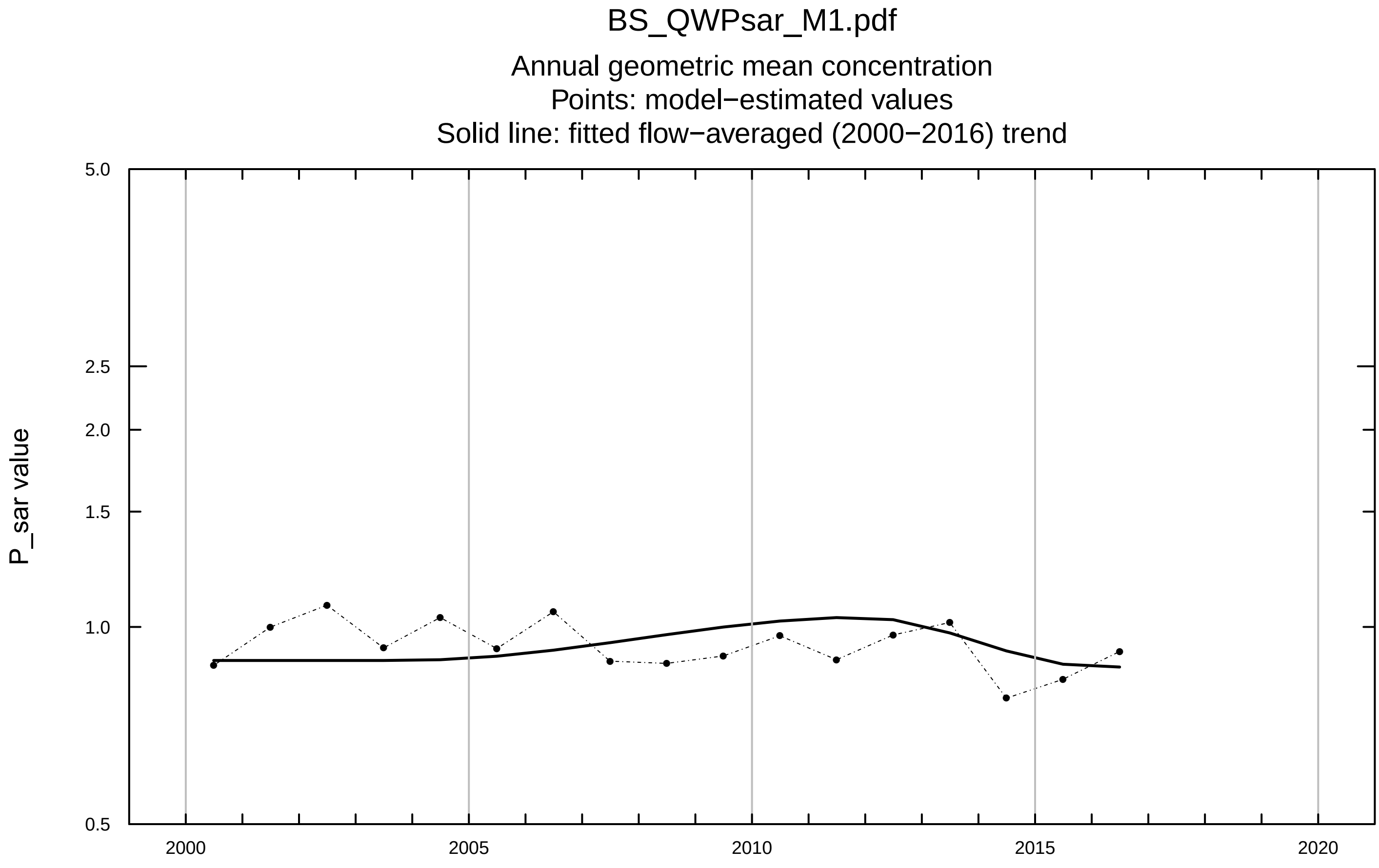
BS_QWPsar_M1.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020

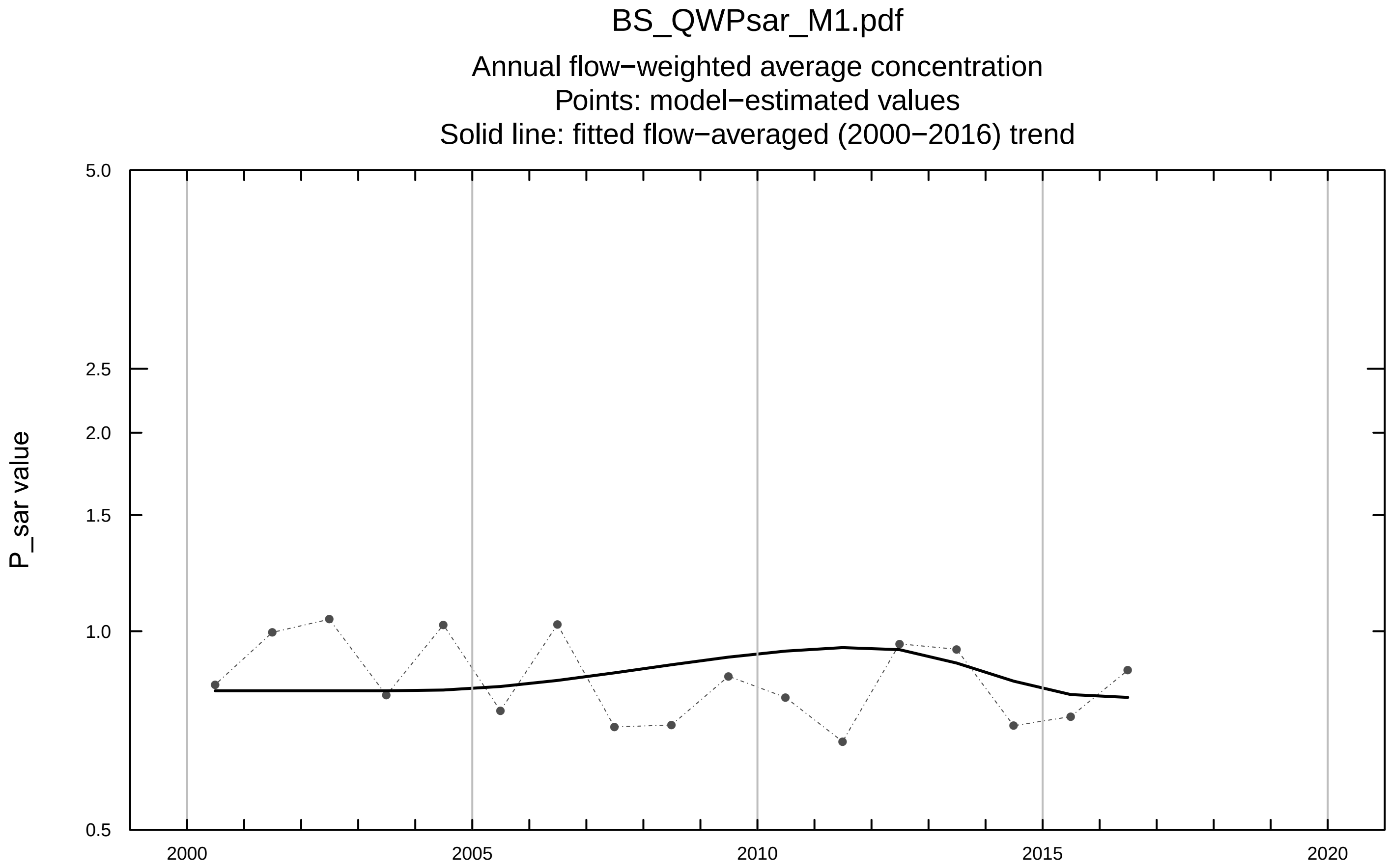

BS_QWPsar_M1.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

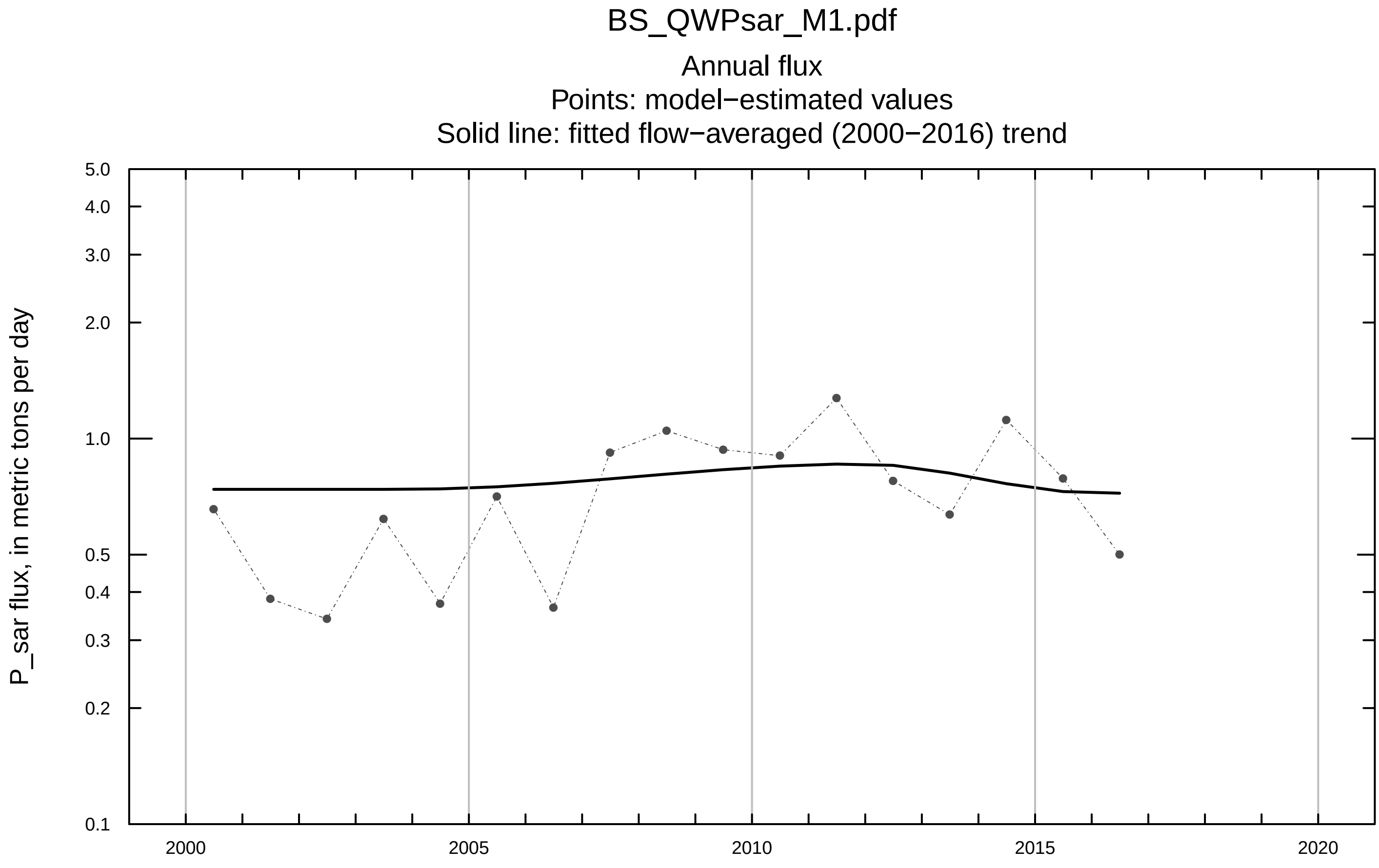

BS_QWPsar_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020

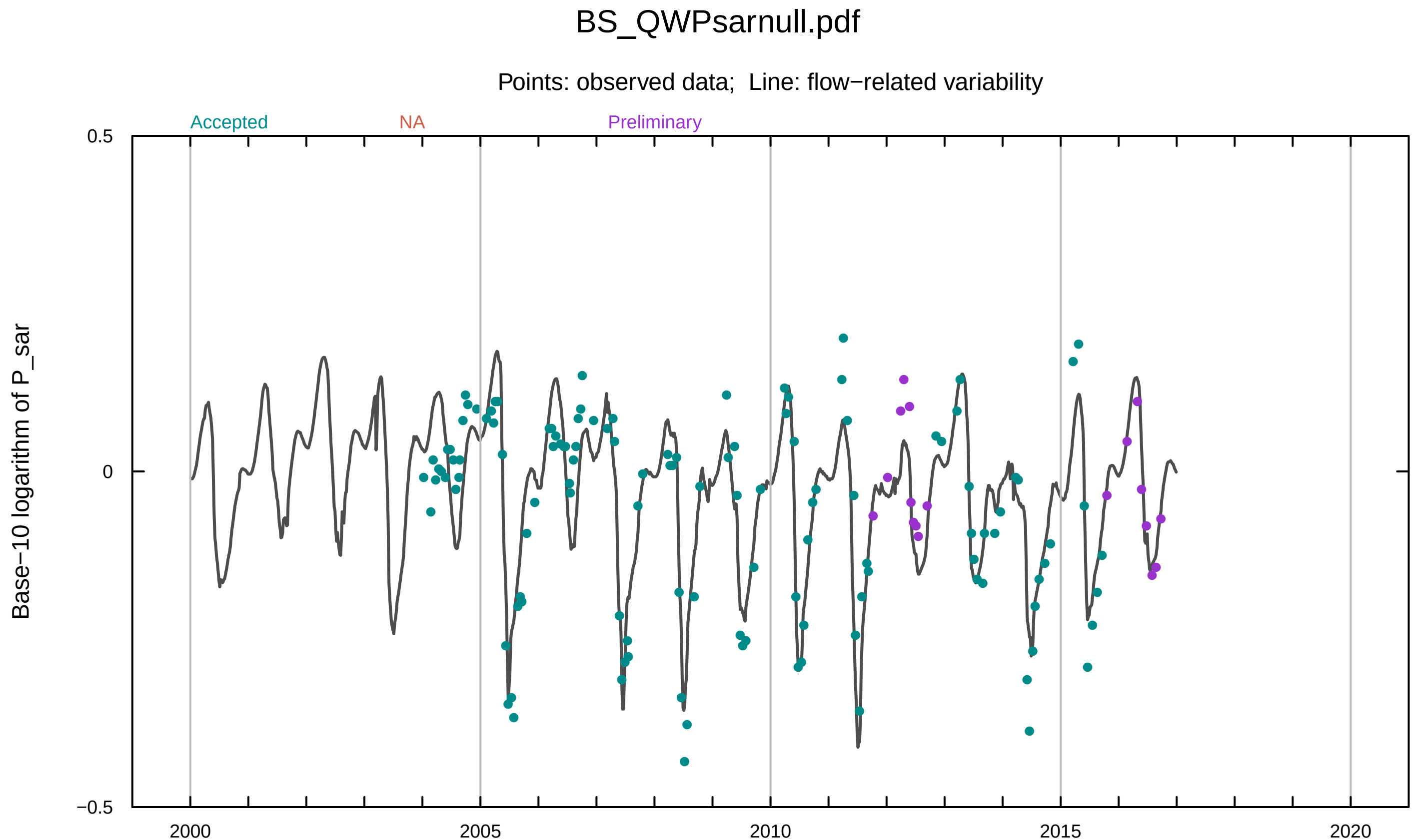


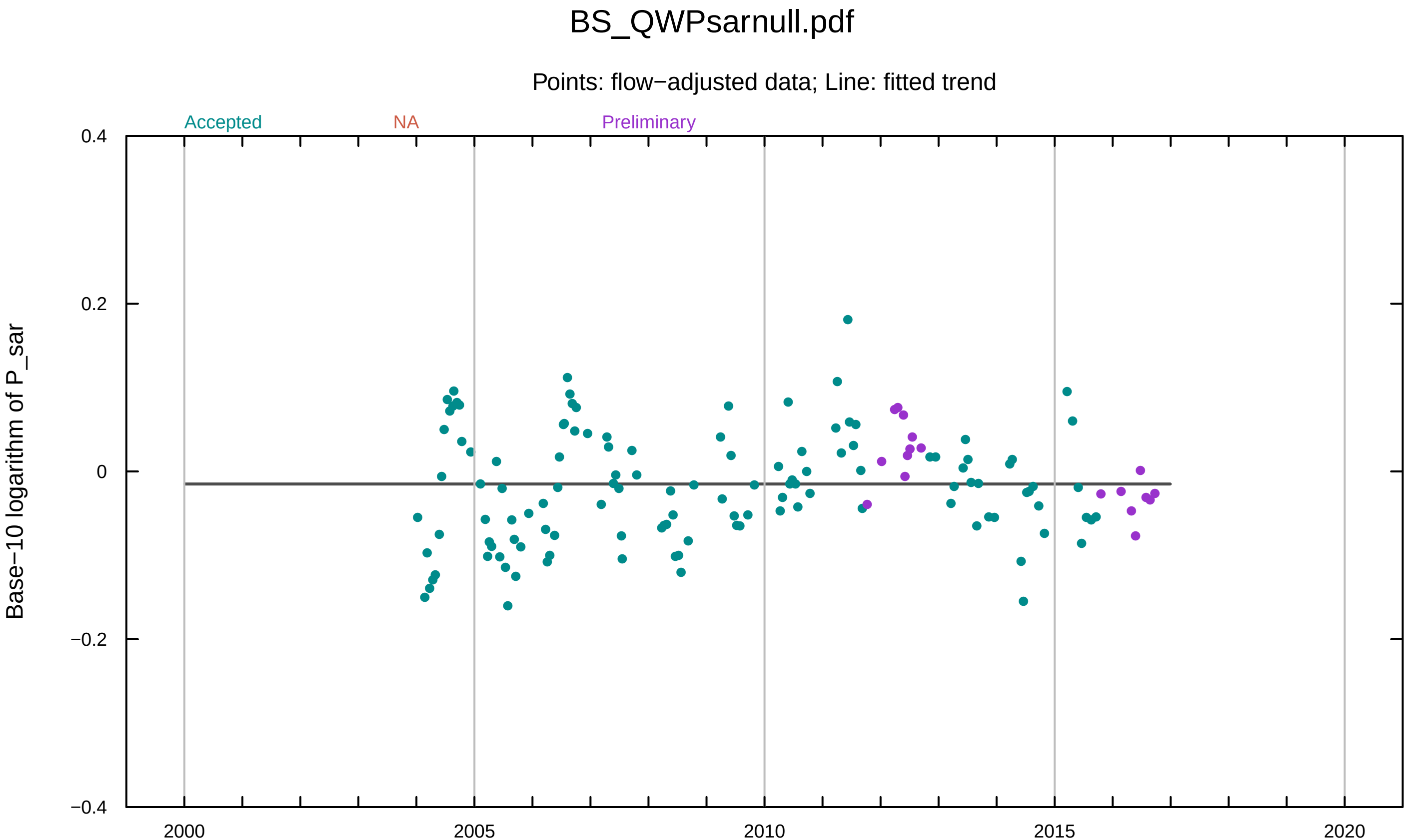
BS_QWPsar_M1.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020

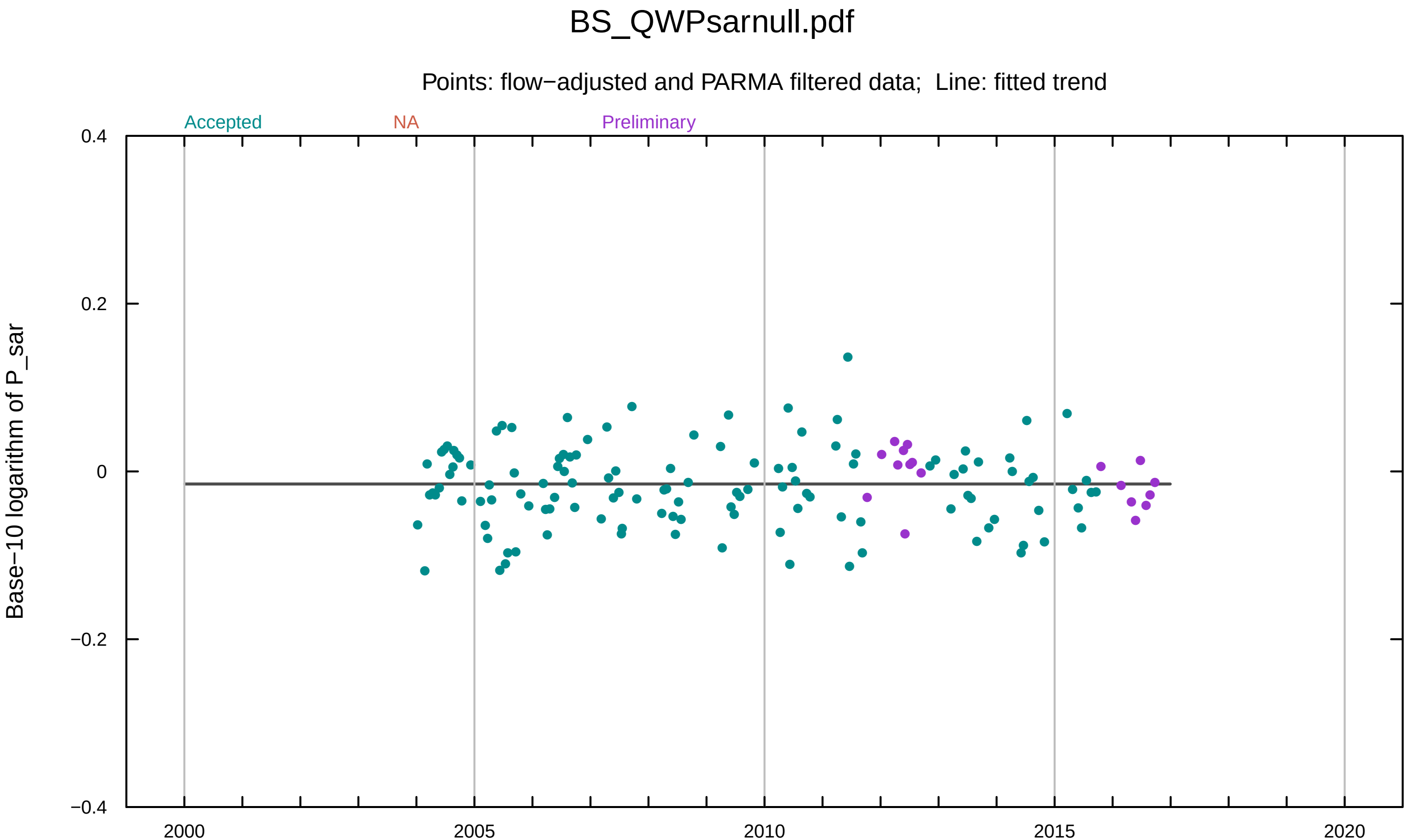

BS_QWPsar_M1.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020

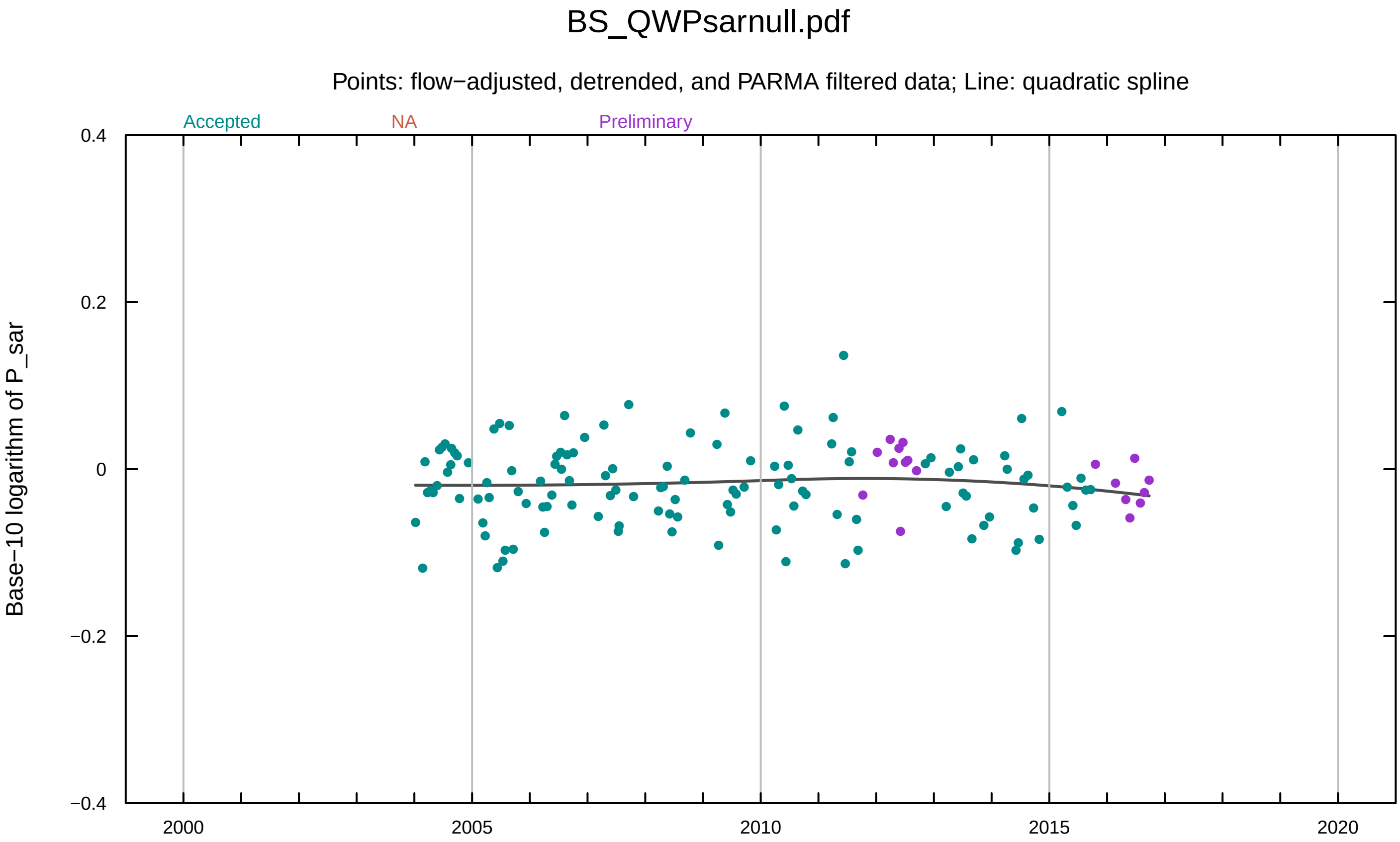

BS_QWPsar_M1.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020

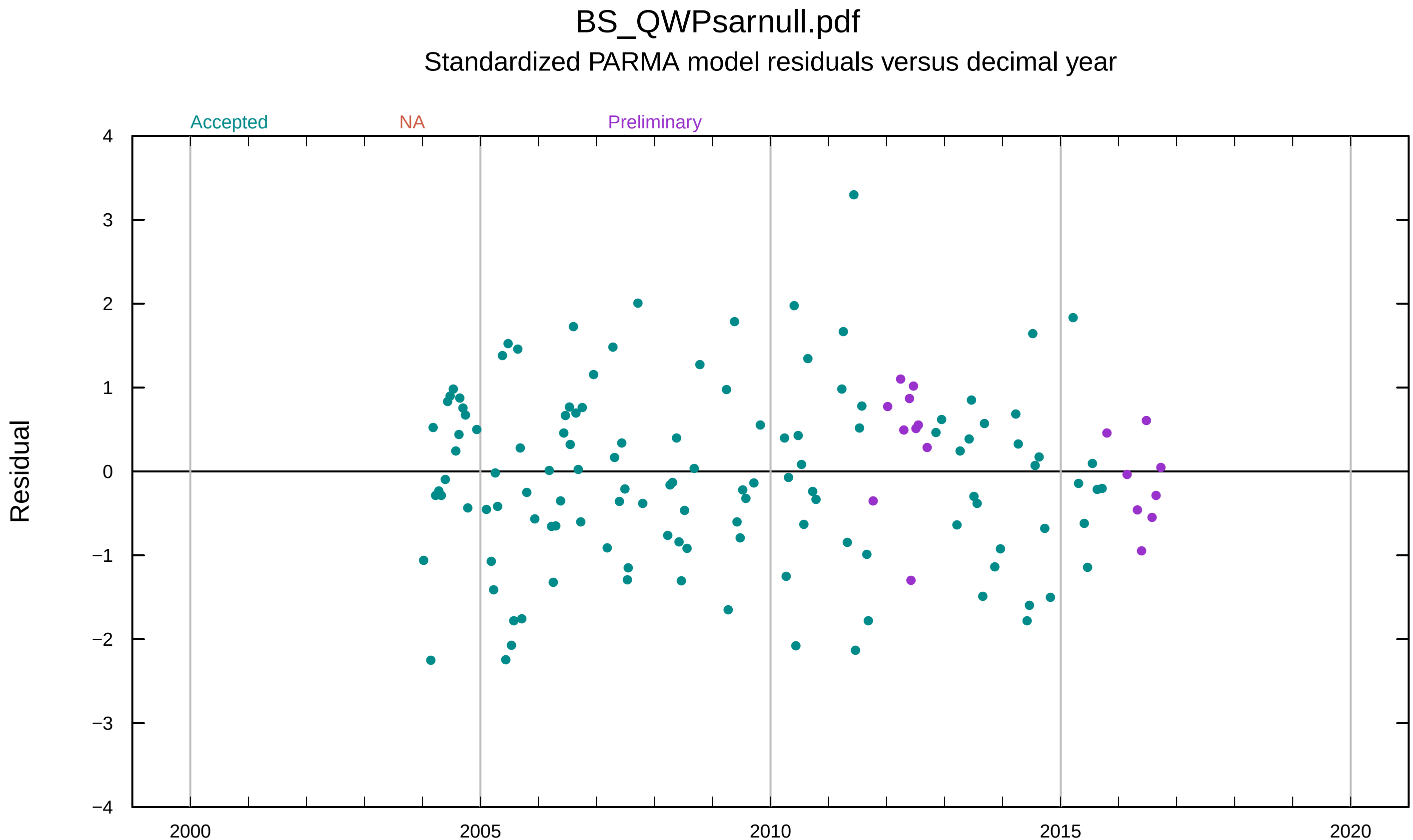

BS_QWPsar_M1.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020


BS_QWPsarnull.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
0.5
0
−0.5
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020


BS_QWPsarnull.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020

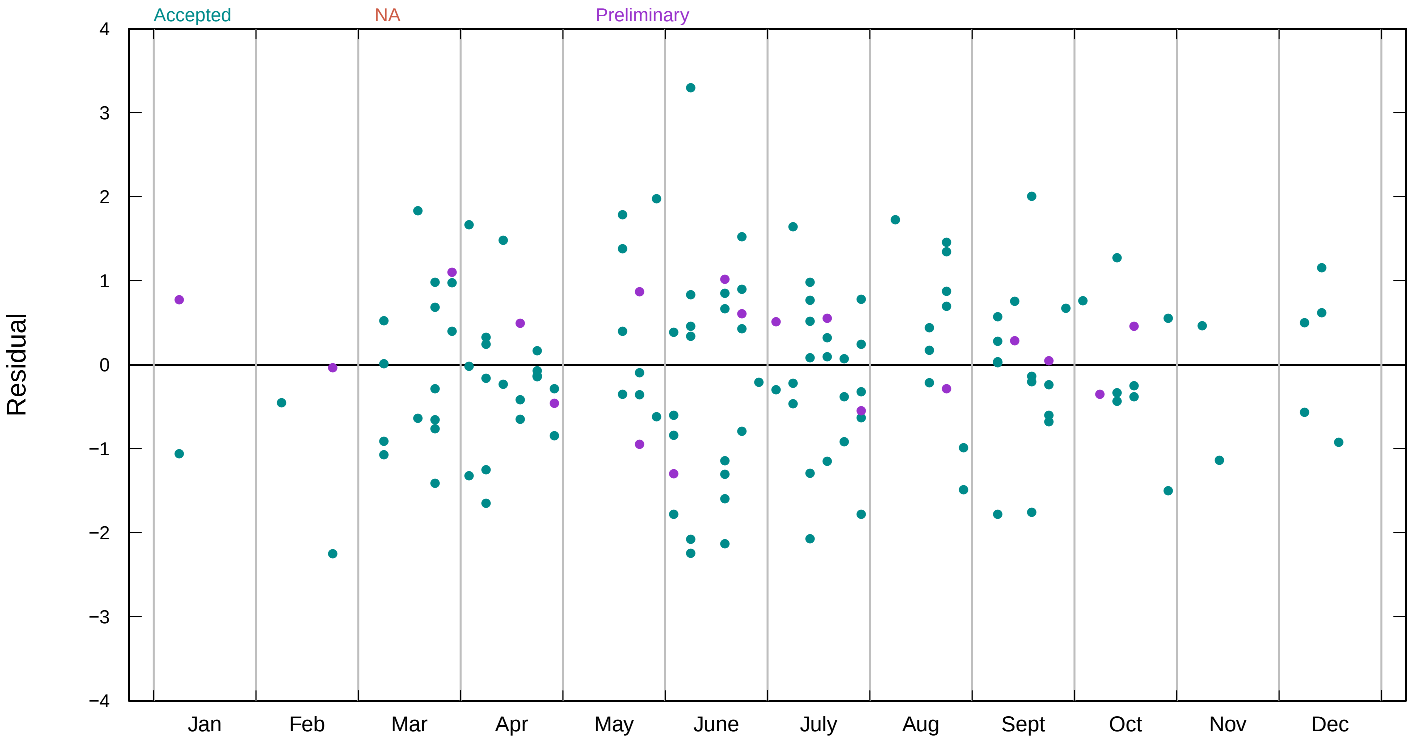

BS_QWPsarnull.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020


BS_QWPsarnull.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020


BS_QWPsarnull.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020

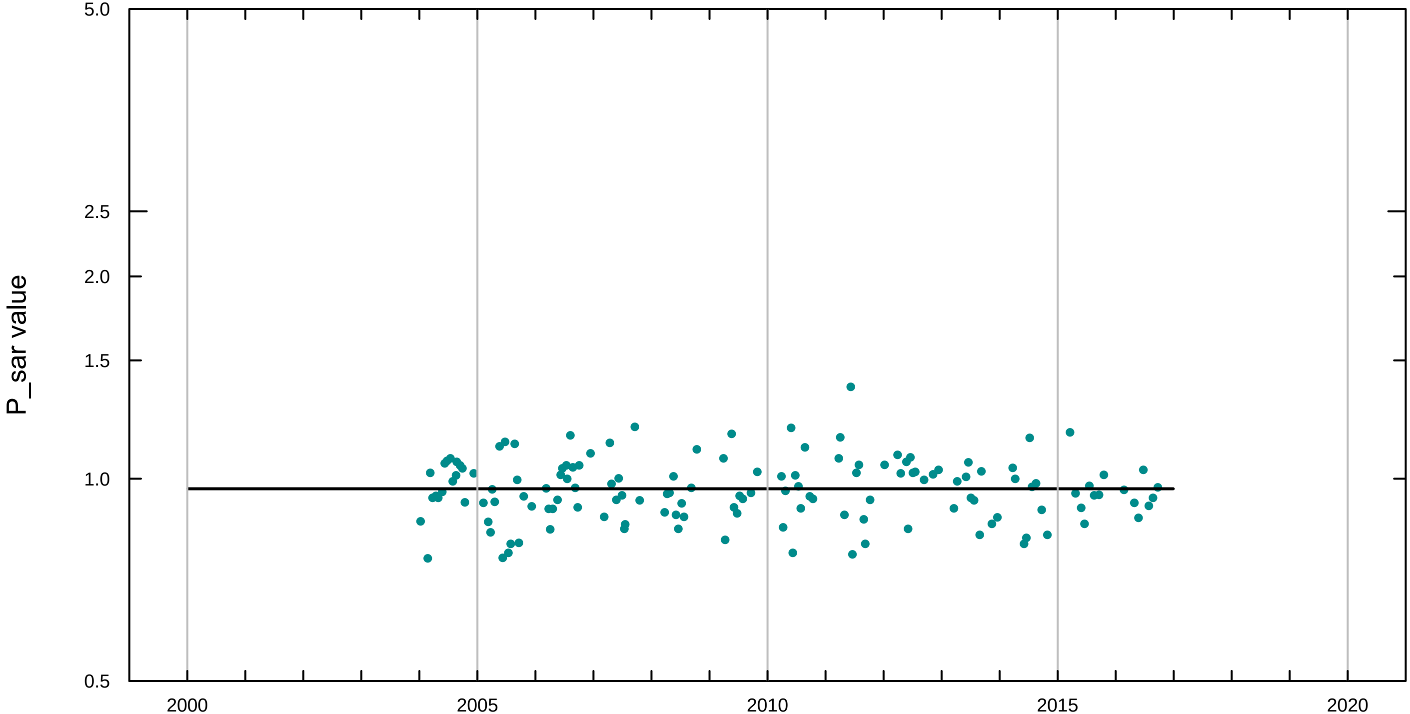
BS_QWPsarnull.pdf

Standardized Parma model residuals versus decimal season



BS_QWPsarnull.pdf

Points: flow−adjusted and PARMA filtered data
Line: fitted trend

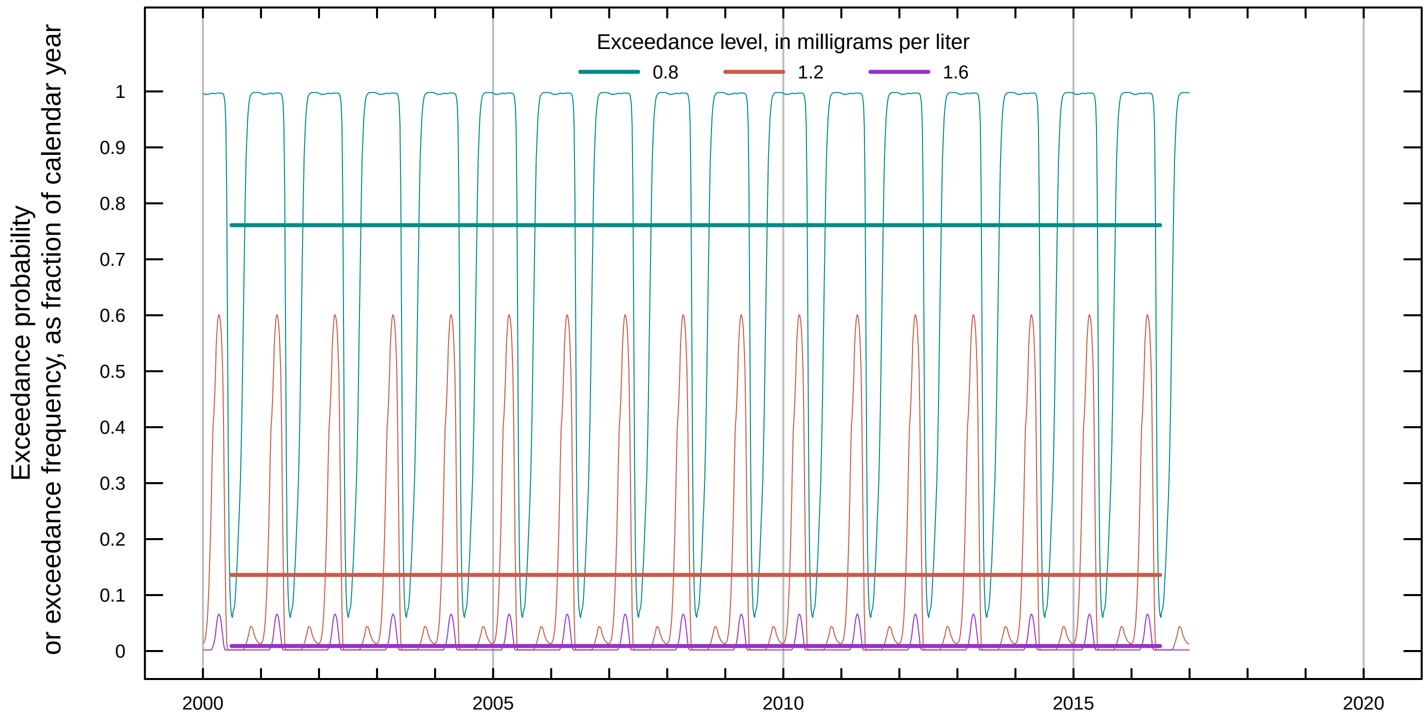


BS_QWPsarnull.pdf

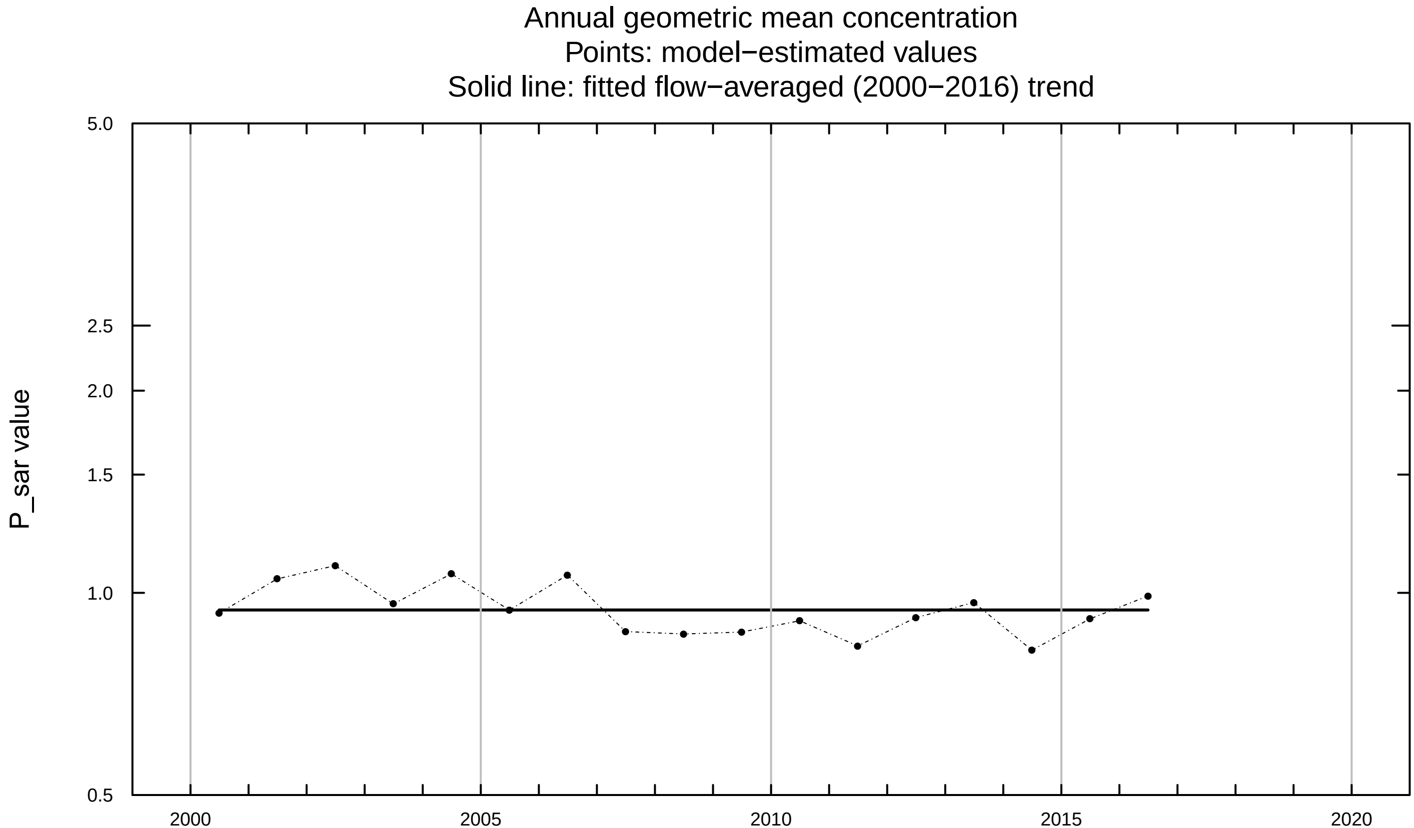
Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

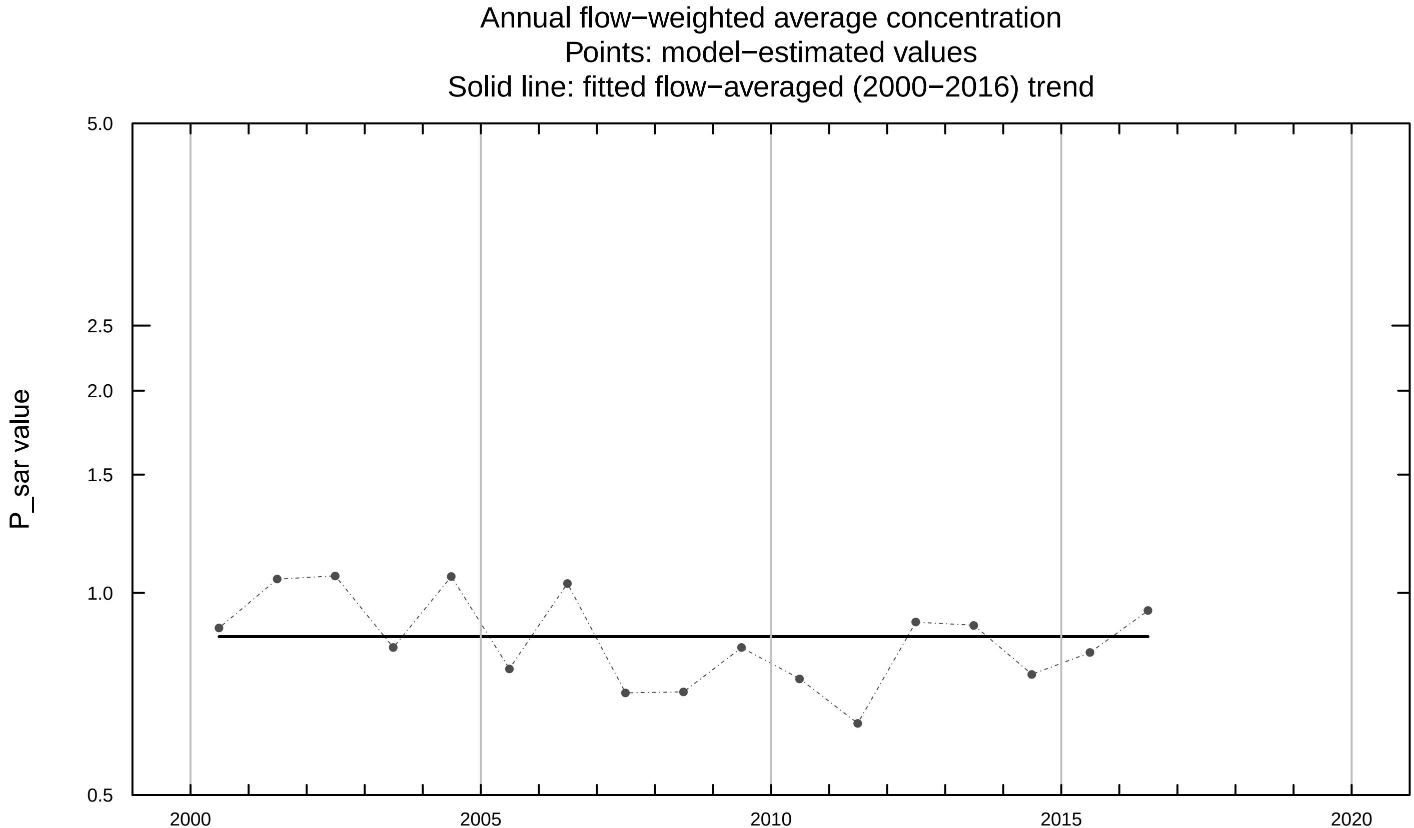
Heavy line: Expected annual flow−averaged exceedance frequency

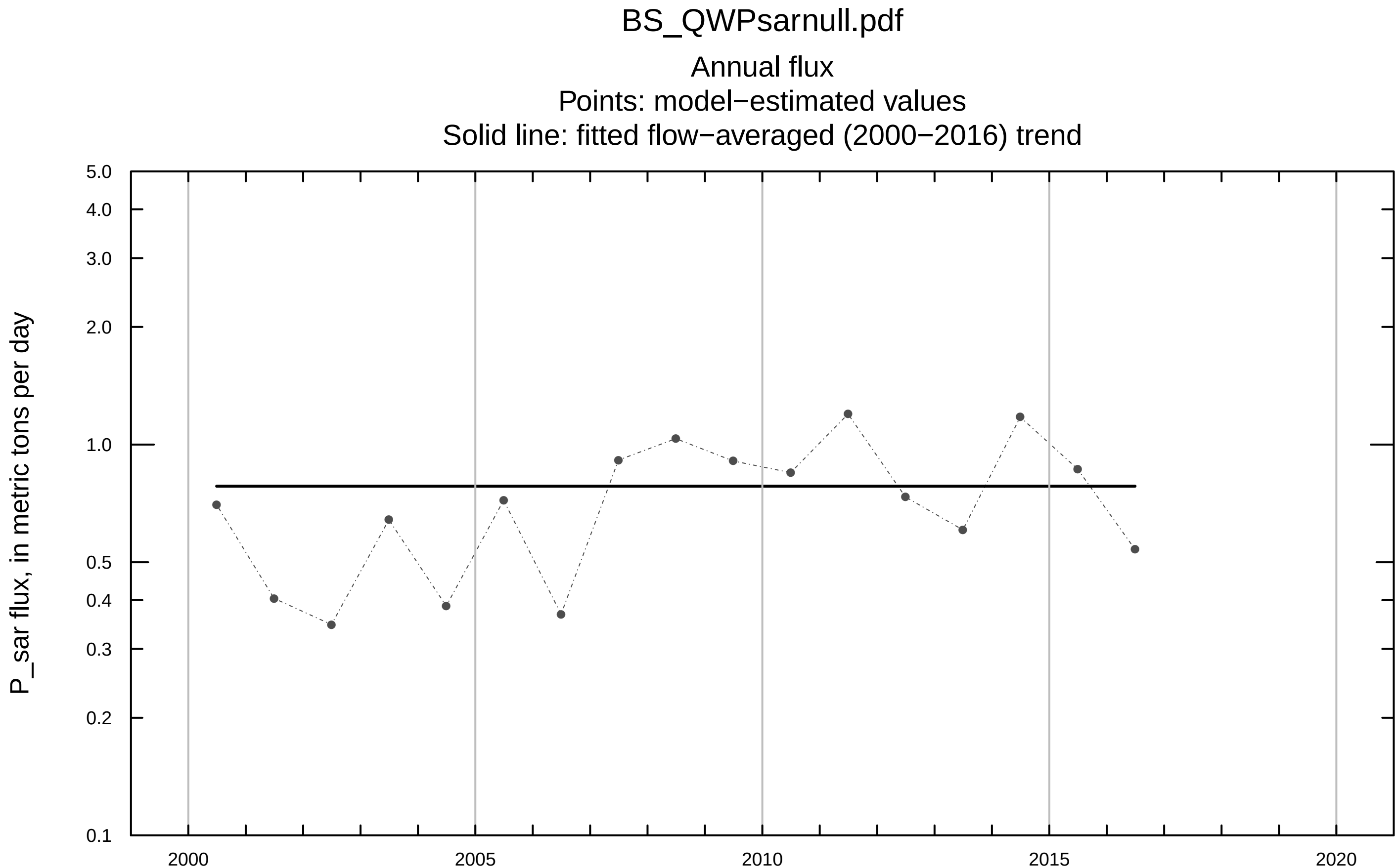


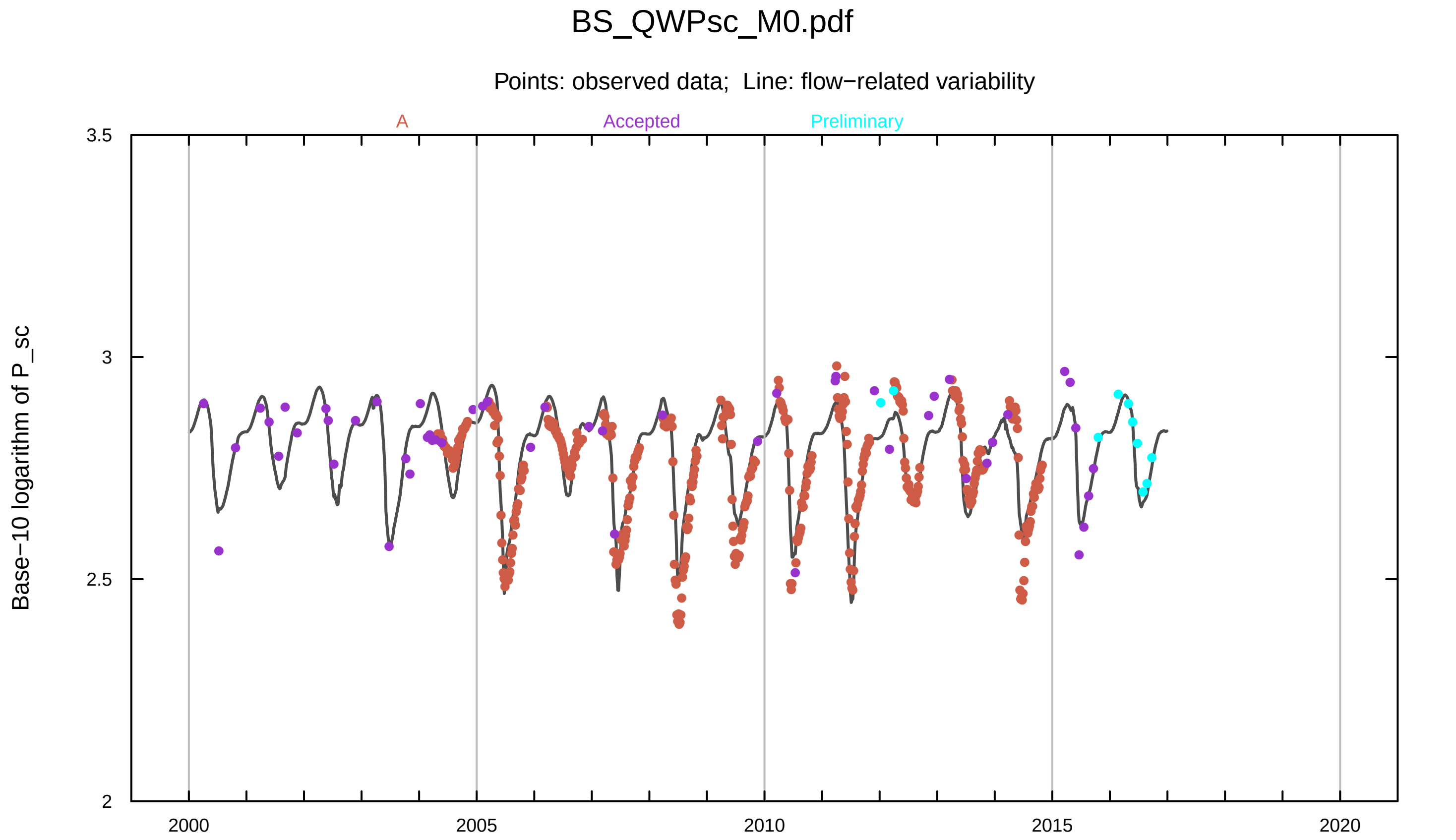
BS_QWPsarnull.pdf



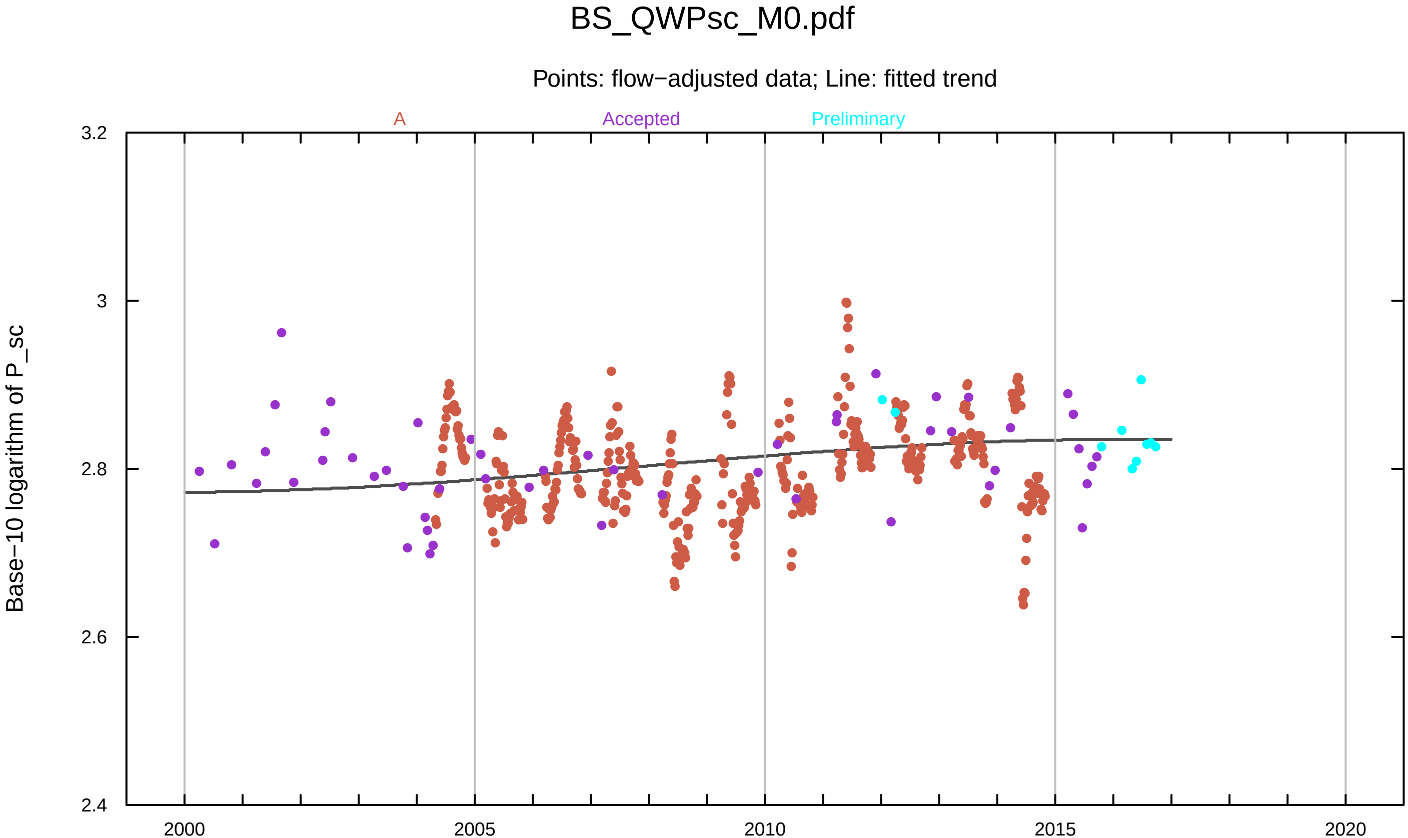
BS_QWPsarnull.pdf



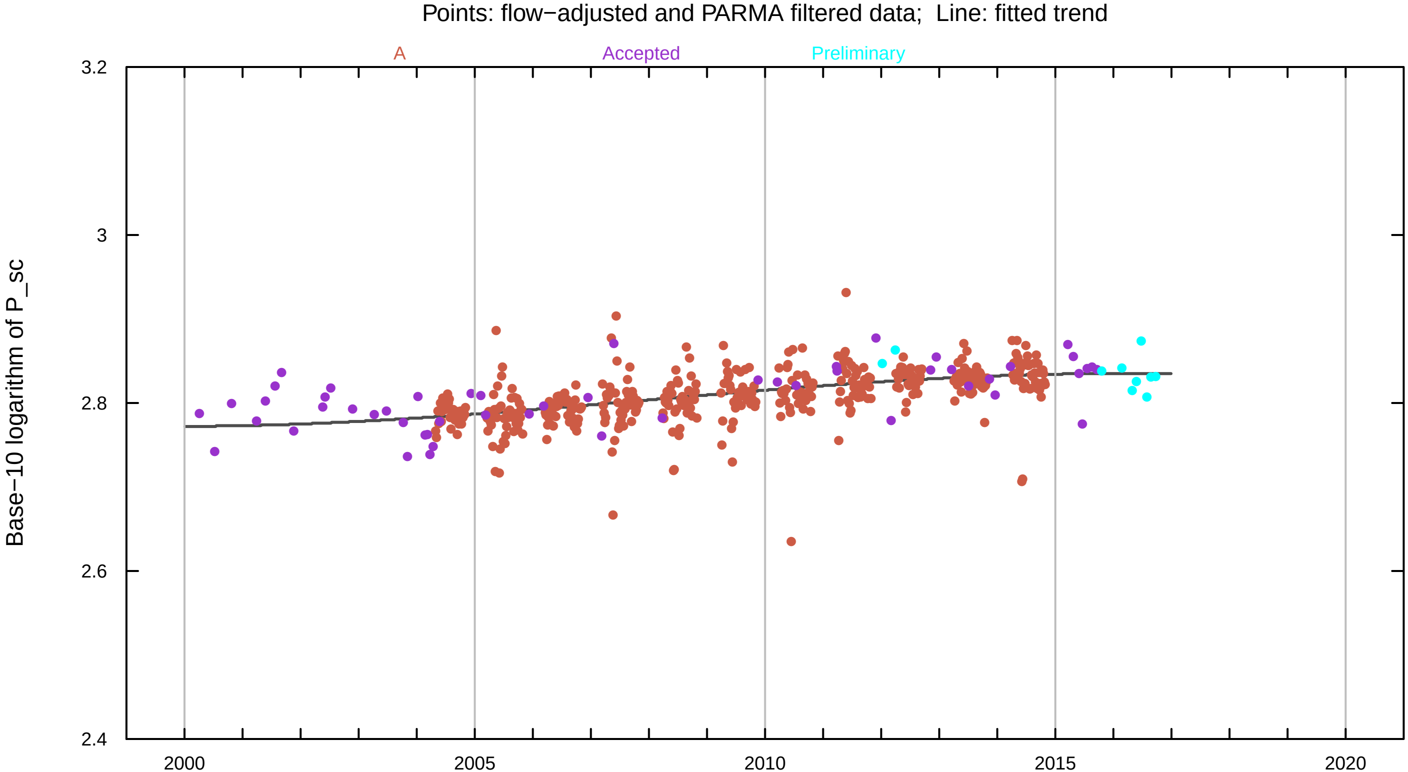

BS_QWPsarnull.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020



BS_QWPsc_M0.pdf
Points: observed data; Line: flow−related variability
A
Accepted
Preliminary
3.5
3
2.5
2
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020

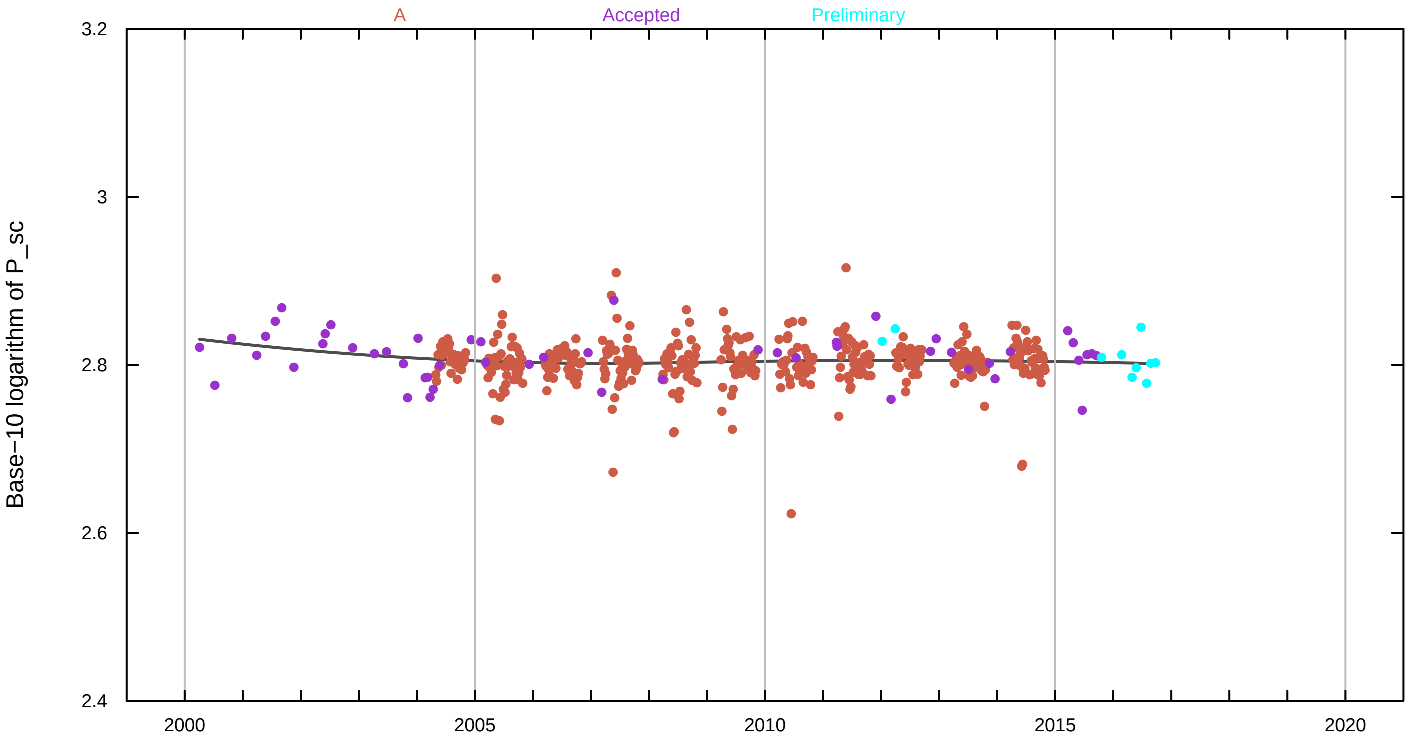

BS_QWPsc_M0.pdf
Points: flow−adjusted data; Line: fitted trend
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020

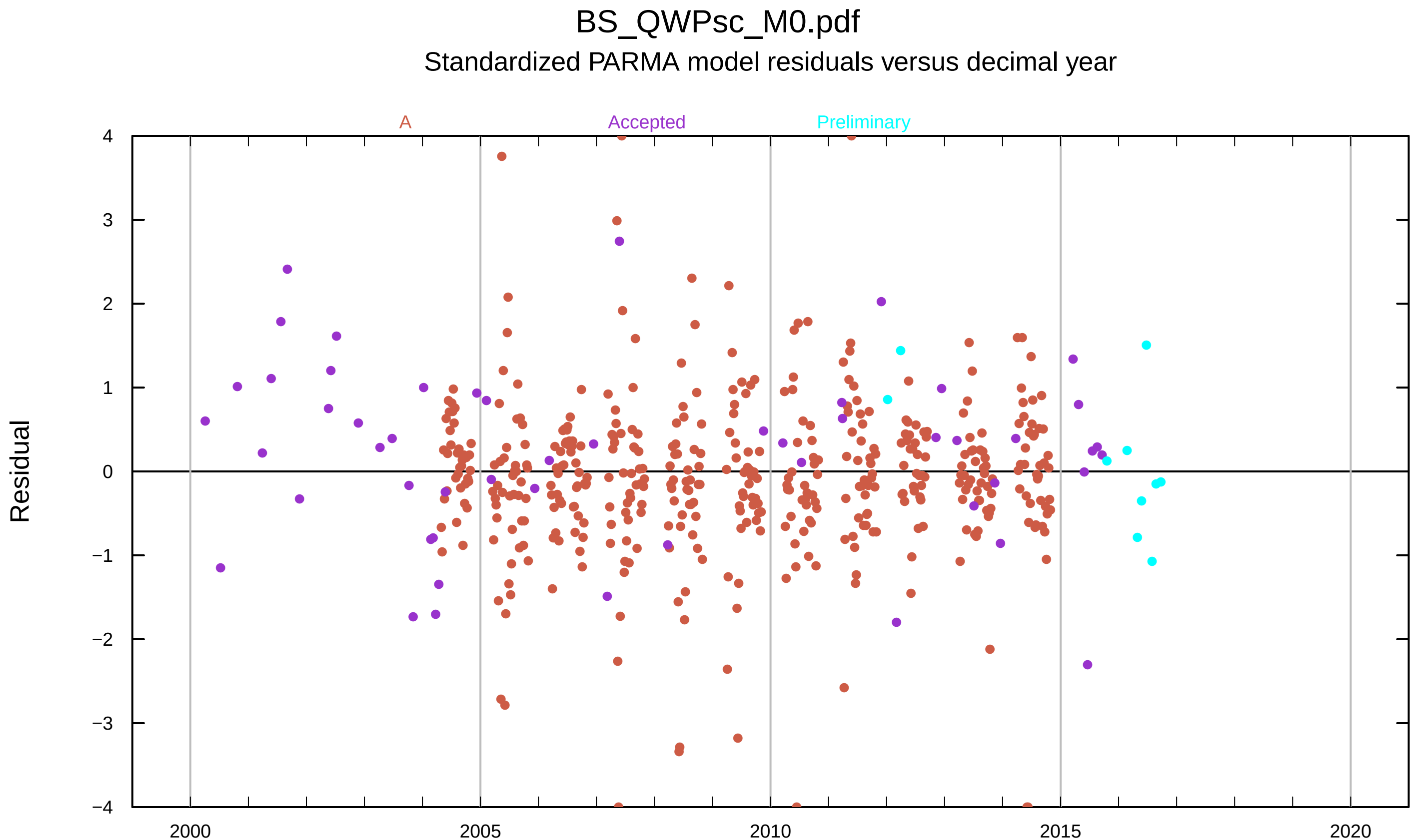
BS_QWPsc_M0.pdf



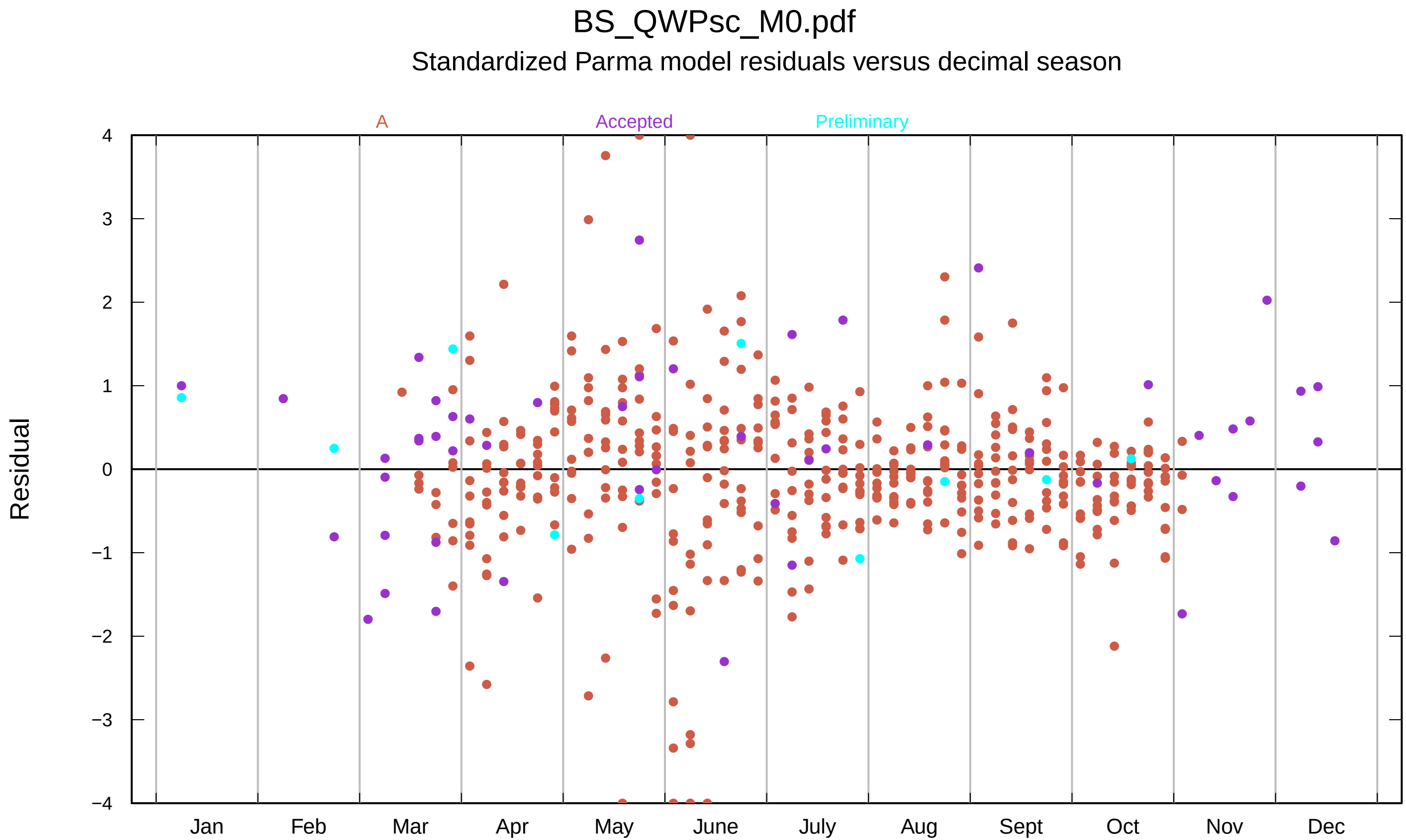
BS_QWPsc_M0.pdf

Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline

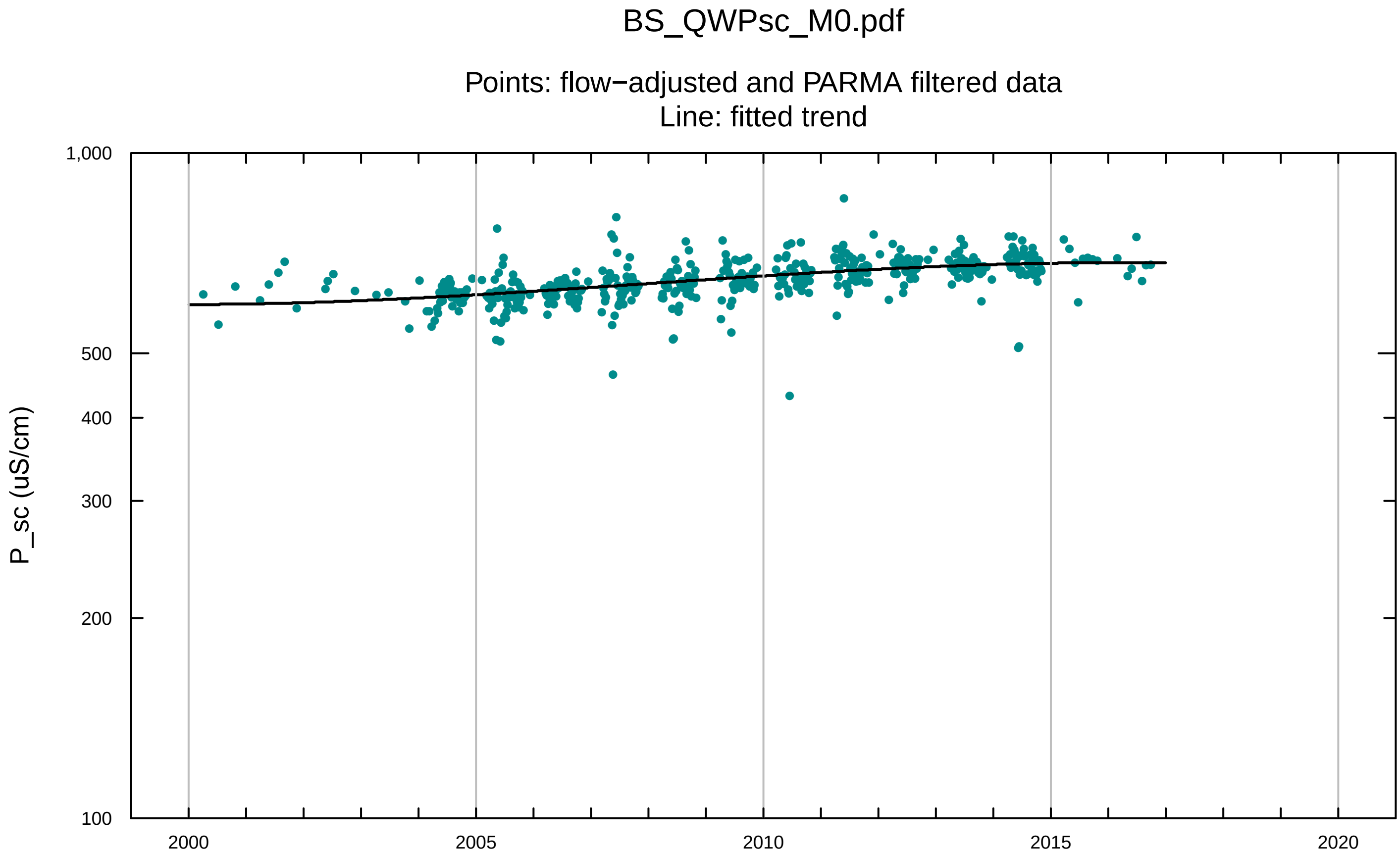




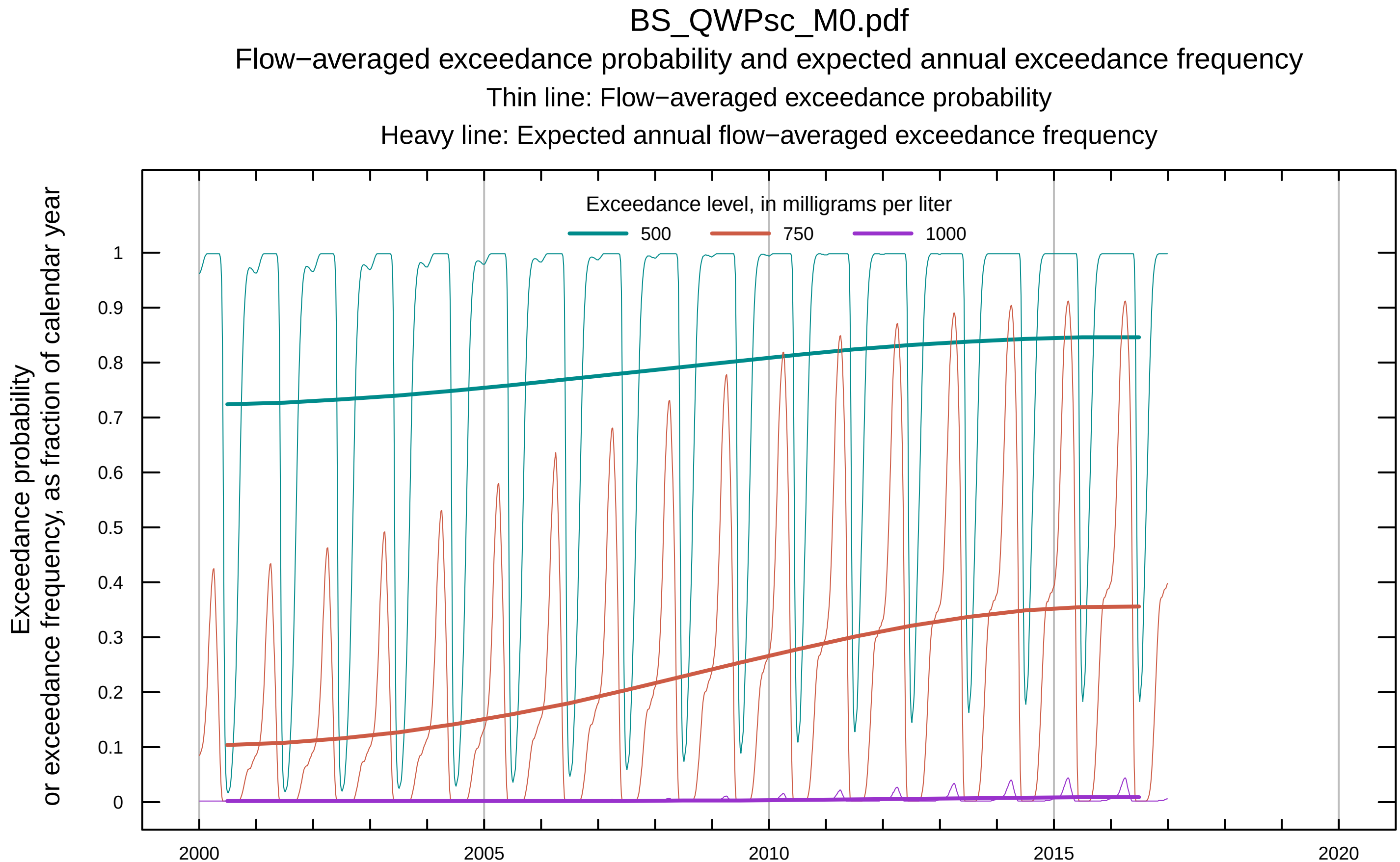
BS_QWPsc_M0.pdf
Standardized PARMA model residuals versus decimal year
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020

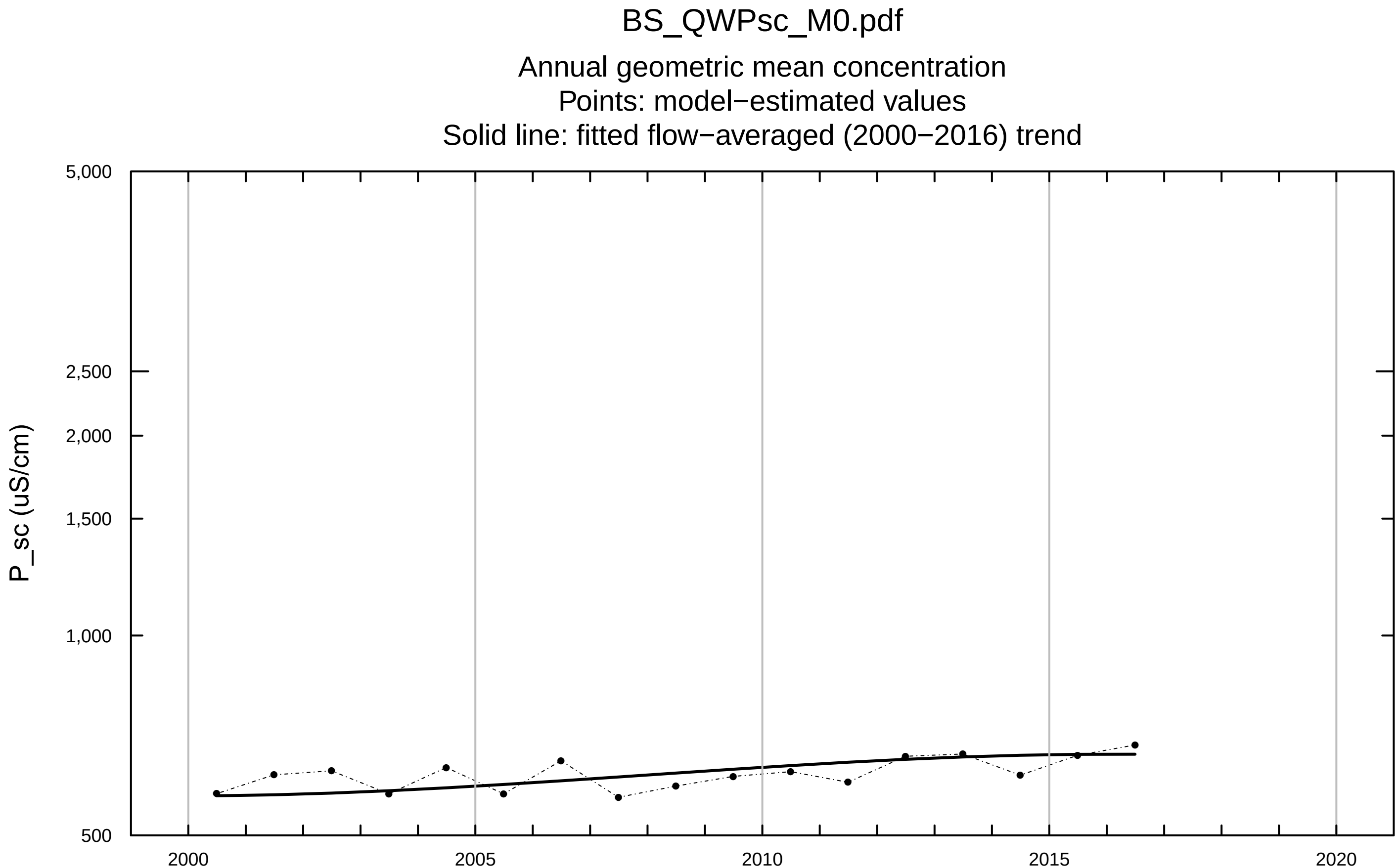


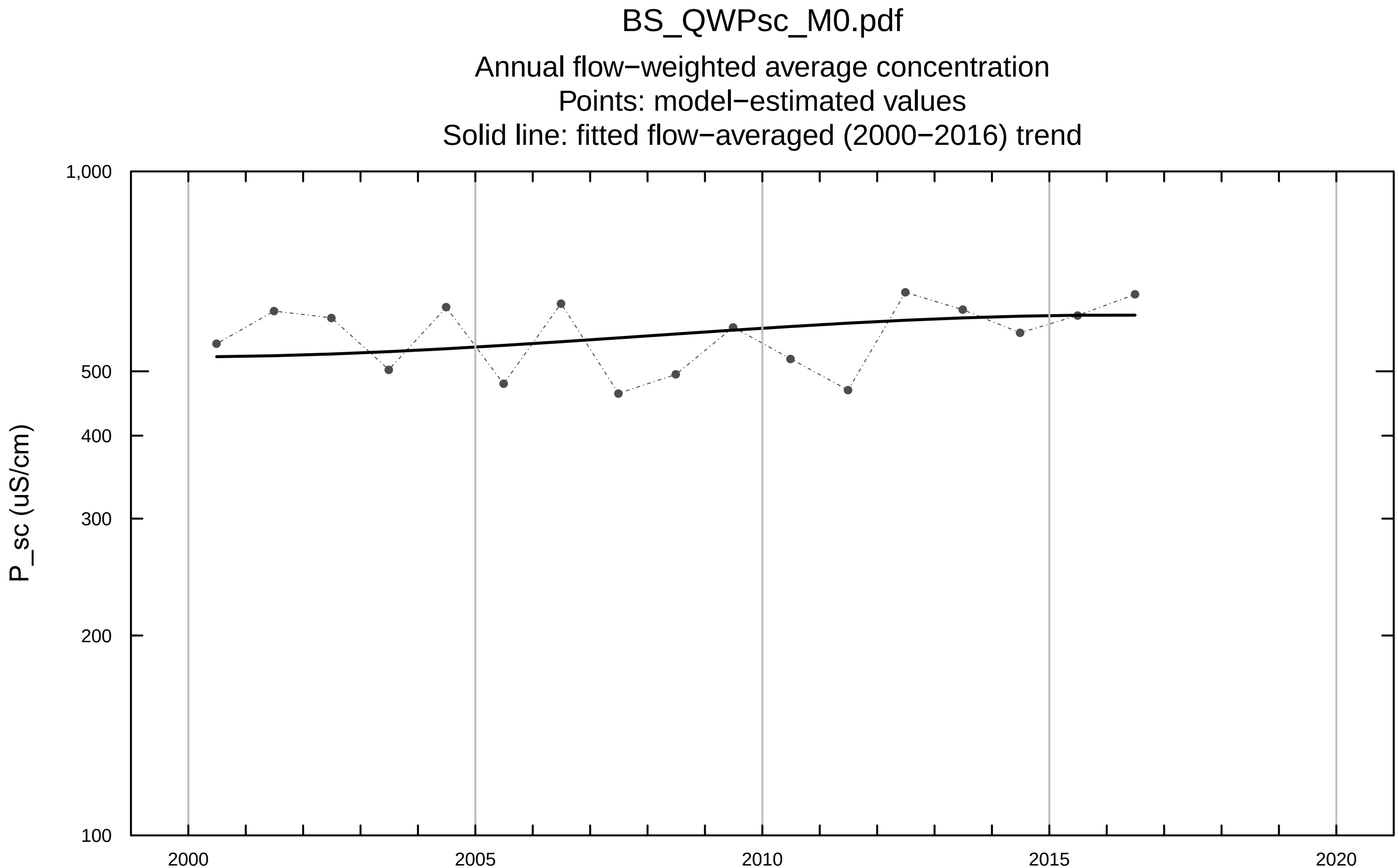
BS_QWPsc_M0.pdf
Standardized Parma model residuals versus decimal season
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

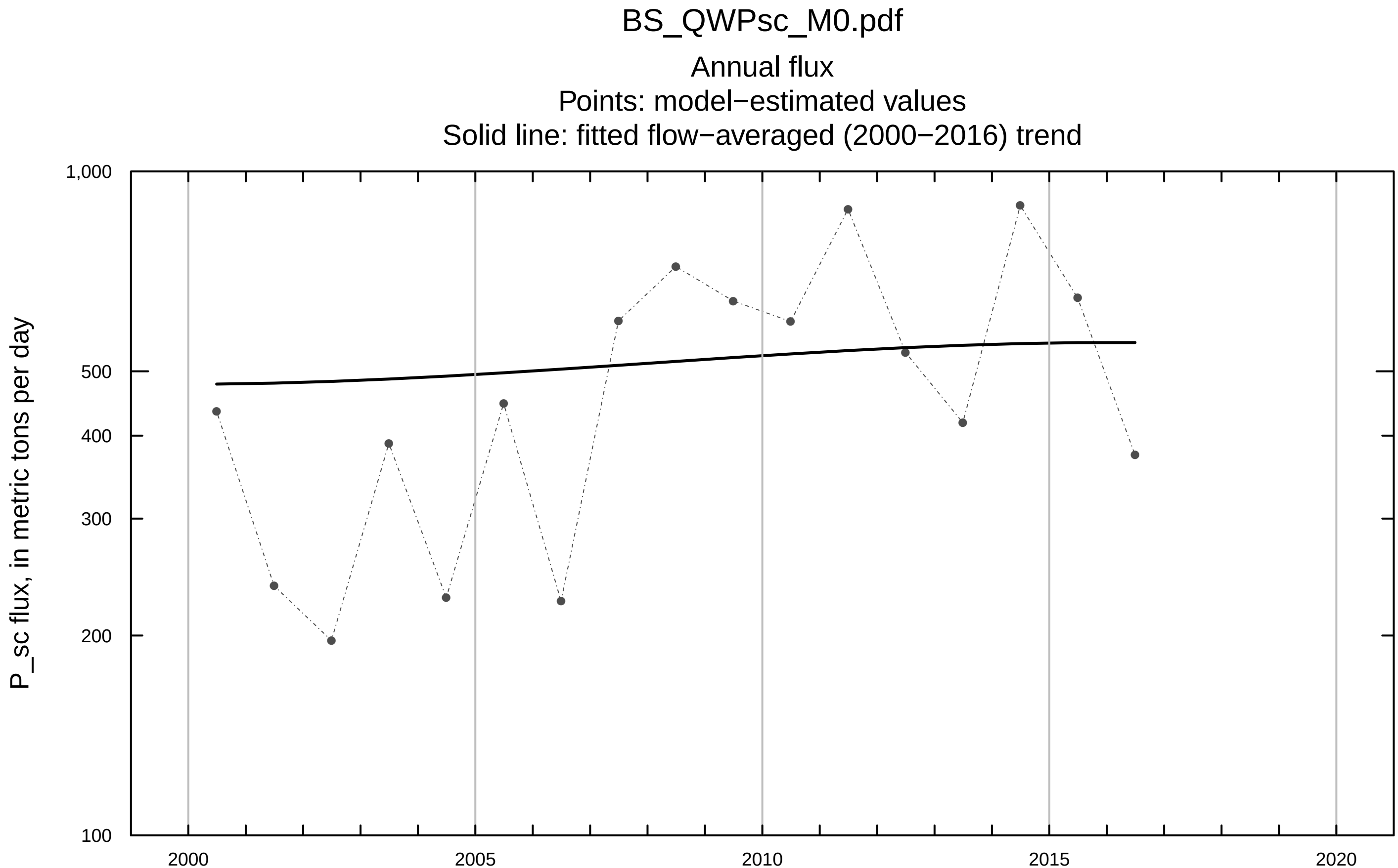


BS_QWPsc_M0.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

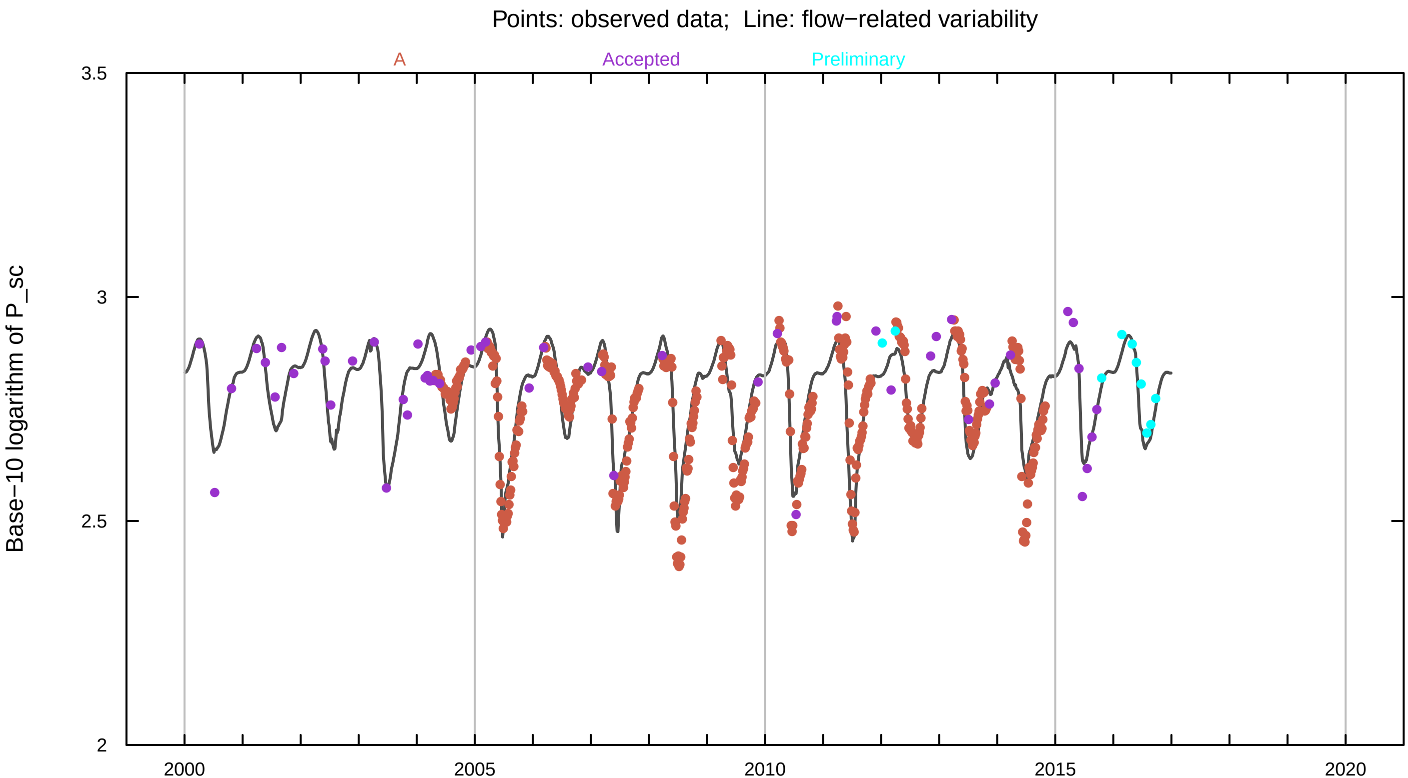

BS_QWPsc_M0.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
500
750
1000
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020

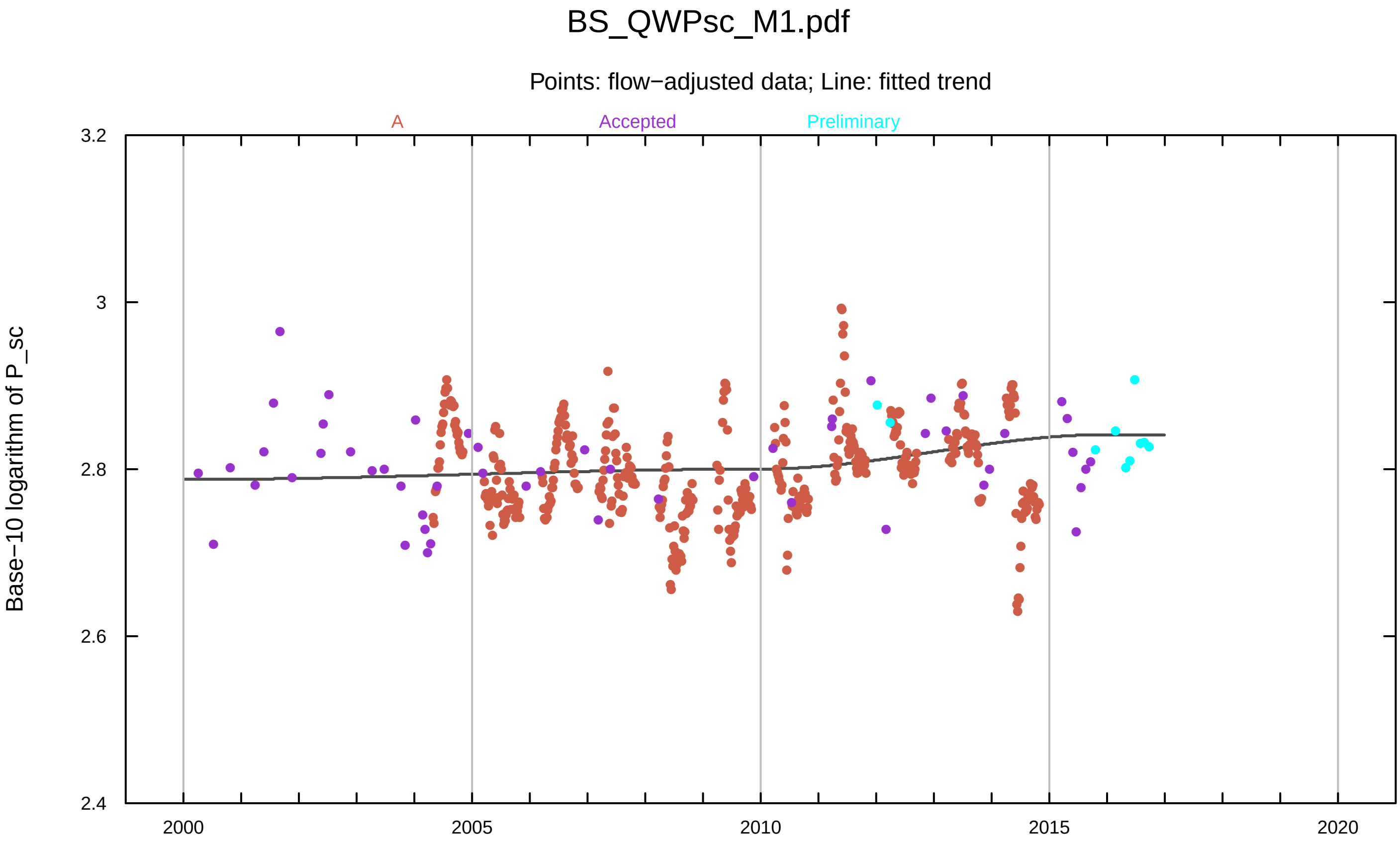

BS_QWPsc_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020

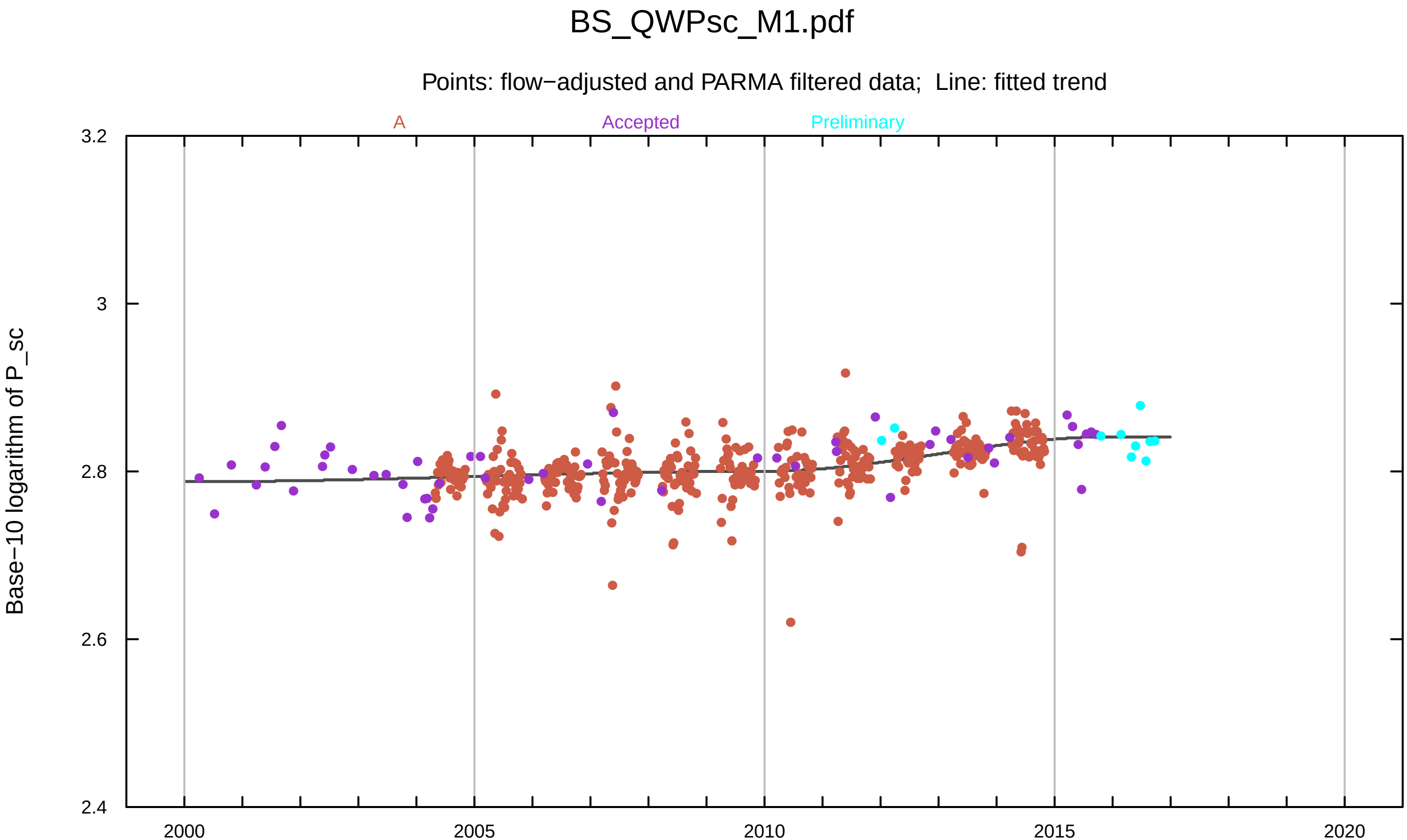

BS_QWPsc_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

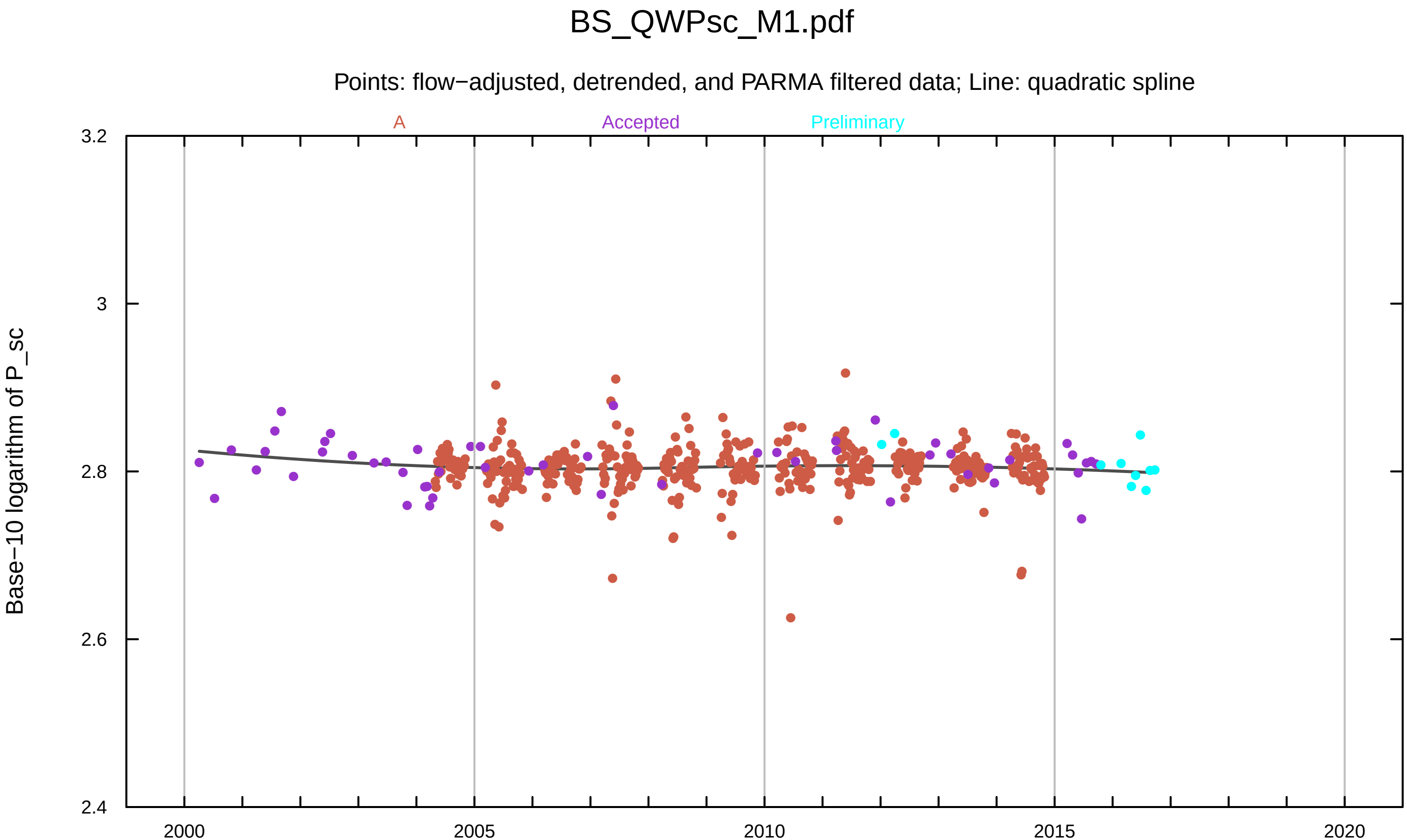

BS_QWPsc_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

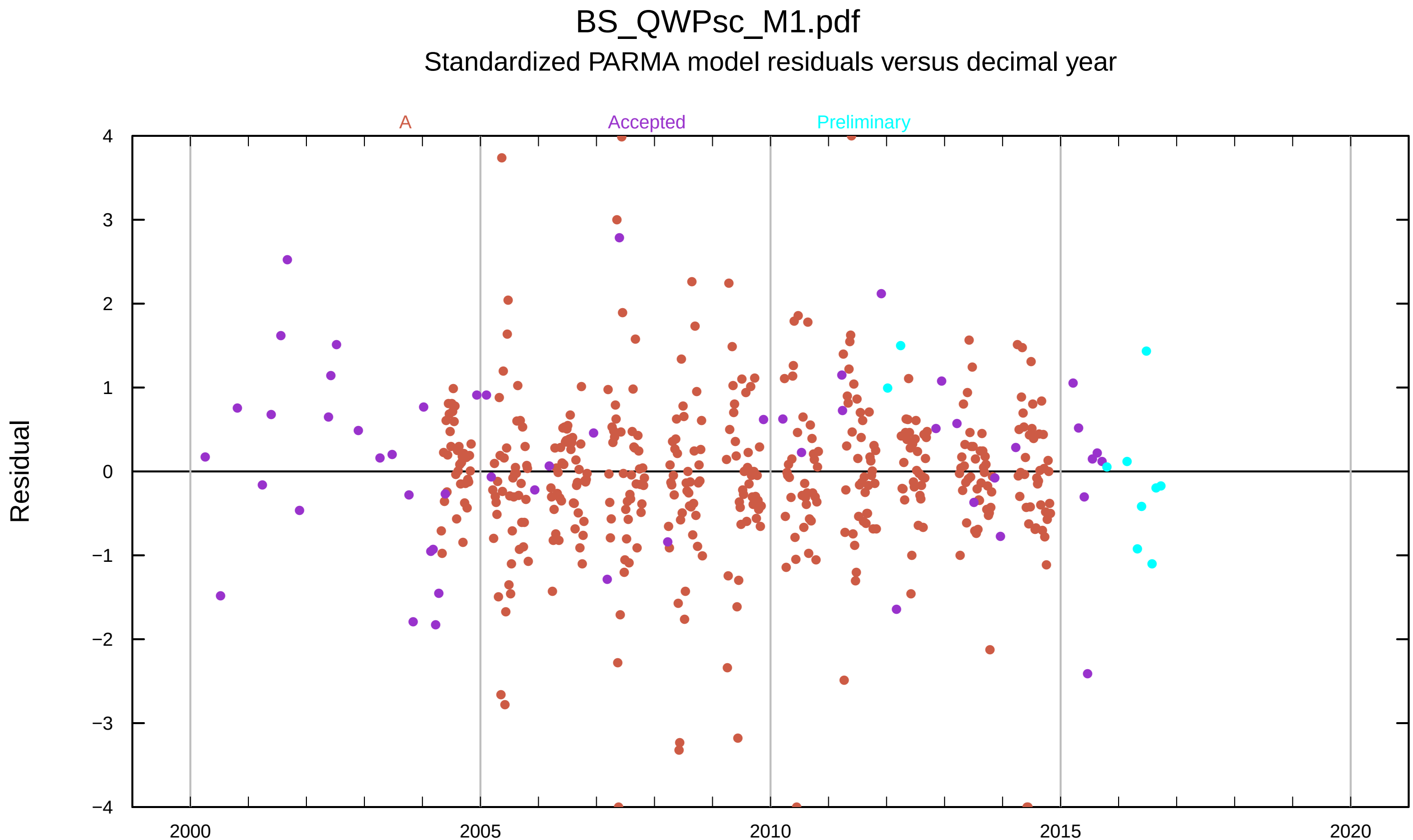
BS_QWPsc_M1.pdf

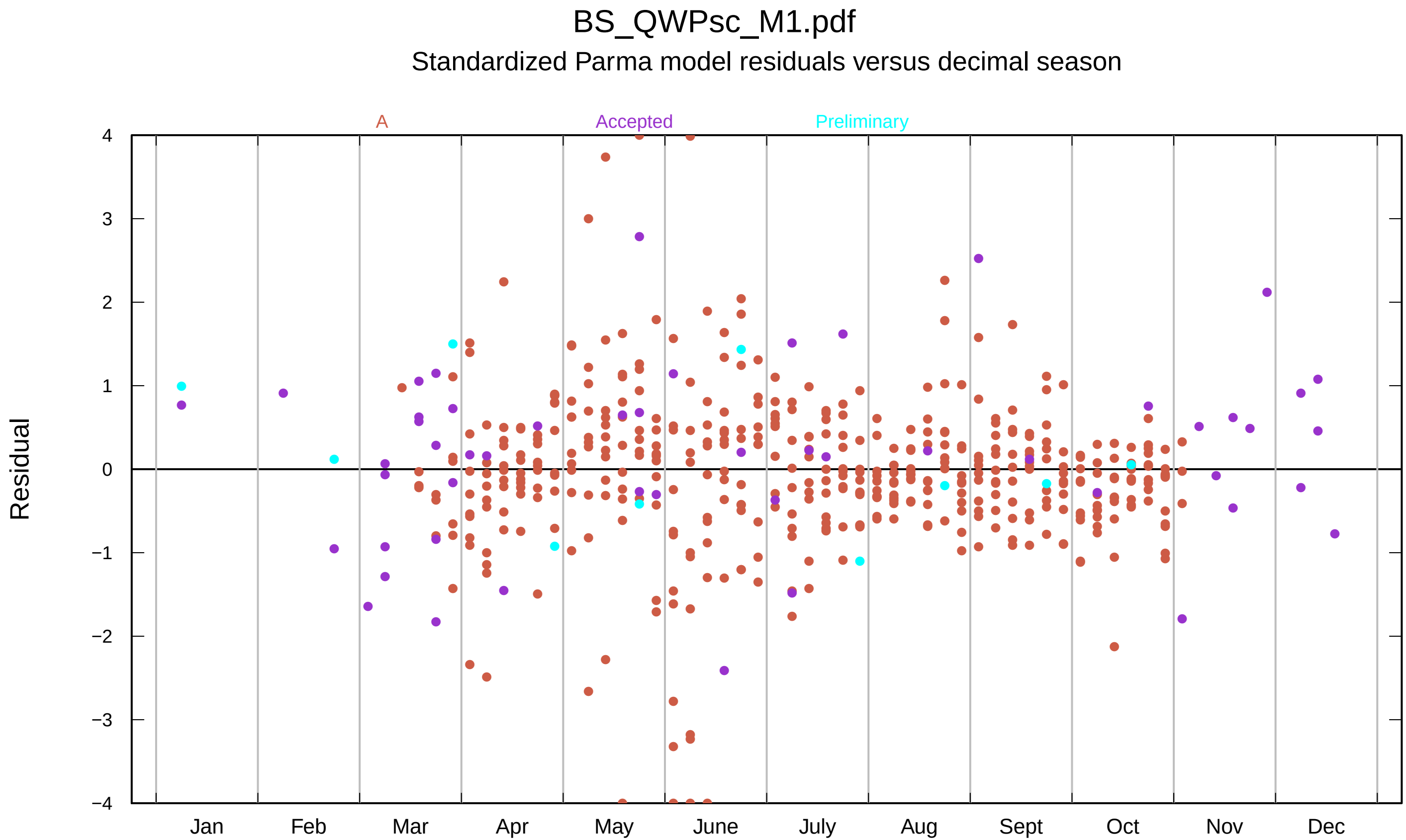


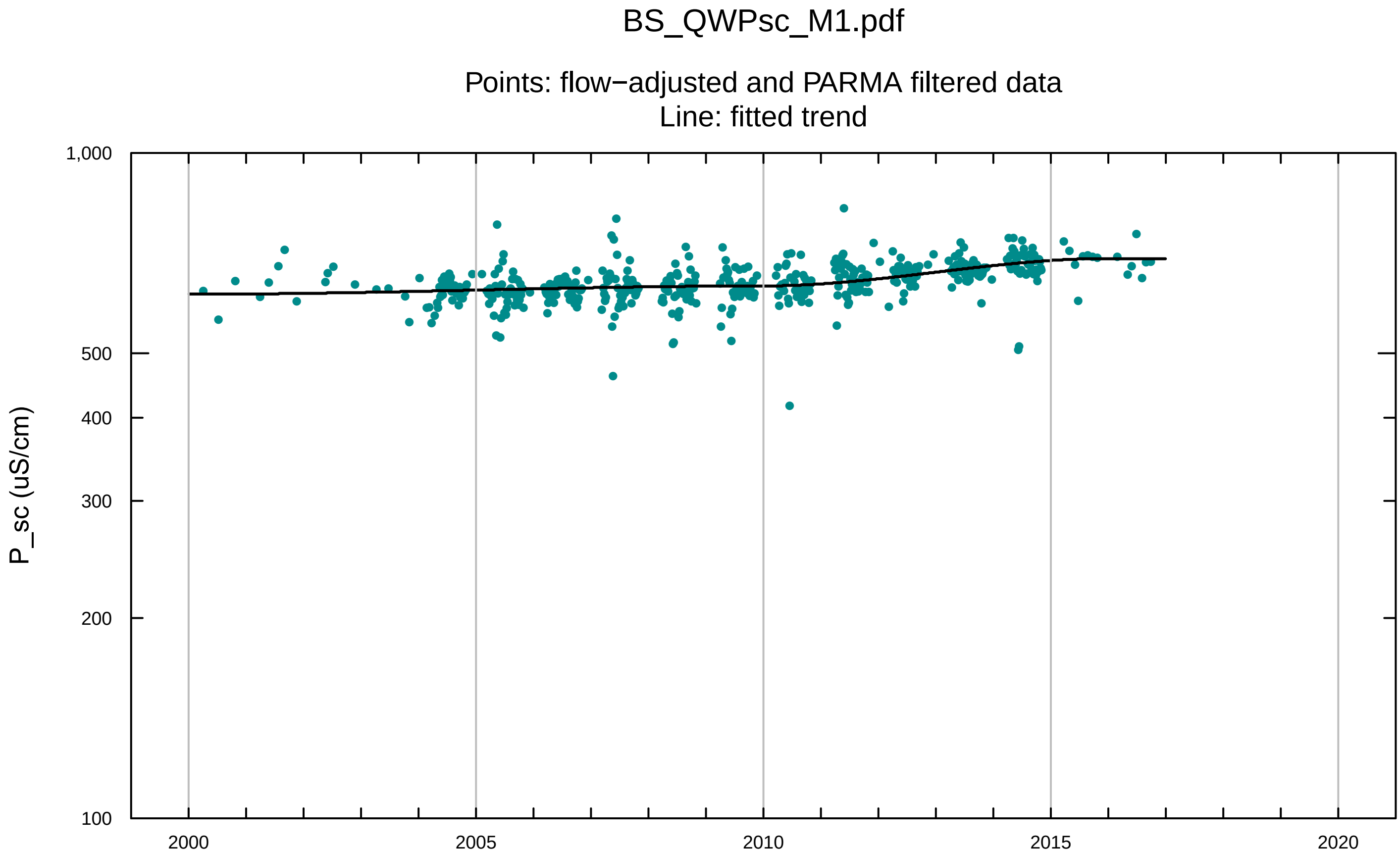

BS_QWPsc_M1.pdf
Points: flow−adjusted data; Line: fitted trend
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020


BS_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
Accepted
Preliminary
3.2
3
2.8
2.6
2.4
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020


BS_QWPsc_M1.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020


BS_QWPsc_M1.pdf
Standardized PARMA model residuals versus decimal year
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020


BS_QWPsc_M1.pdf
Standardized Parma model residuals versus decimal season
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

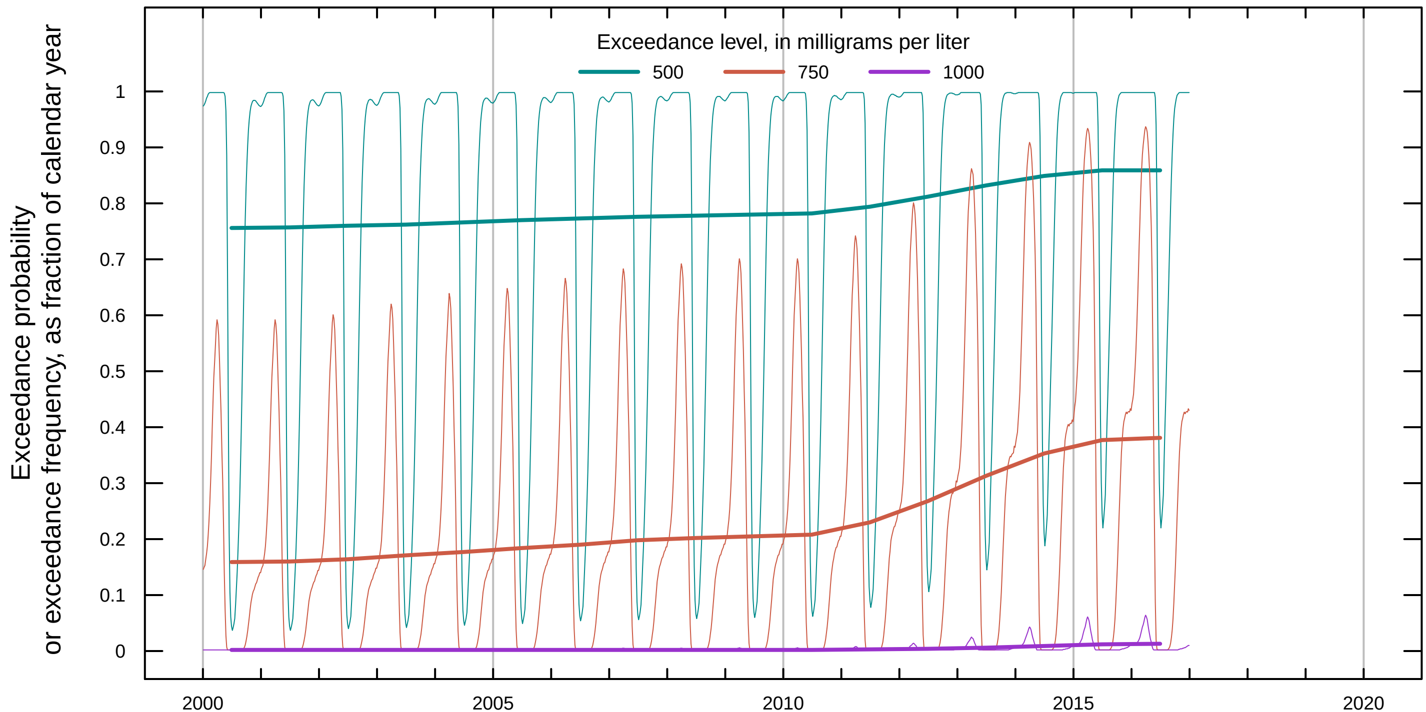

BS_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

BS_QWPsc_M1.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

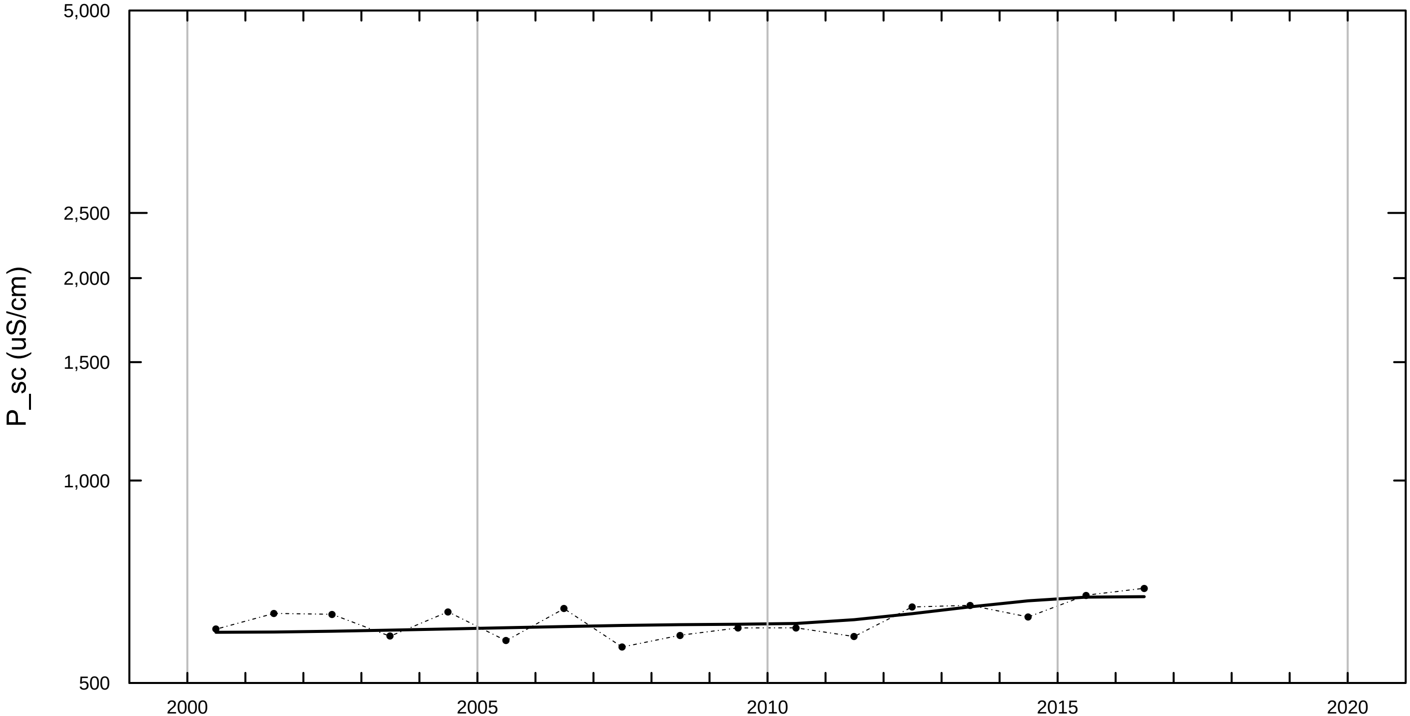
Thin line: Flow−averaged exceedance probability

Heavy line: Expected annual flow−averaged exceedance frequency



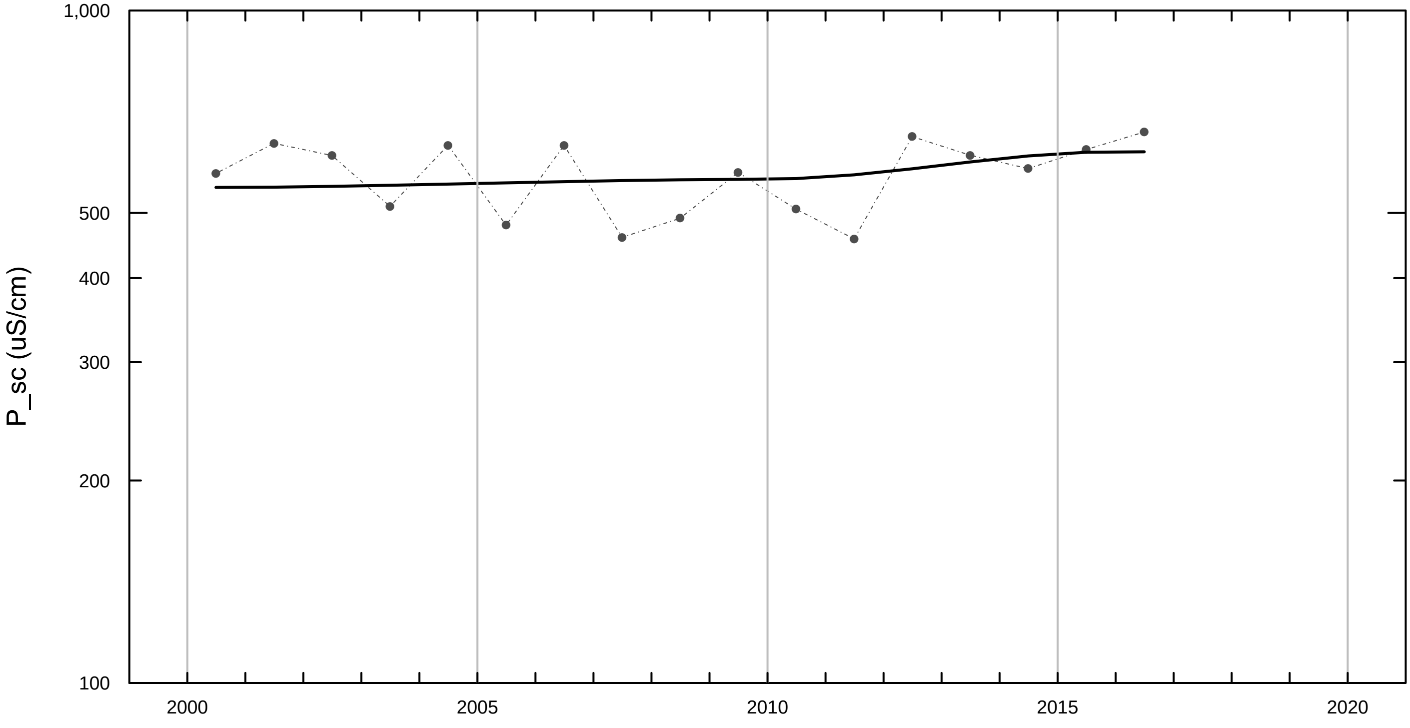
BS_QWPsc_M1.pdf

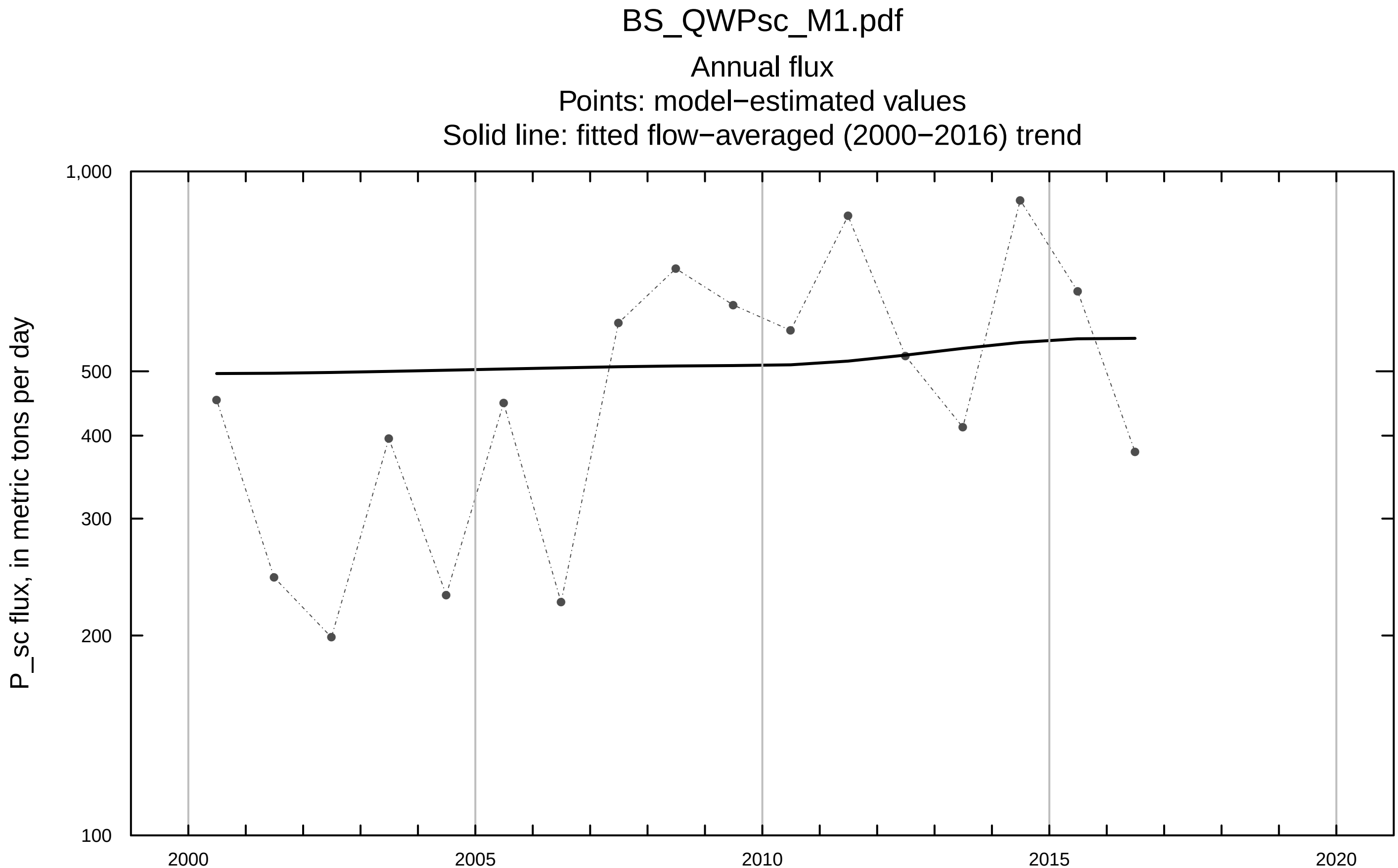
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend

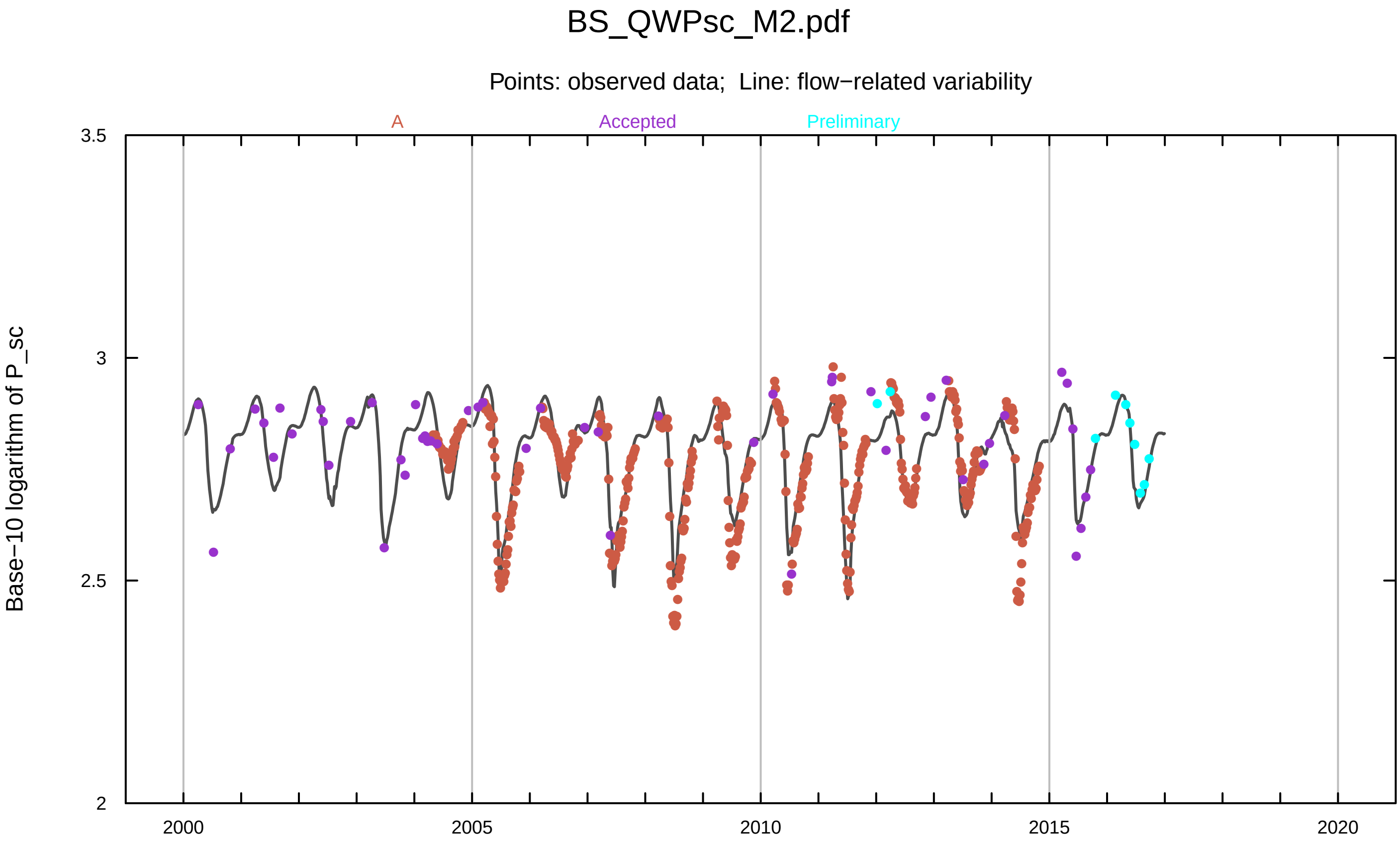


BS_QWPsc_M1.pdf

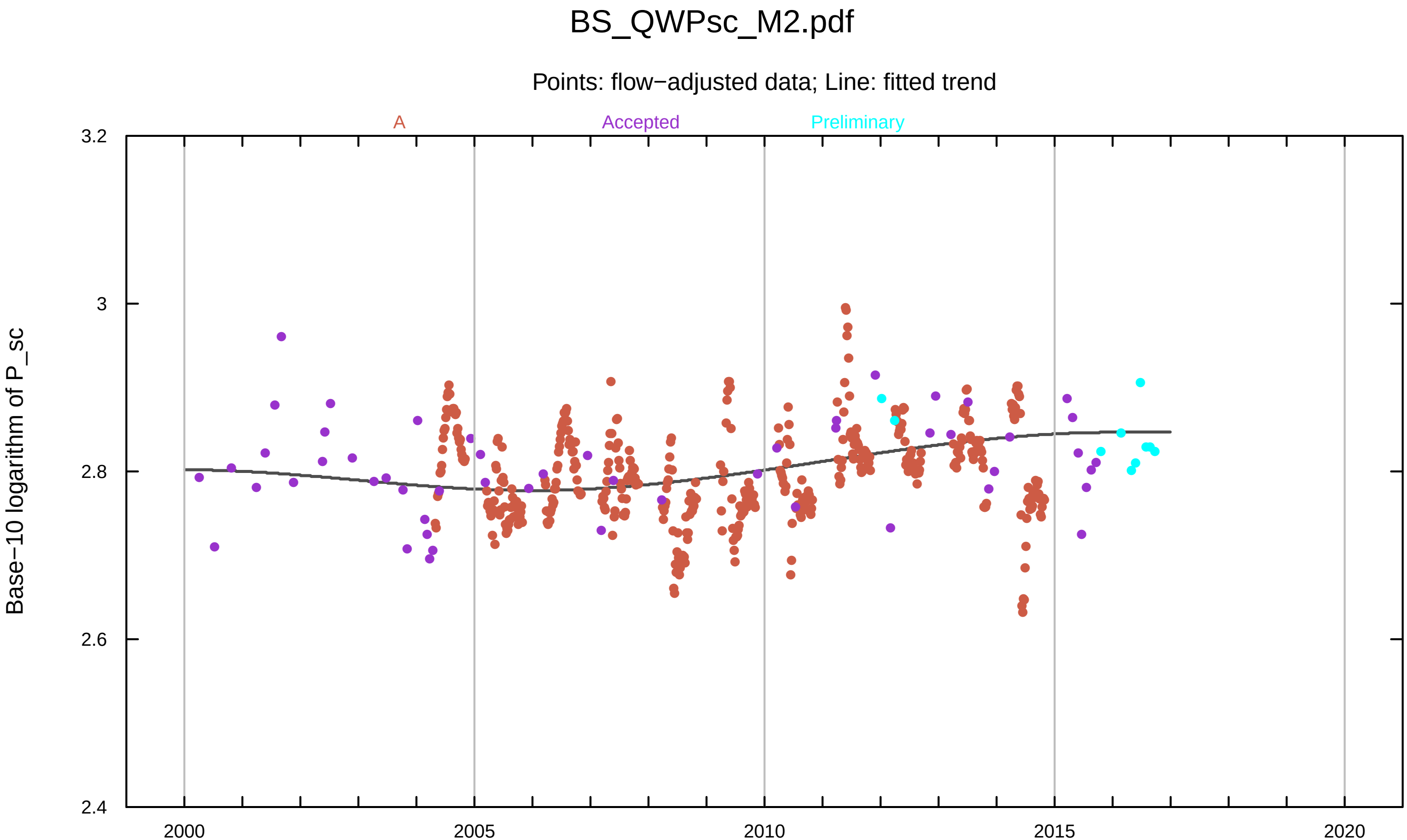
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend



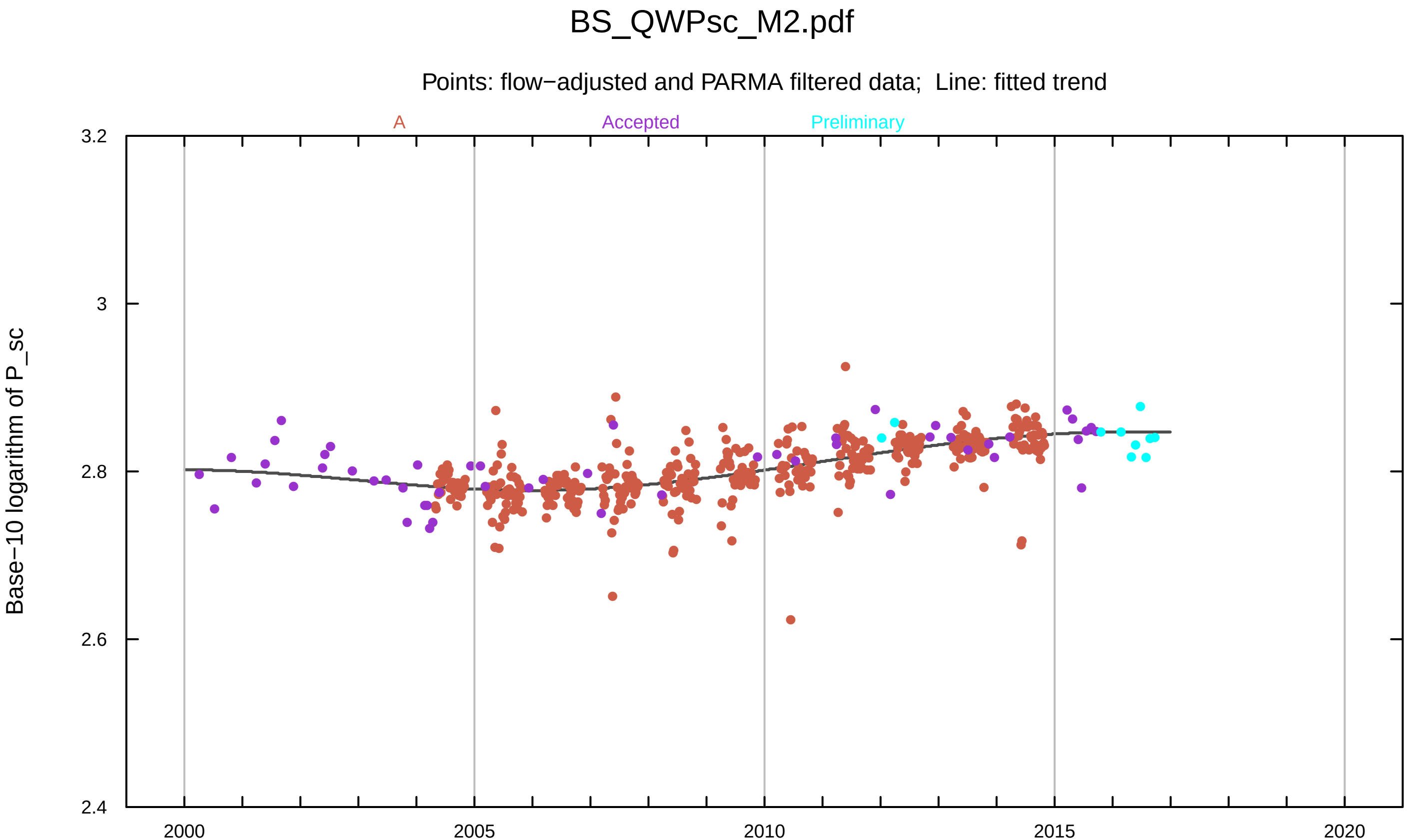

BS_QWPsc_M1.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

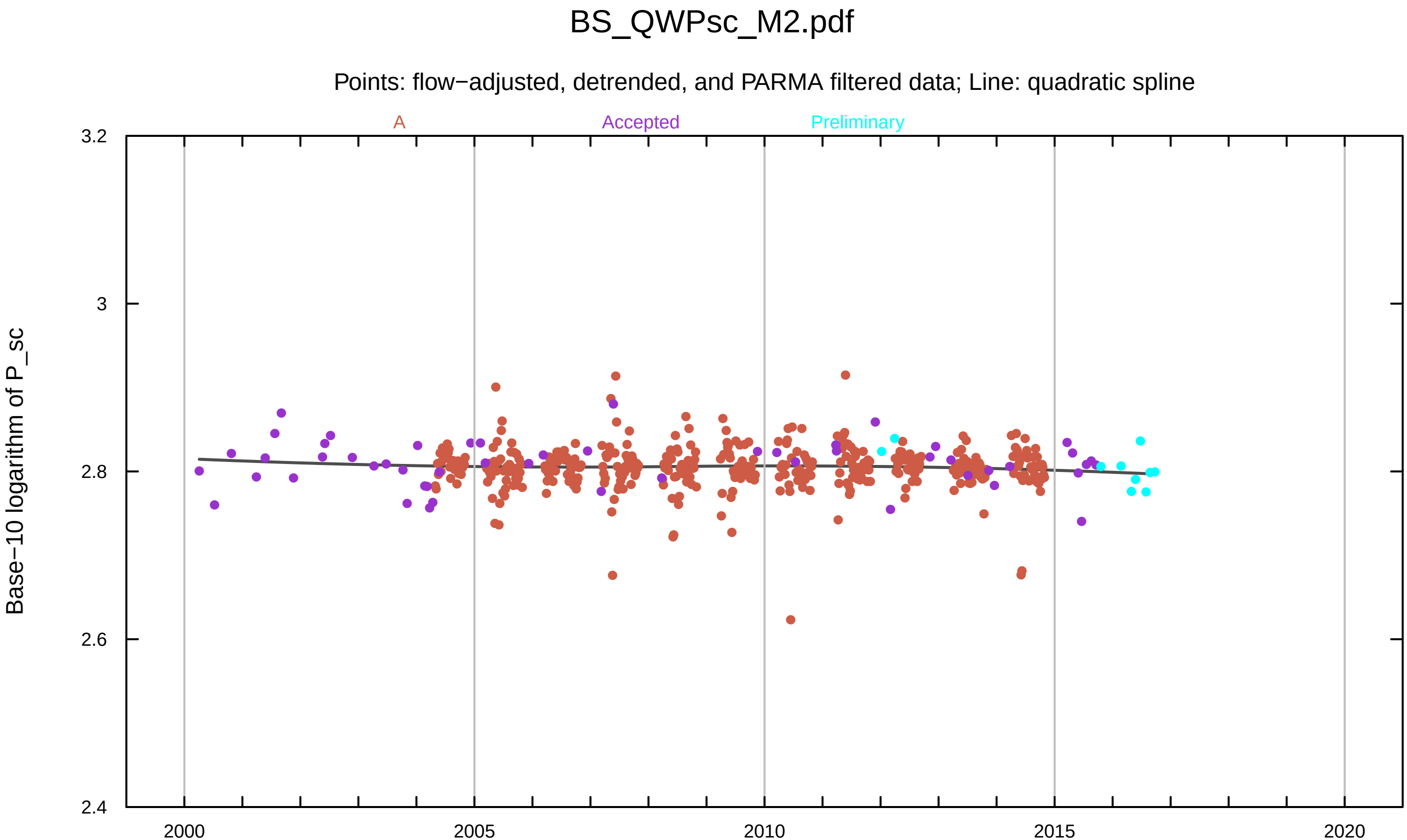


BS_QWPsc_M2.pdf
Points: observed data; Line: flow−related variability
A
Accepted
Preliminary
3.5
3
2.5
2
2000
2005
2010
2015
2020
Base−10 logarithm of P_sc

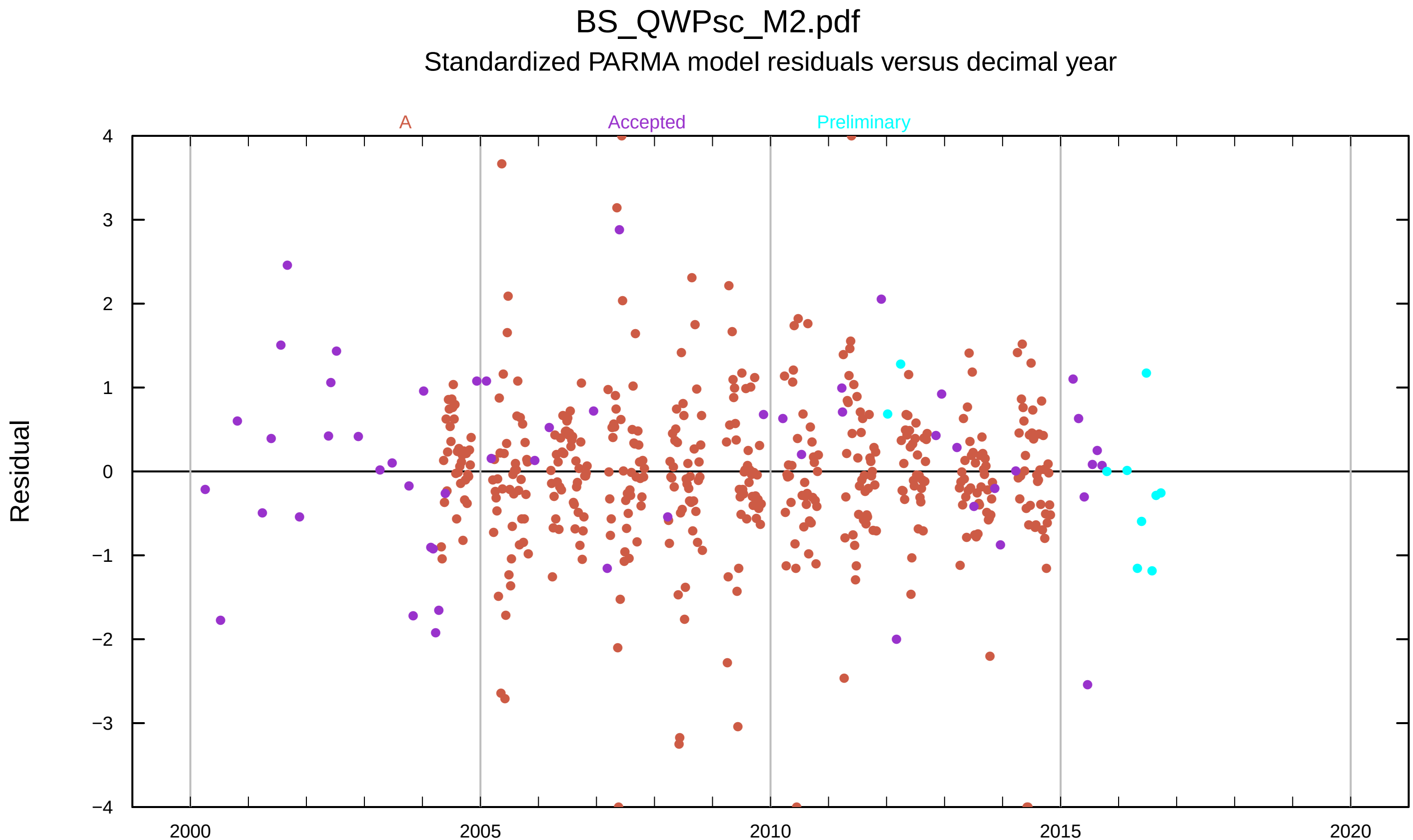


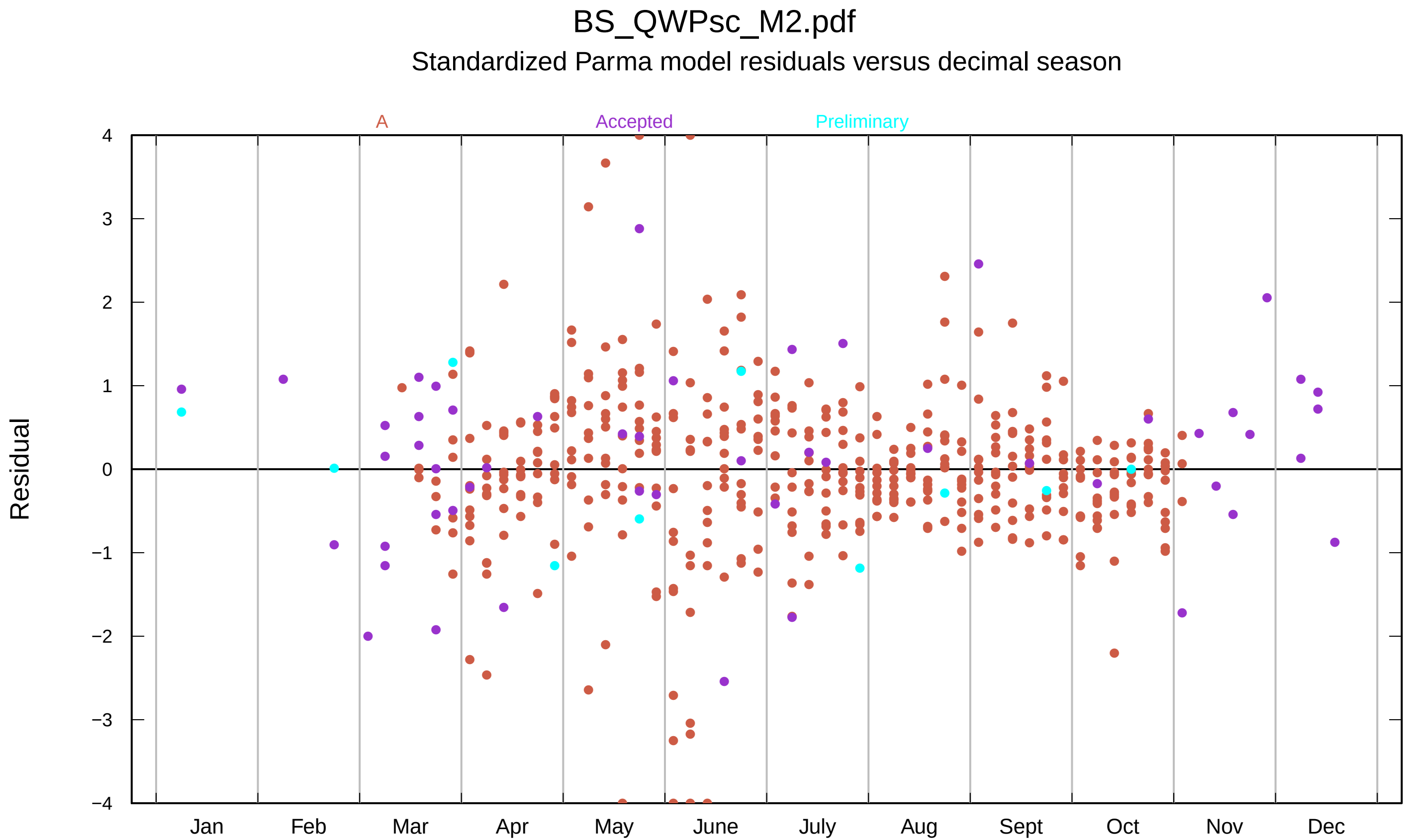
BS_QWPsc_M2.pdf
Points: flow−adjusted data; Line: fitted trend
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020

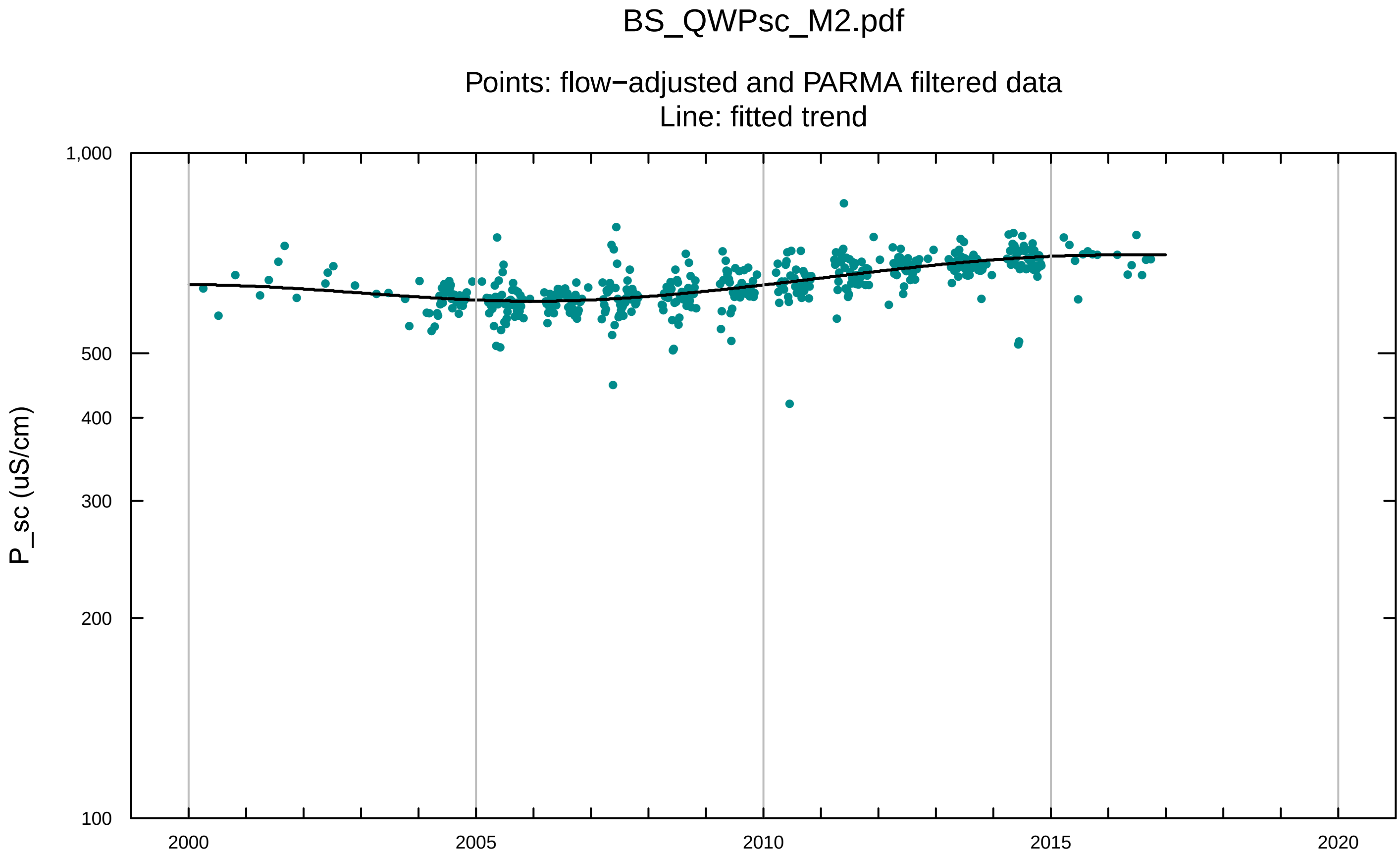

BS_QWPsc_M2.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020



BS_QWPsc_M2.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020


BS_QWPsc_M2.pdf
Standardized PARMA model residuals versus decimal year
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020


BS_QWPsc_M2.pdf
Standardized Parma model residuals versus decimal season
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

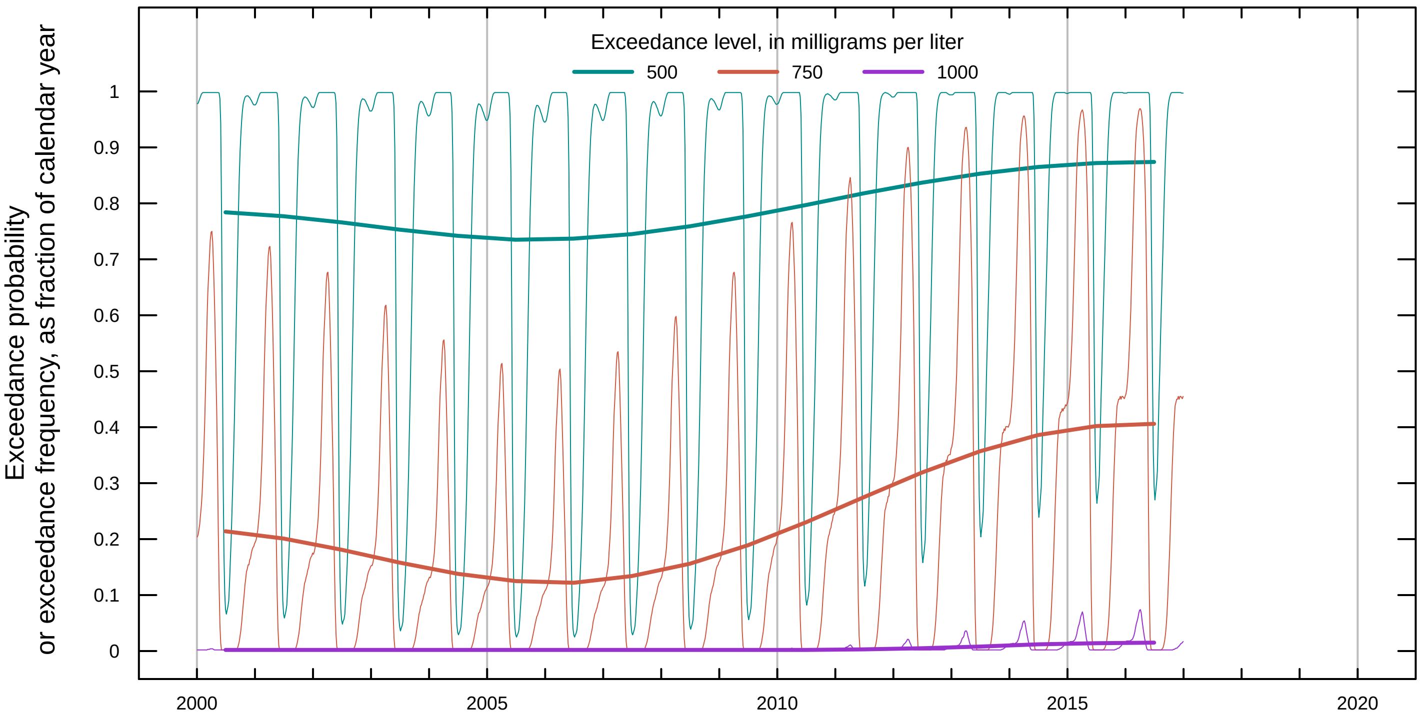

BS_QWPsc_M2.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

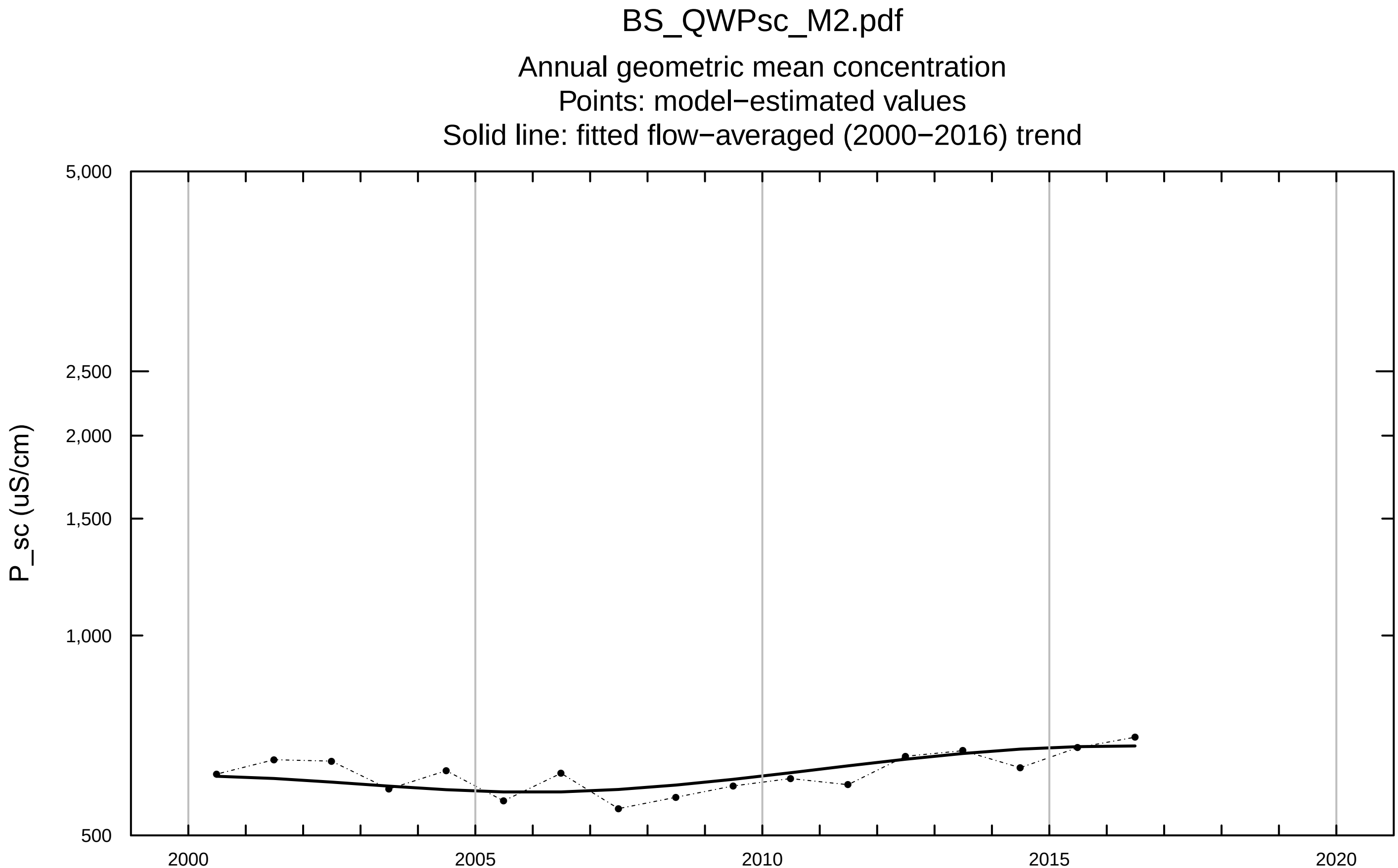
BS_QWPsc_M2.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

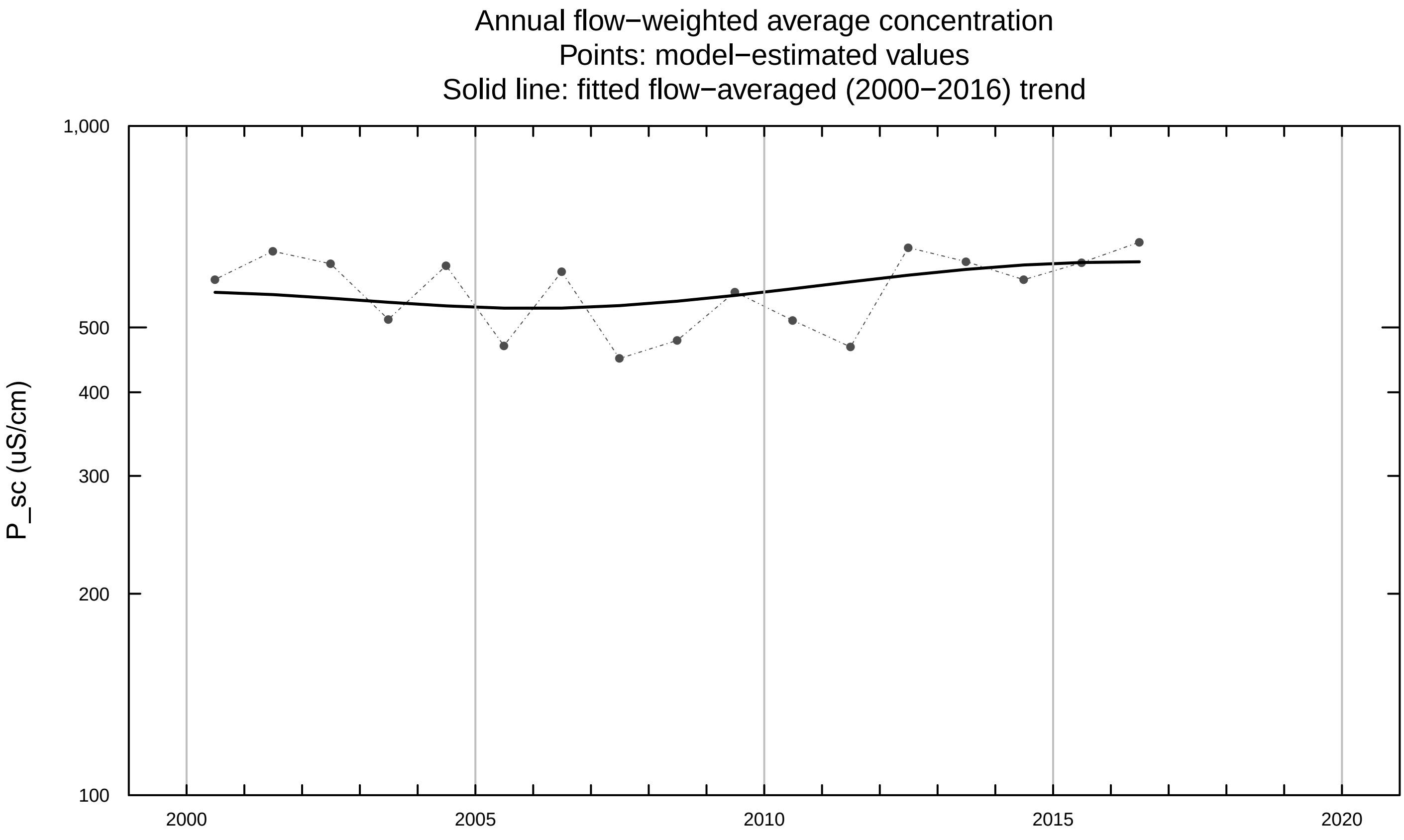
Thin line: Flow−averaged exceedance probability

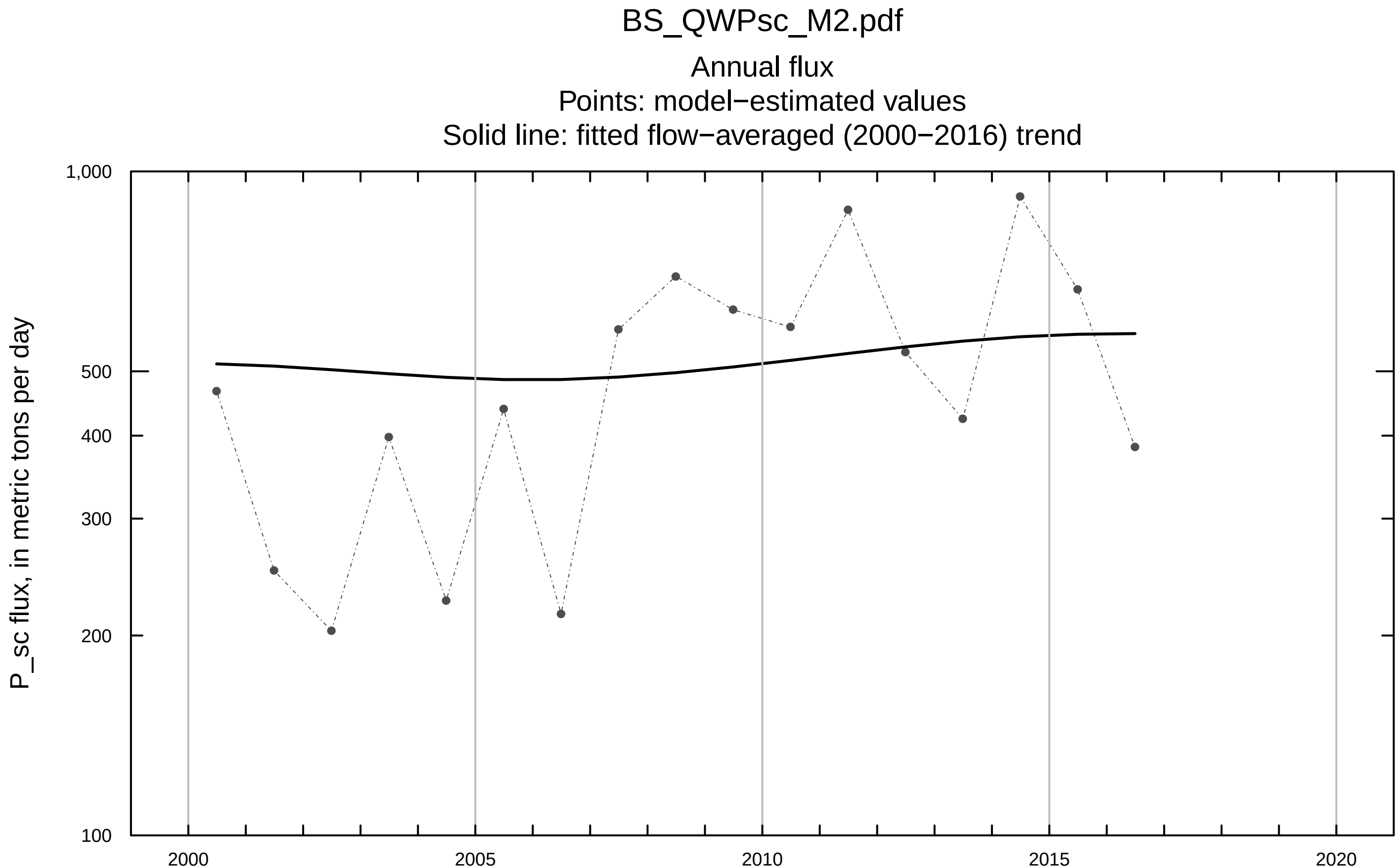
Heavy line: Expected annual flow−averaged exceedance frequency

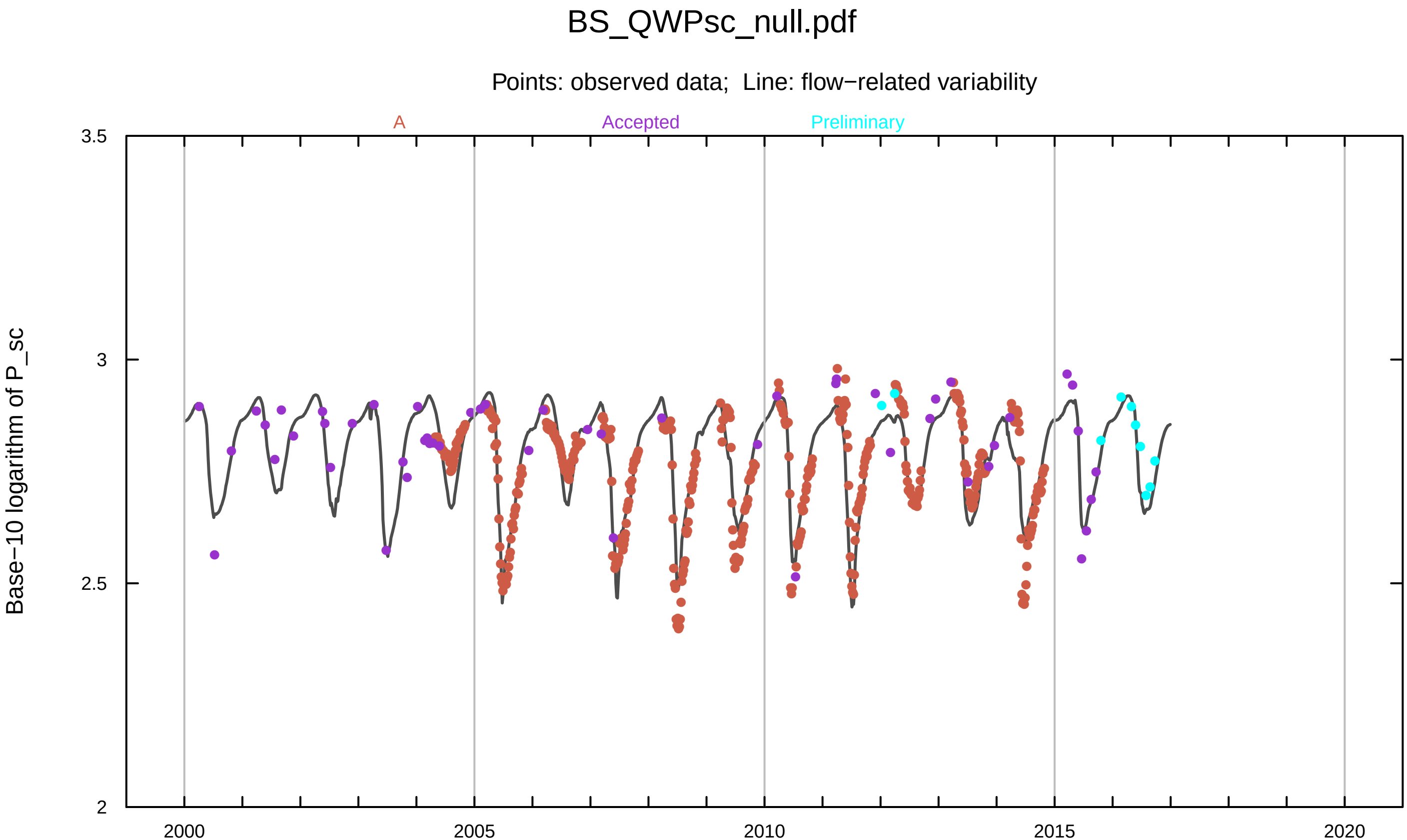



BS_QWPsc_M2.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020

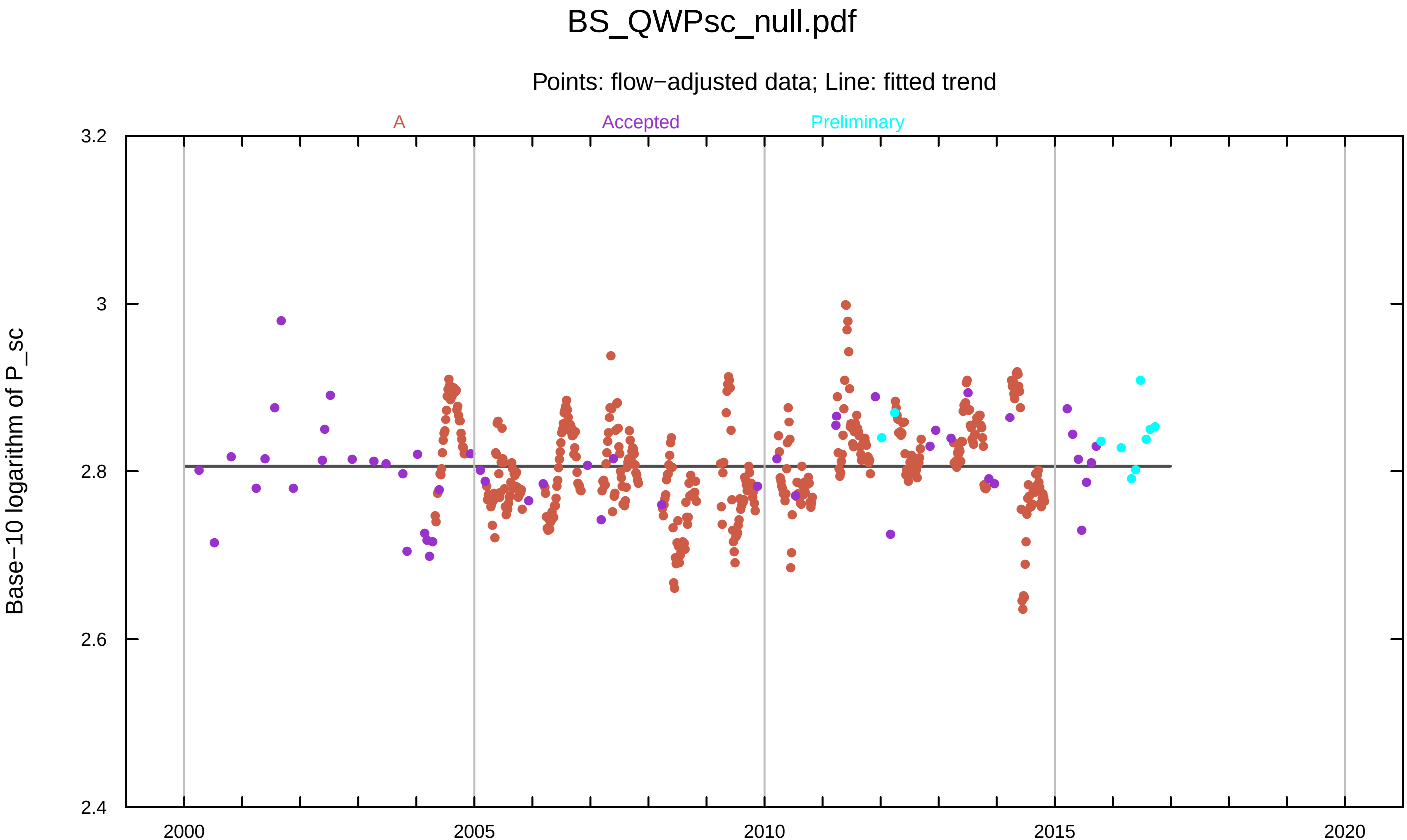
BS_QWPsc_M2.pdf

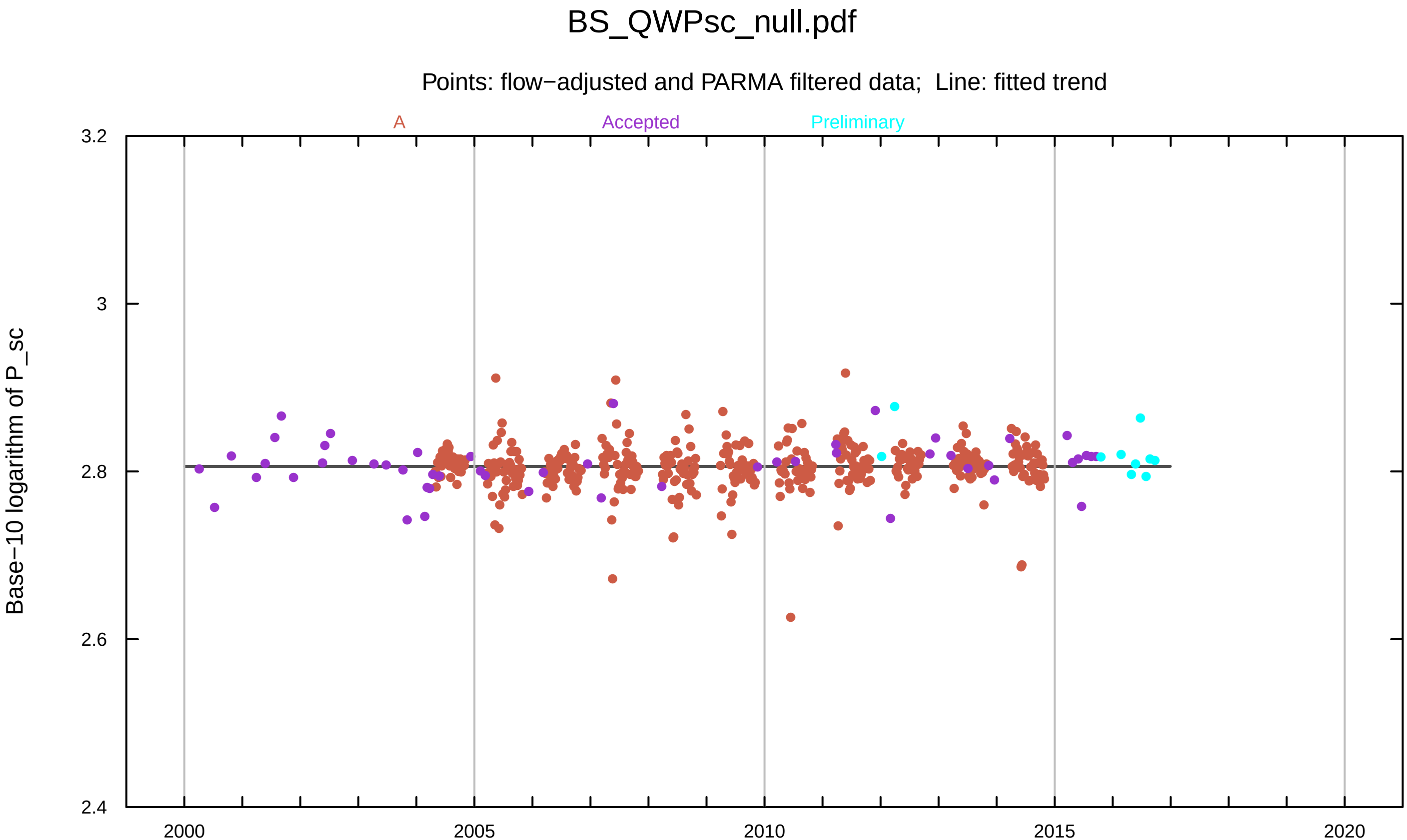



BS_QWPsc_M2.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

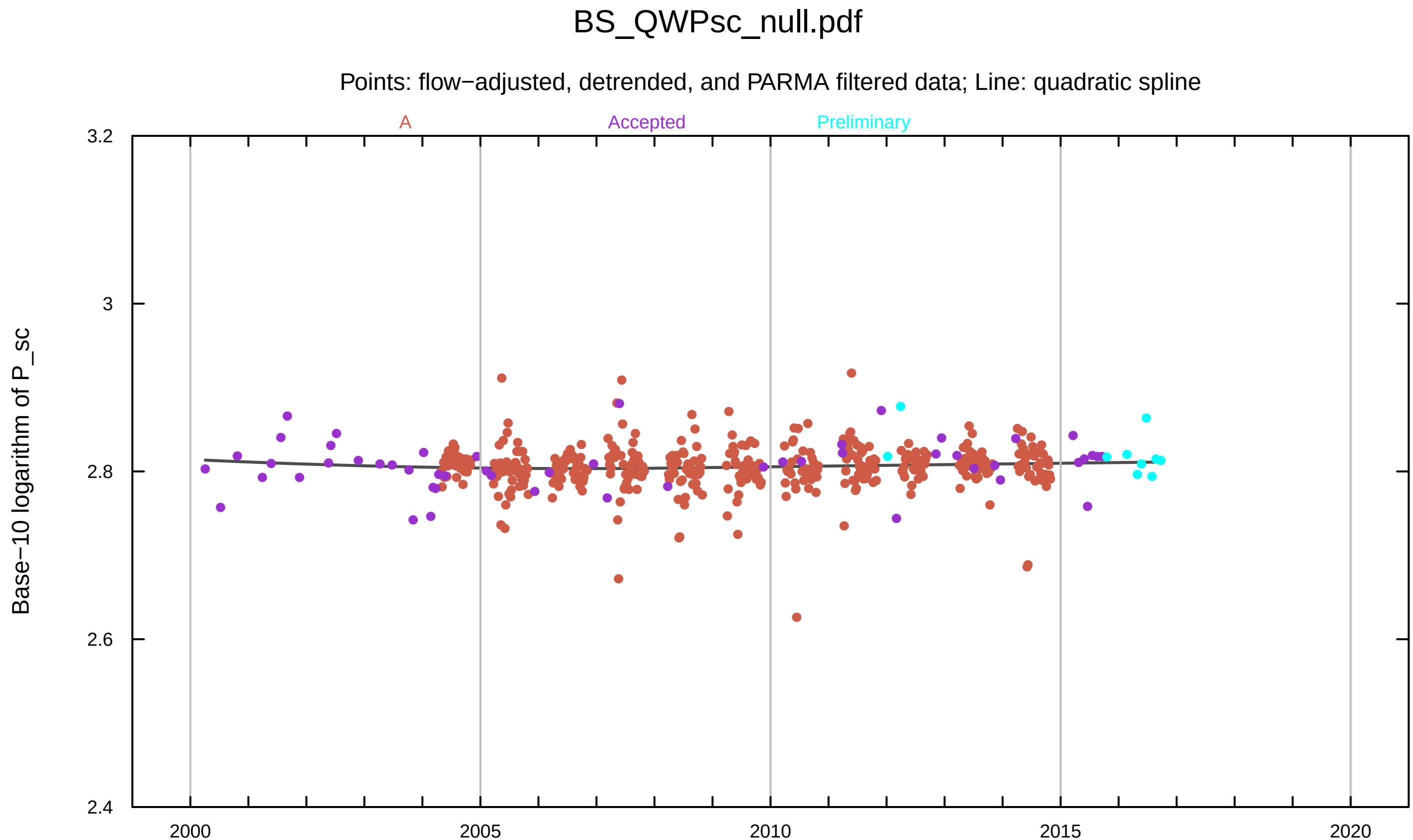


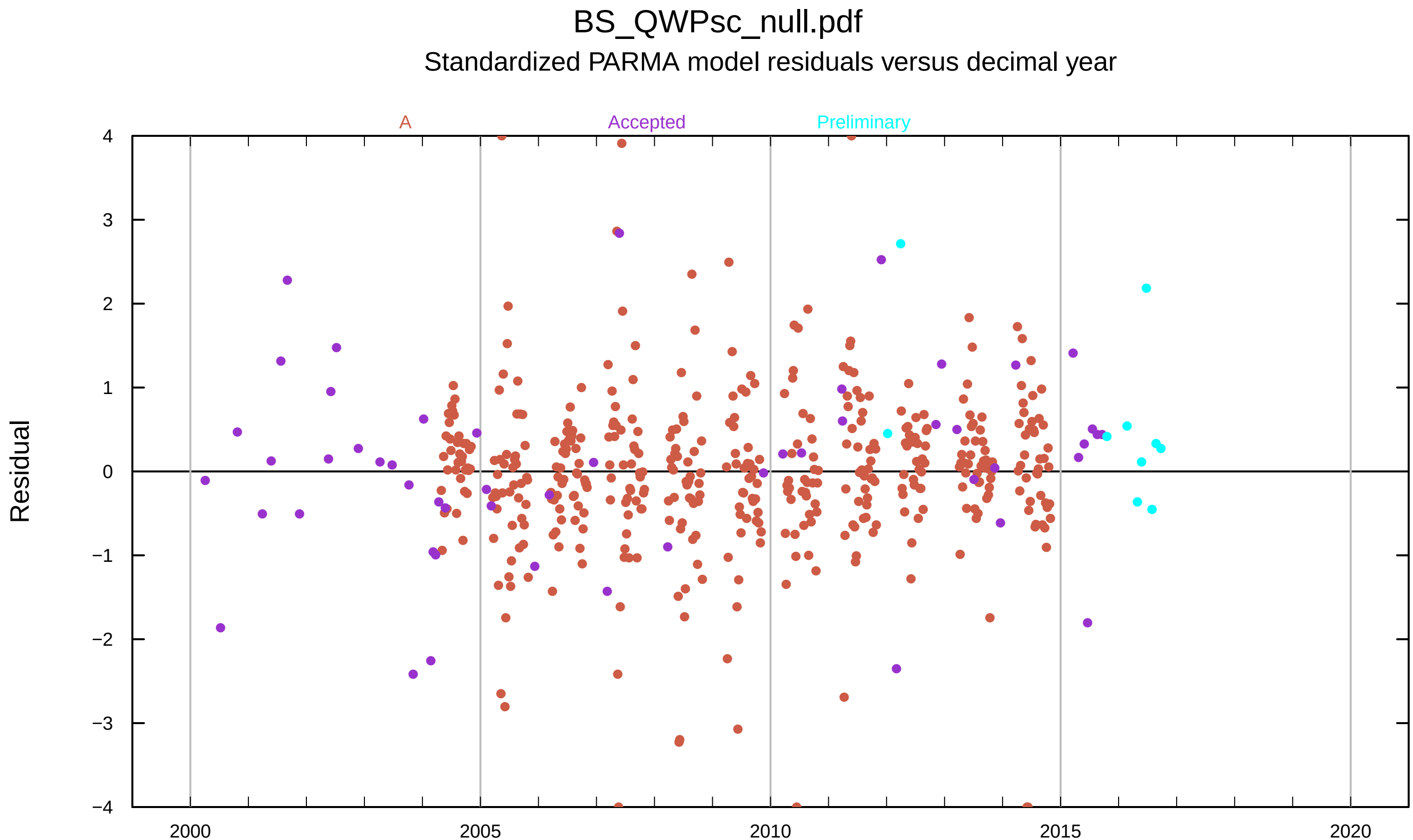
BS_QWPsc_null.pdf
Points: observed data; Line: flow−related variability
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.5
3
2.5
2
2000
2005
2010
2015
2020

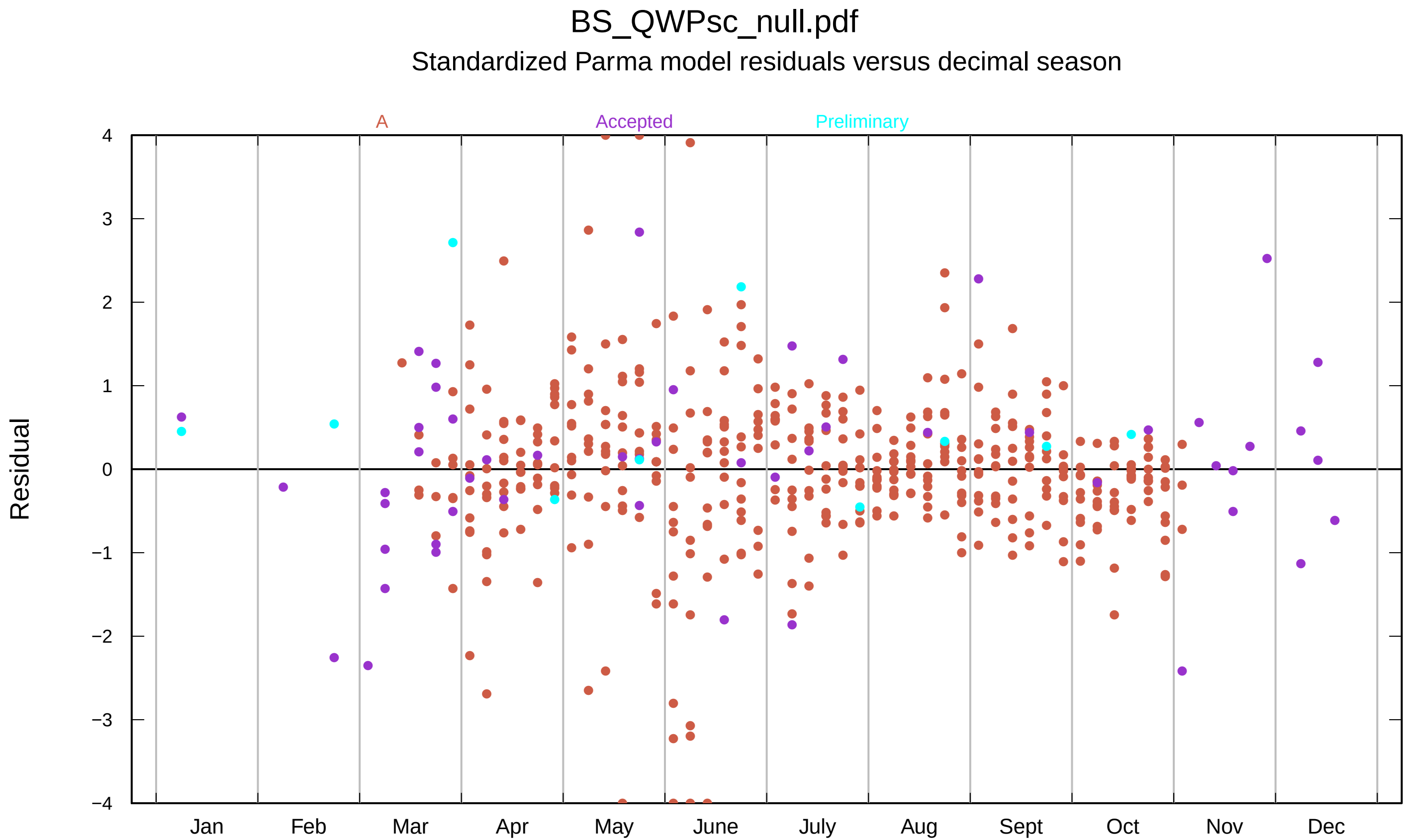

BS_QWPsc_null.pdf
Points: flow−adjusted data; Line: fitted trend
A
Accepted
Preliminary
3.2
3
2.8
2.6
2.4
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020

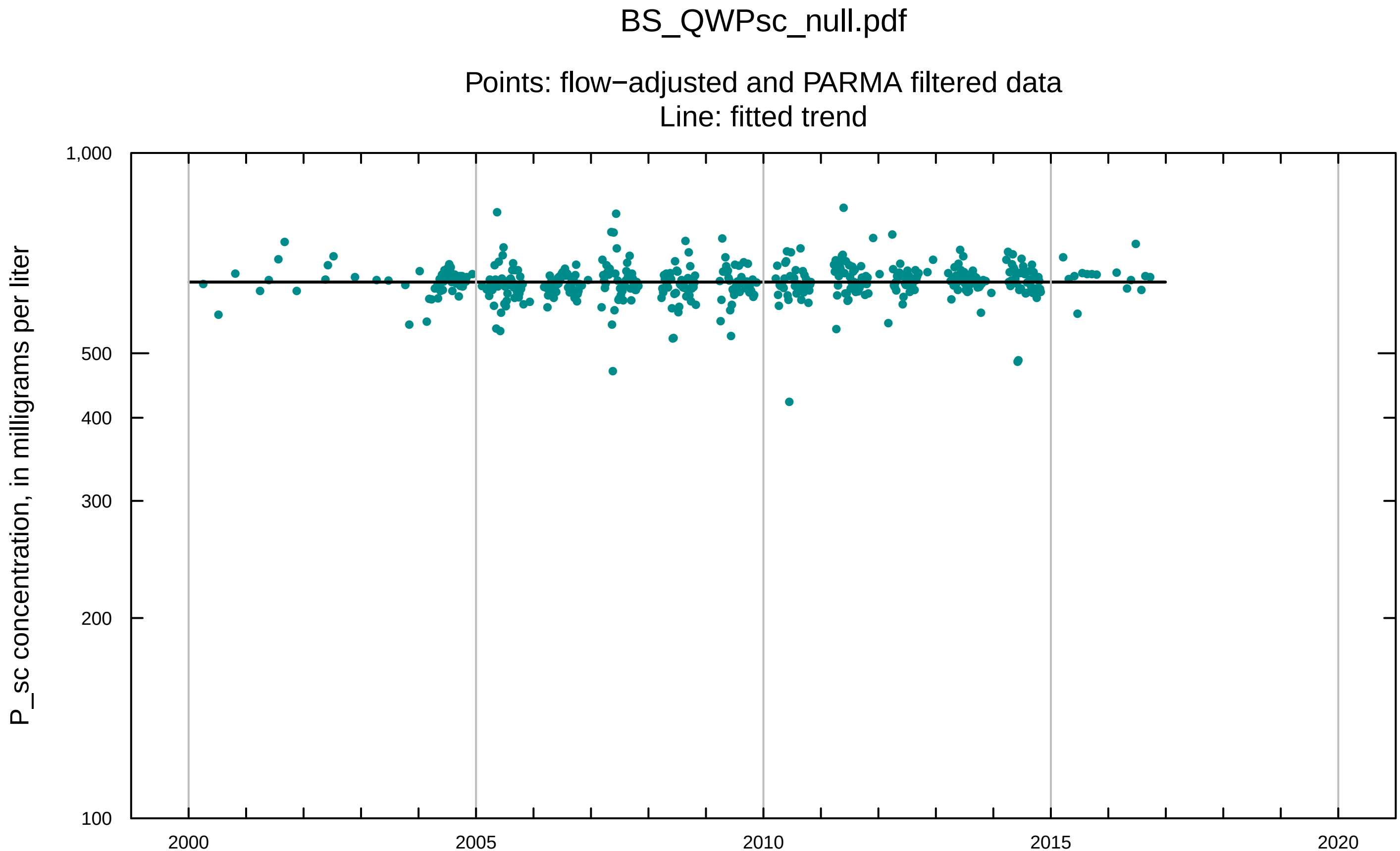


BS_QWPsc_null.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020


BS_QWPsc_null.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
Accepted
Preliminary
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020


BS_QWPsc_null.pdf
Standardized PARMA model residuals versus decimal year
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020


BS_QWPsc_null.pdf
Standardized Parma model residuals versus decimal season
A
Accepted
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec



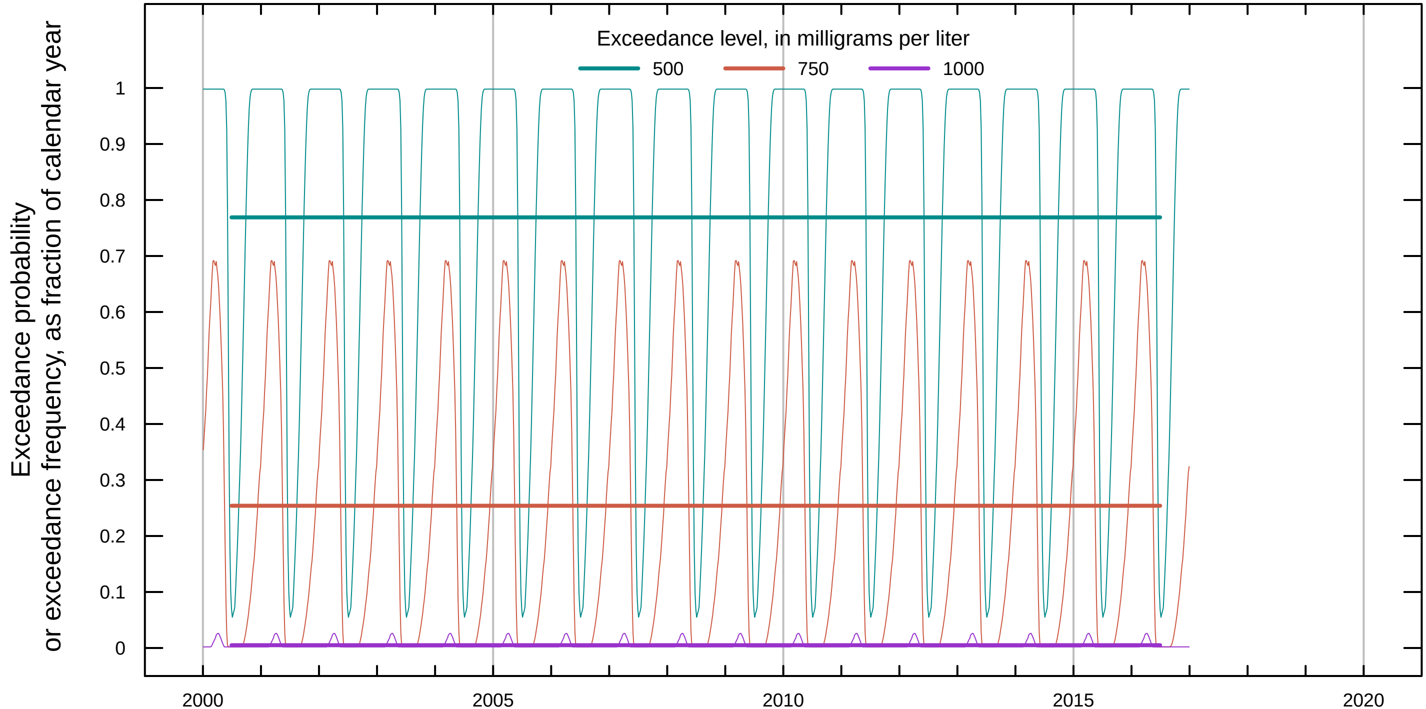
BS_QWPsc_null.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc concentration, in milligrams per liter
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

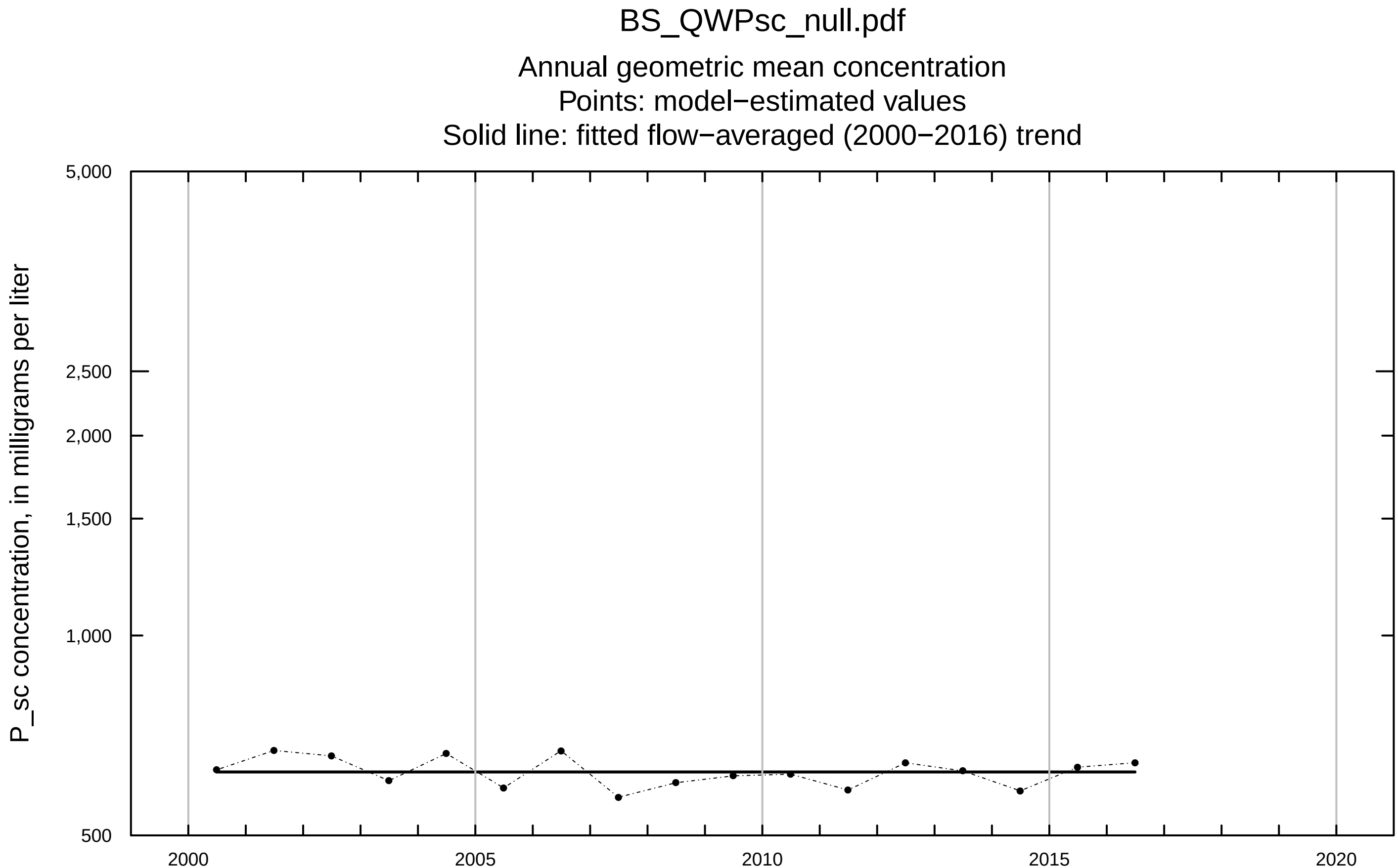
BS_QWPsc_null.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

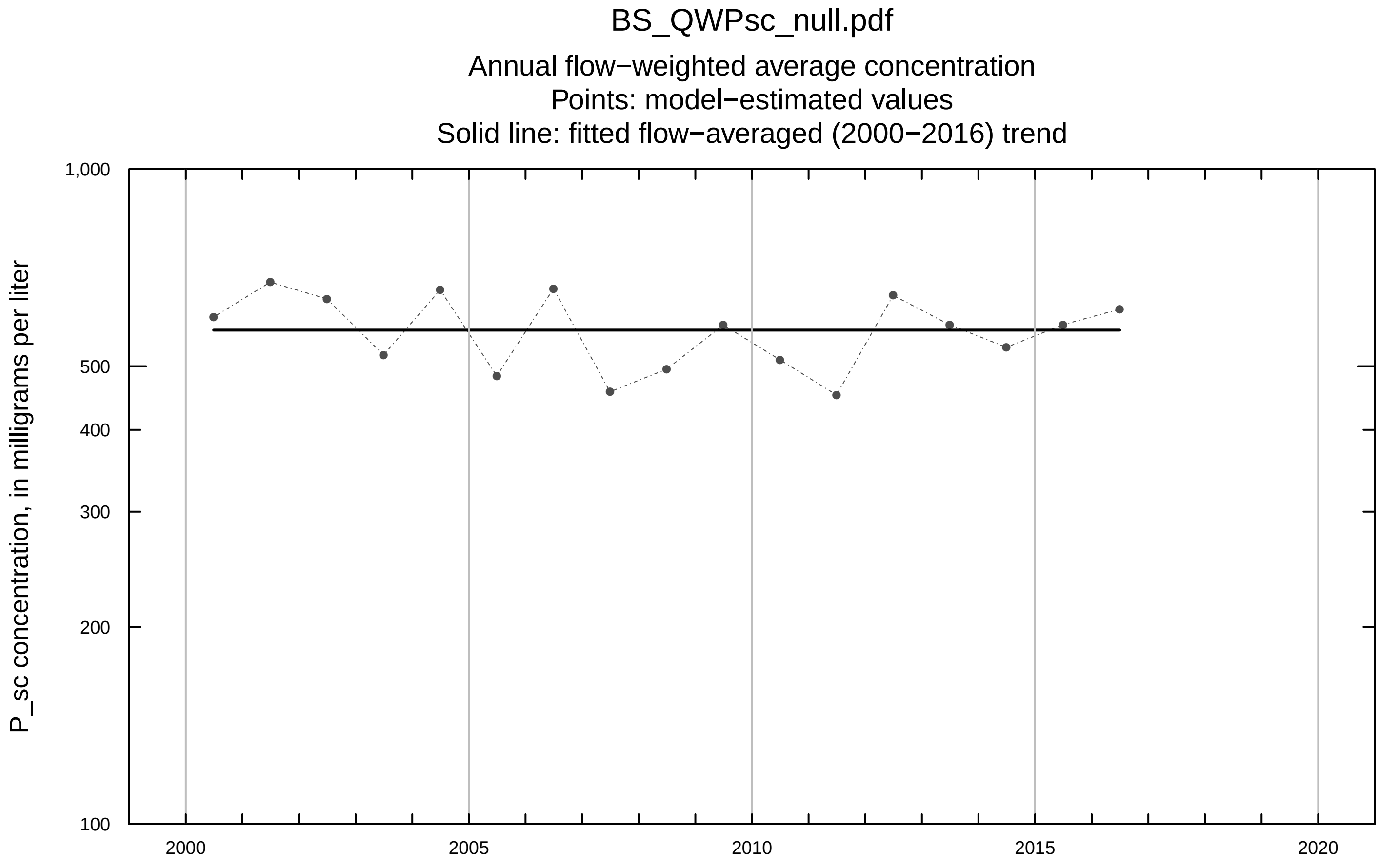
Thin line: Flow−averaged exceedance probability

Heavy line: Expected annual flow−averaged exceedance frequency

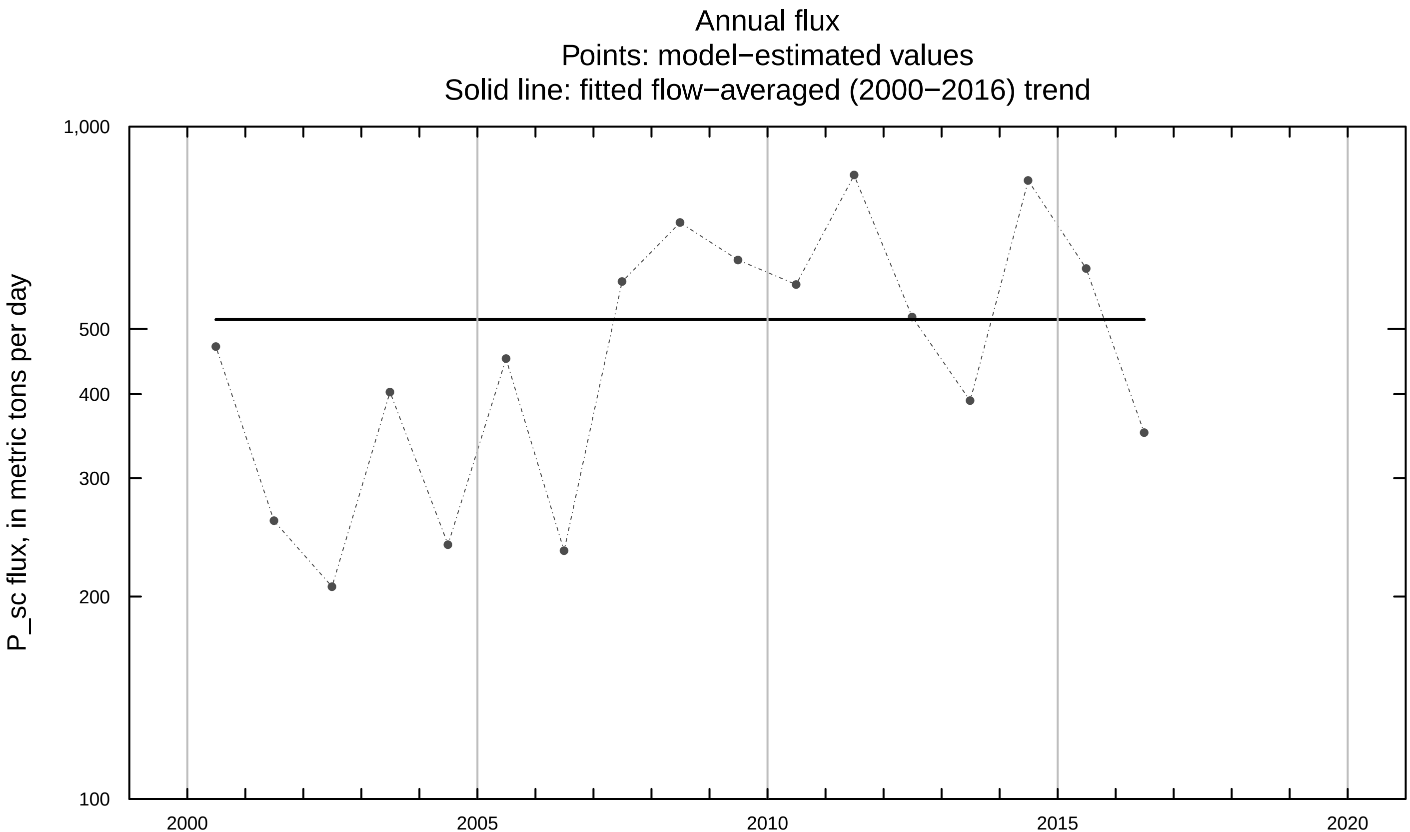




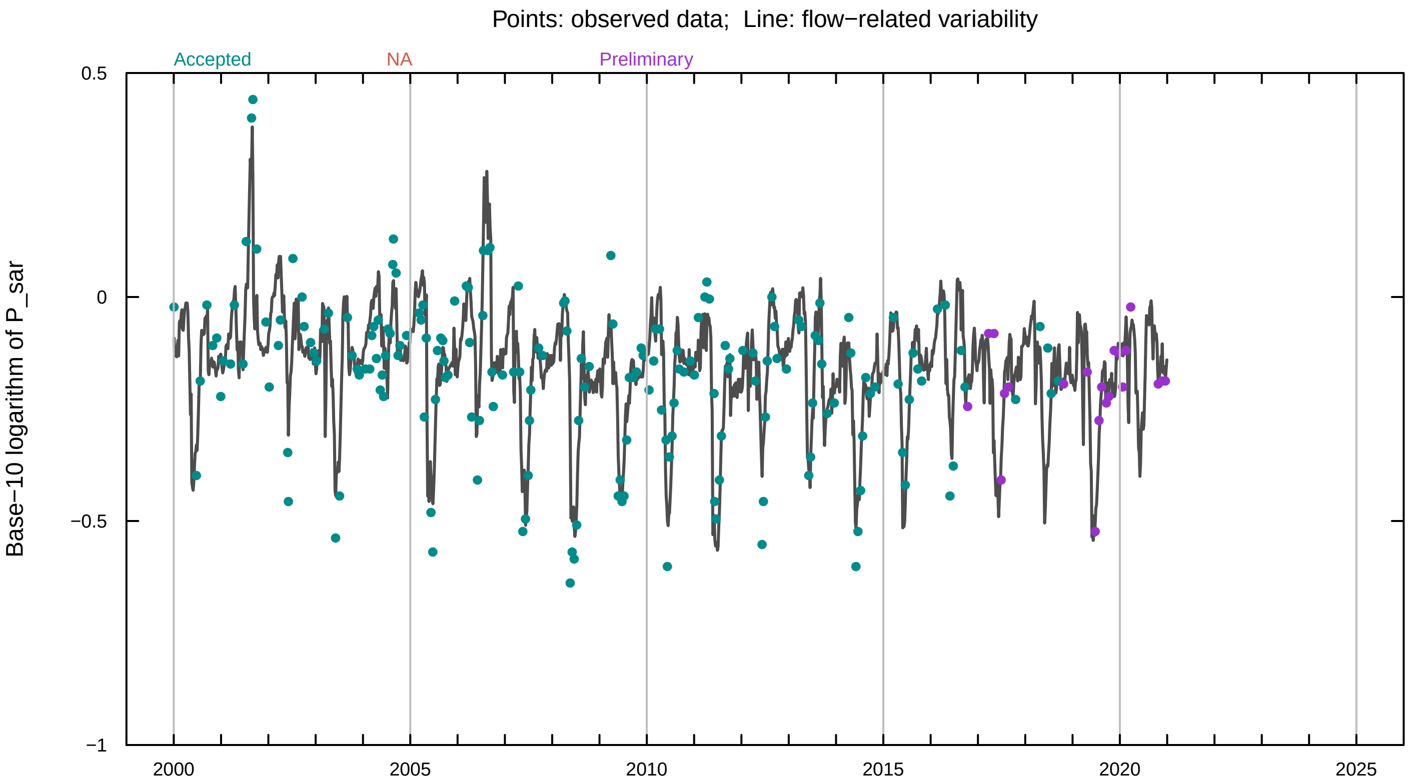
BS_QWPsc_null.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc concentration, in milligrams per liter
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020

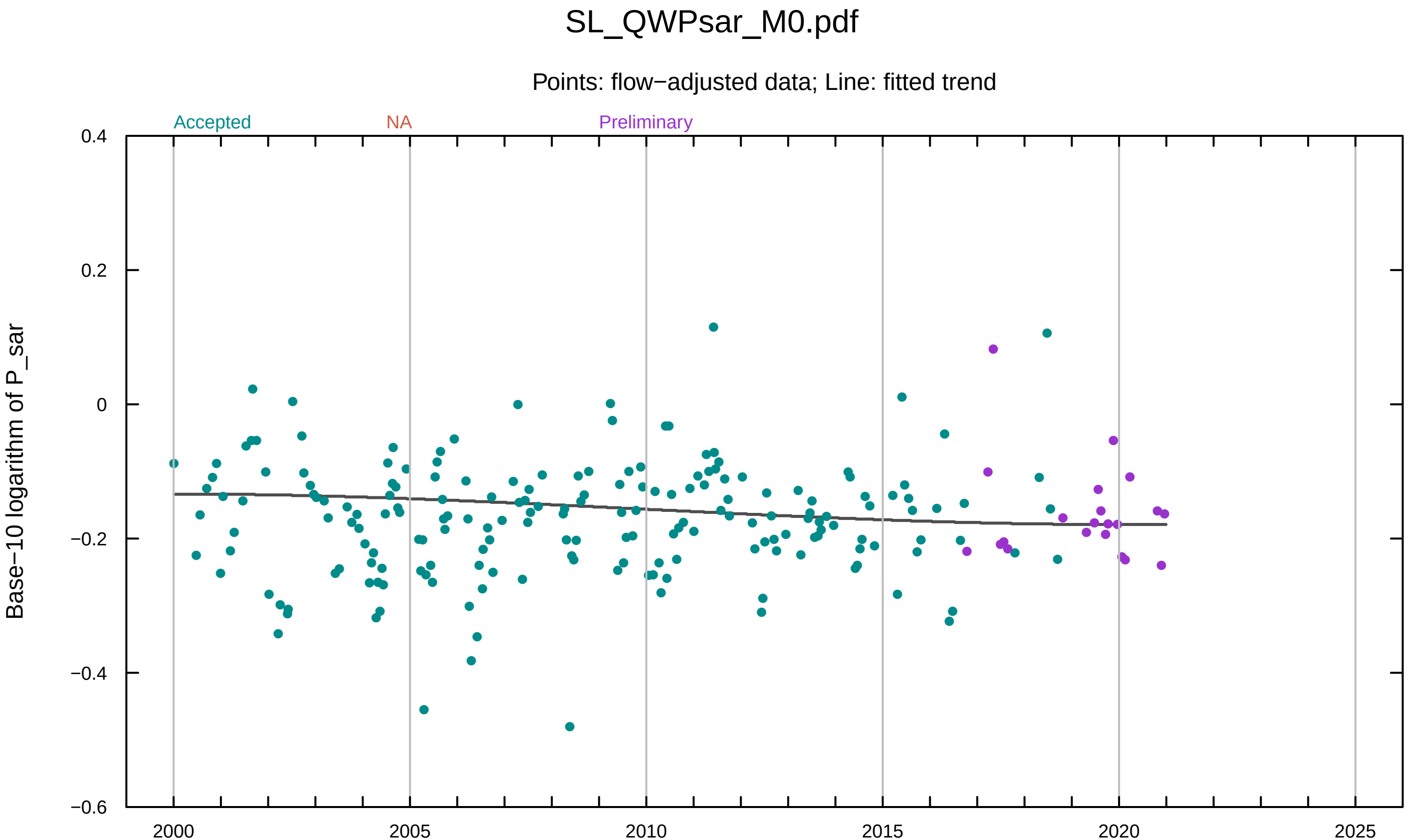

BS_QWPsc_null.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2016) trend
P_sc concentration, in milligrams per liter
1,000
500
400
300
200
100
2000
2005
2010
2015
2020

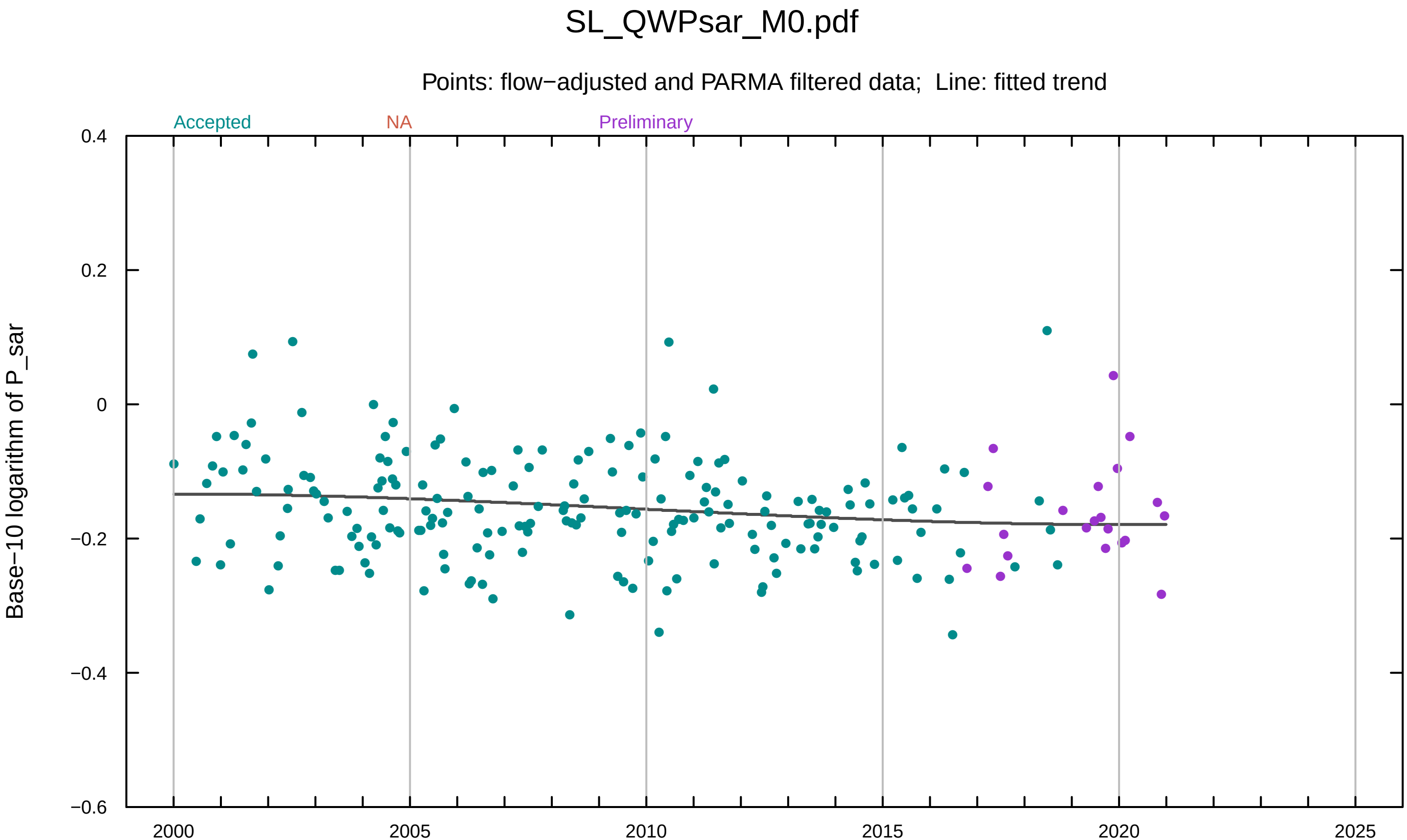
BS_QWPsc_null.pdf



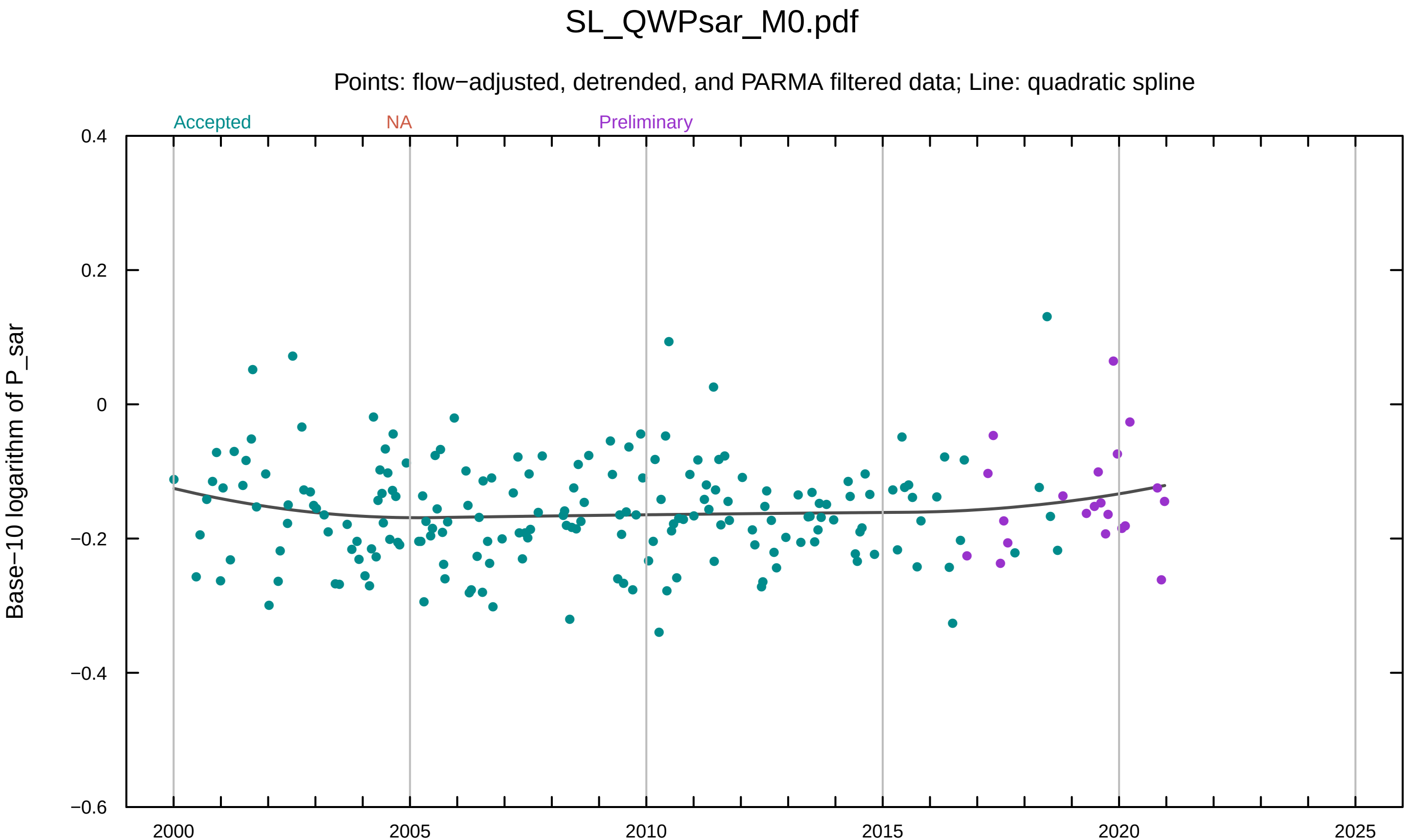
SL_QWPsar_M0.pdf

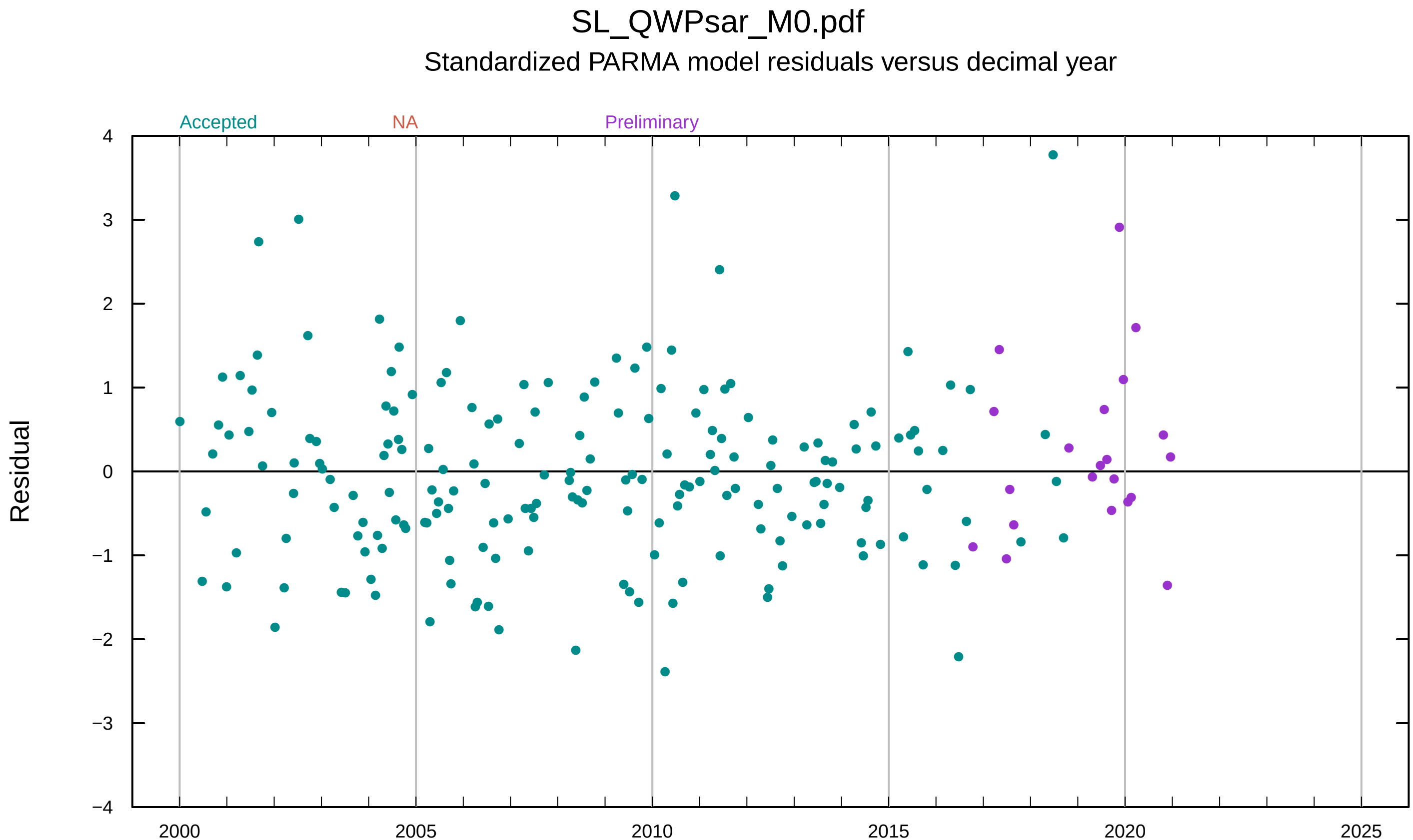


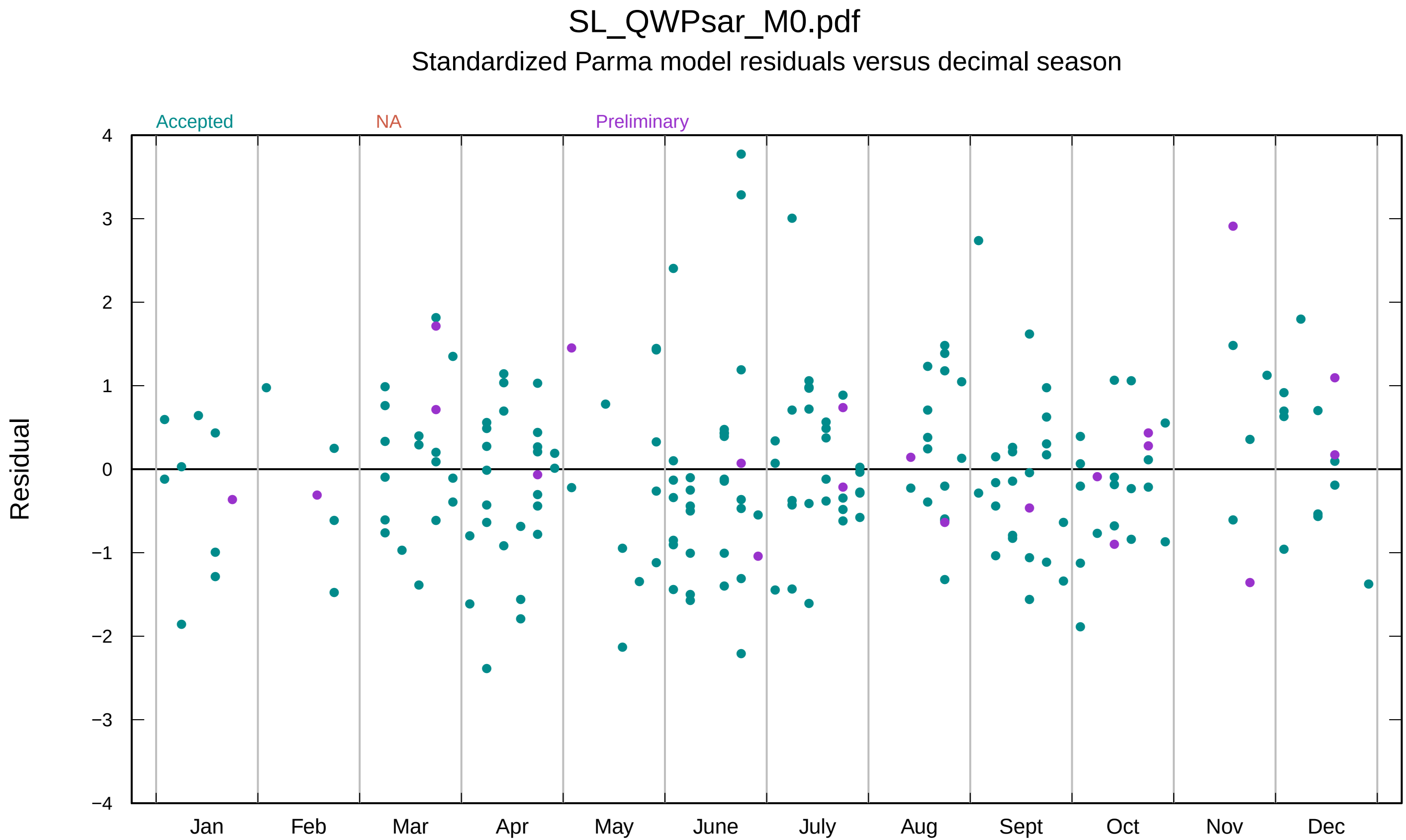

SL_QWPsar_M0.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
−0.6
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025



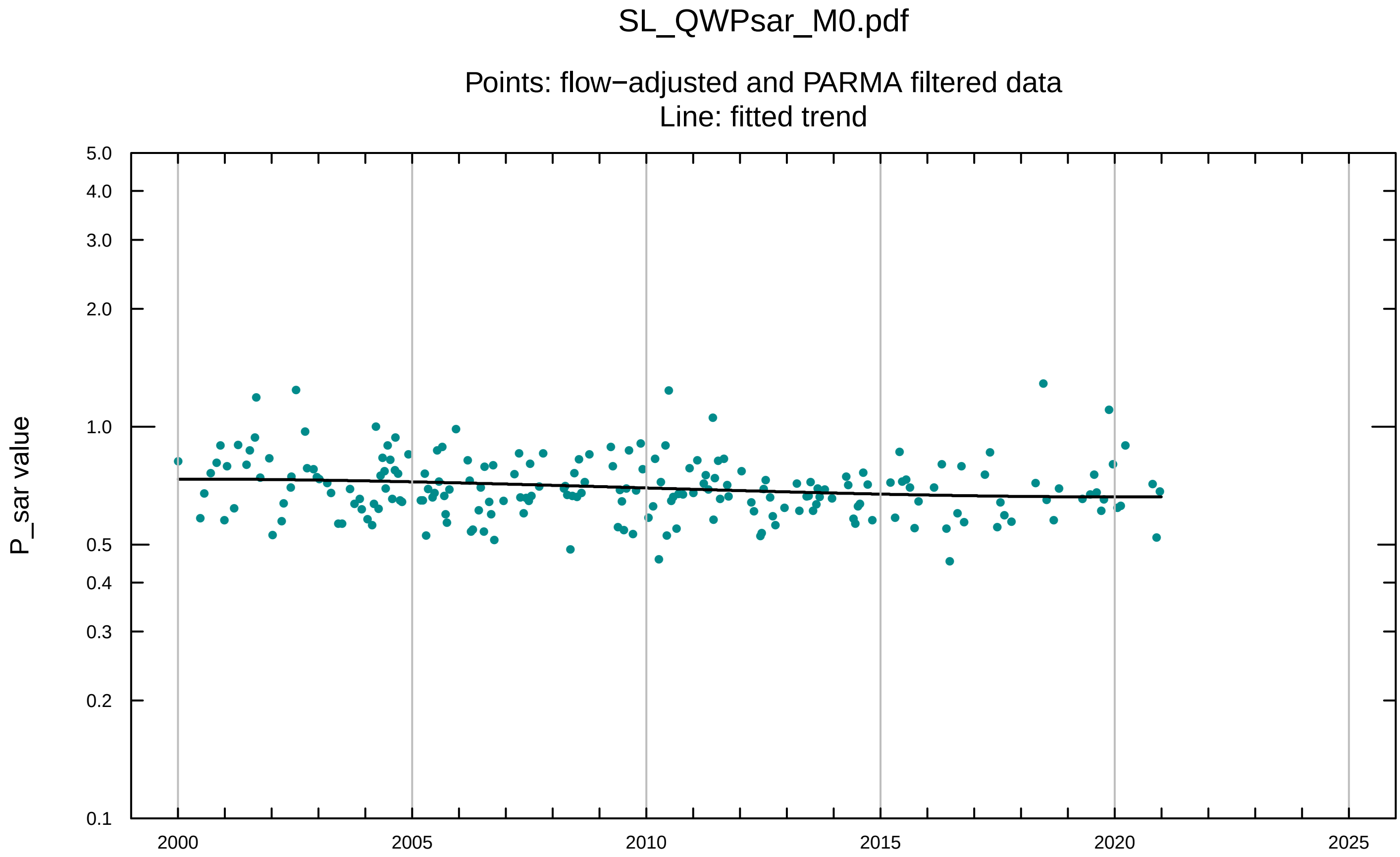
SL_QWPsar_M0.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025


SL_QWPsar_M0.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025


SL_QWPsar_M0.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025



SL_QWPsar_M0.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec



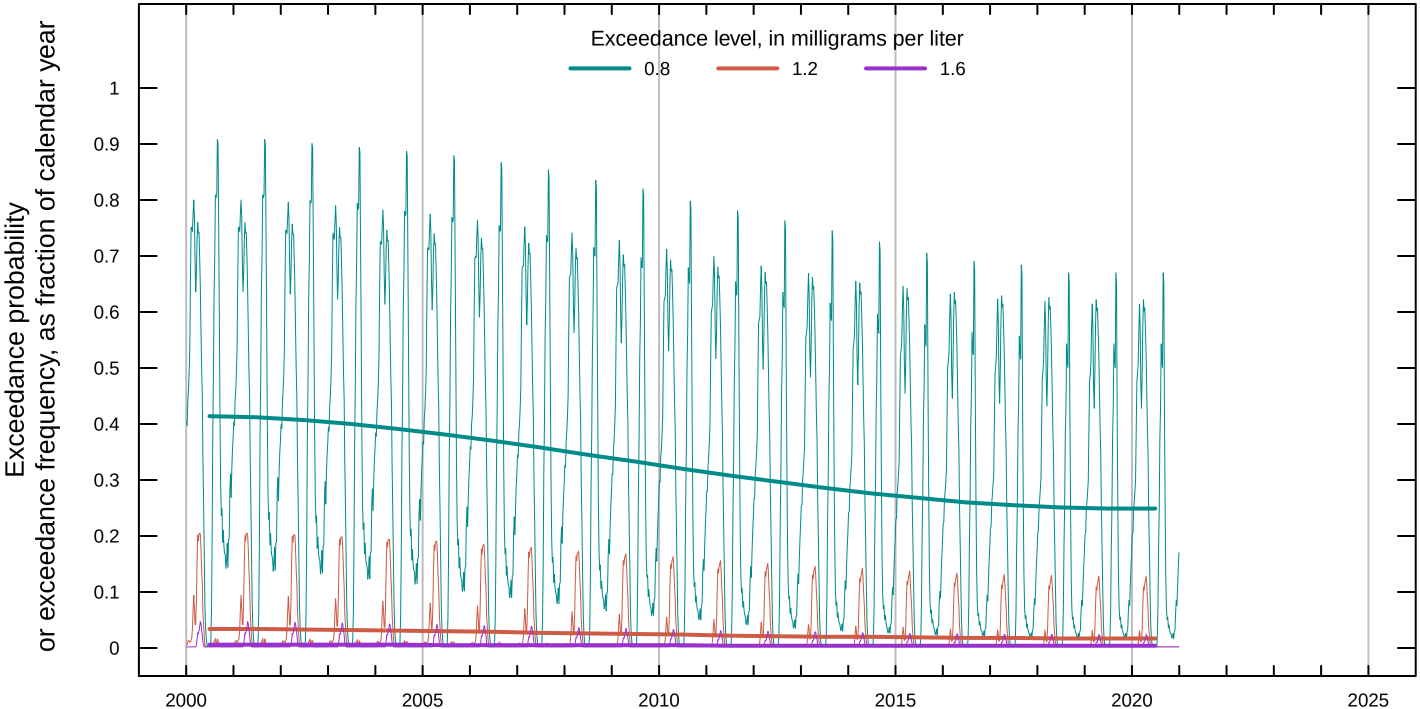
SL_QWPsar_M0.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

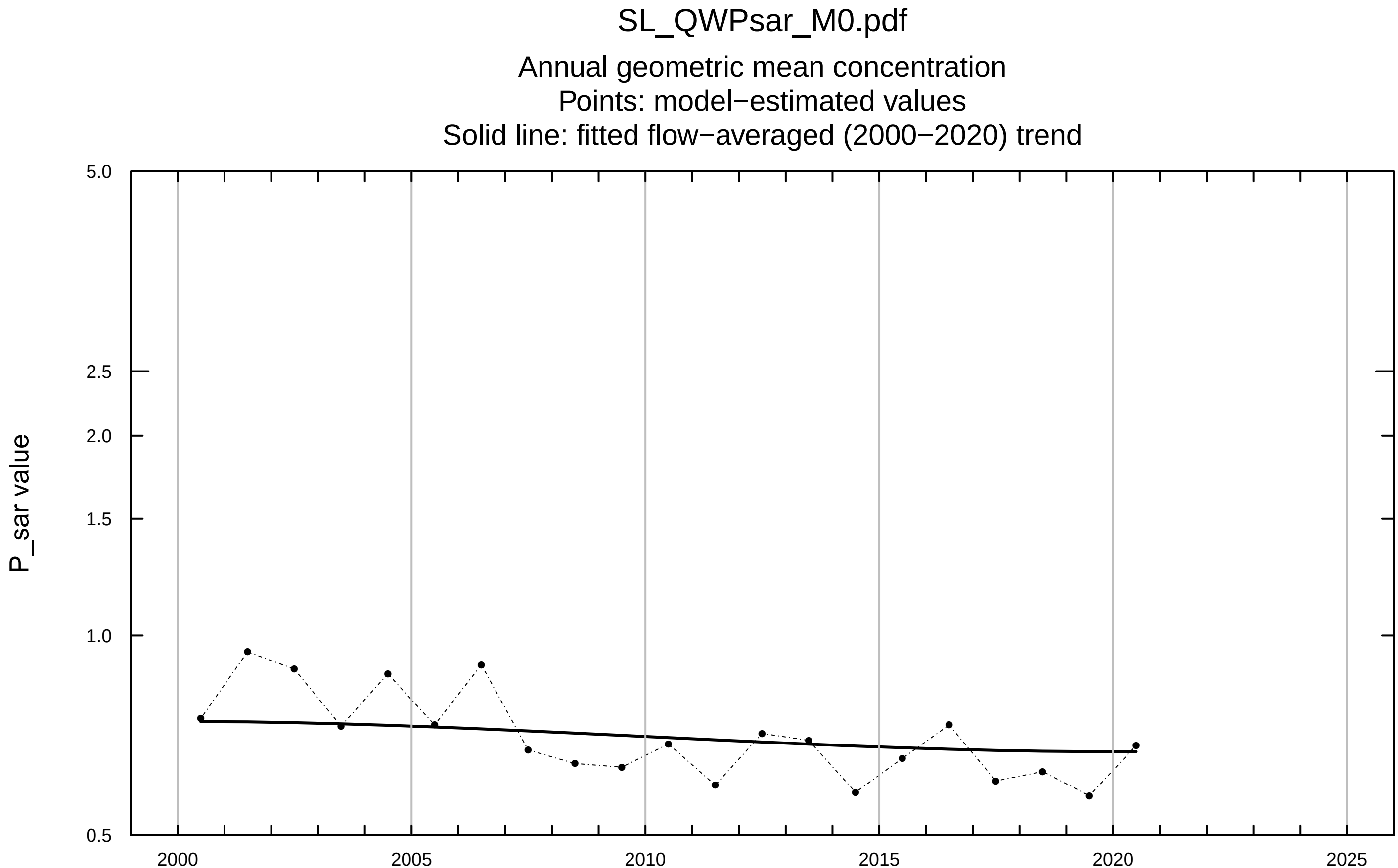
SL_QWPsar_M0.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

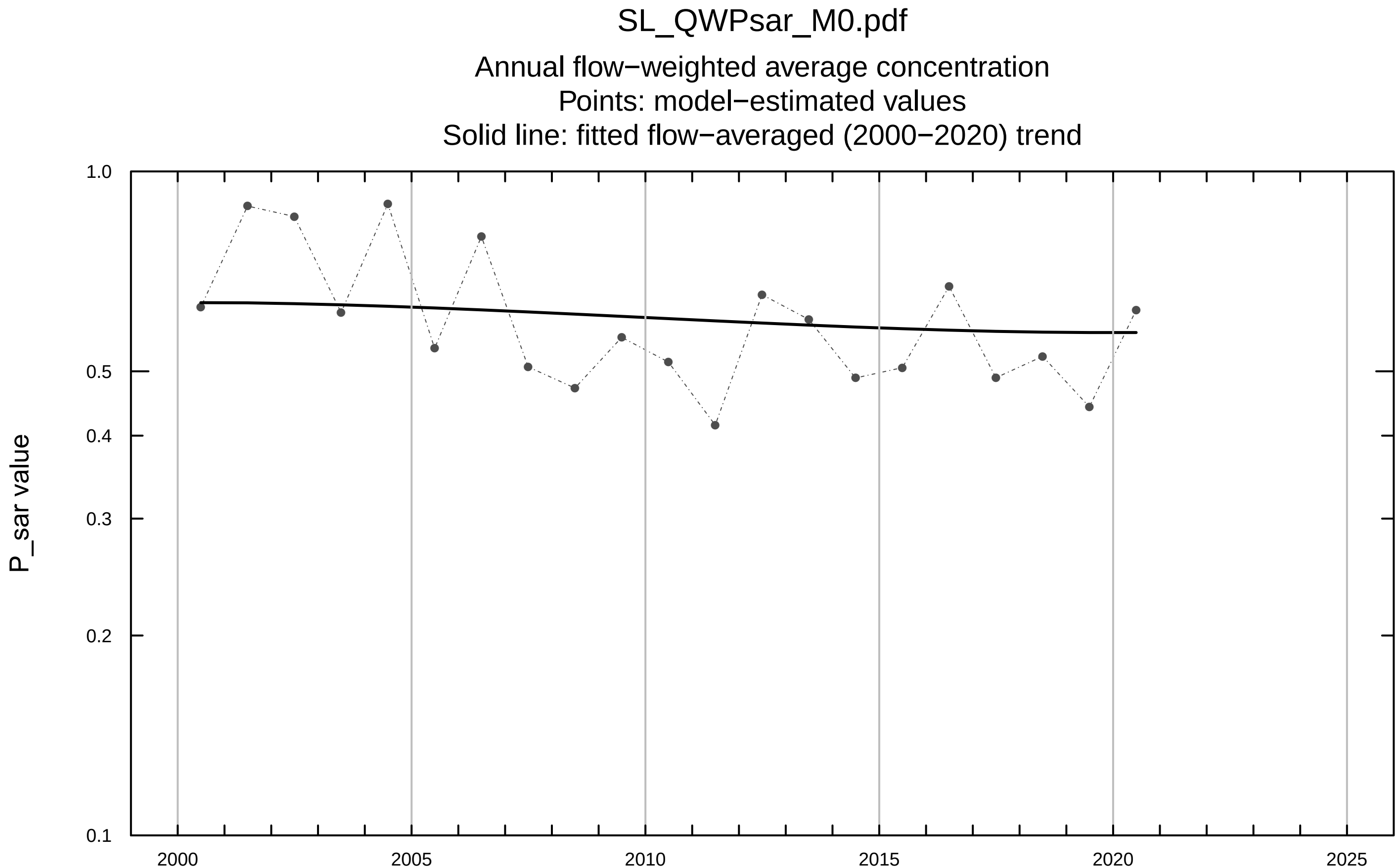
Thin line: Flow−averaged exceedance probability

Heavy line: Expected annual flow−averaged exceedance frequency

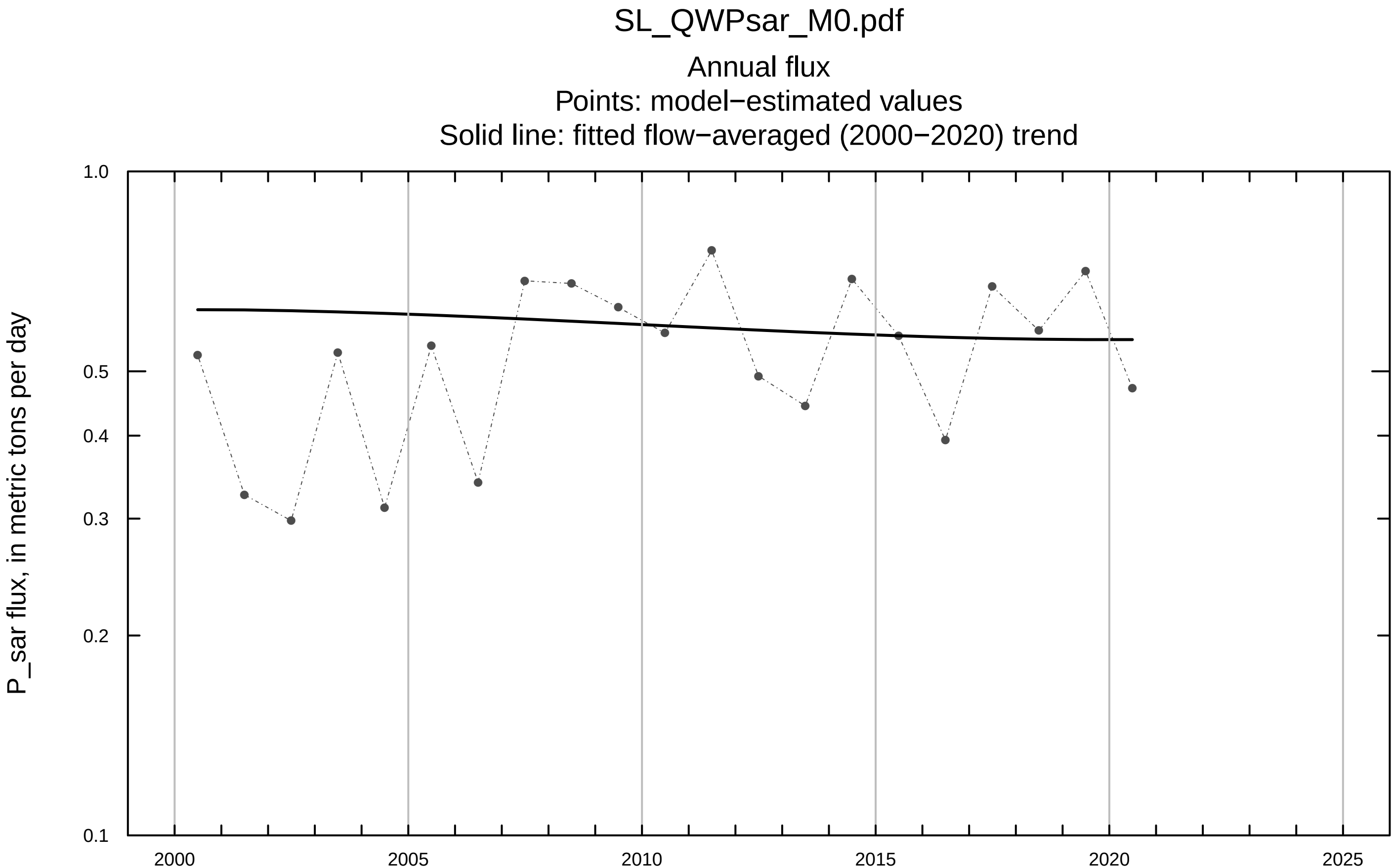


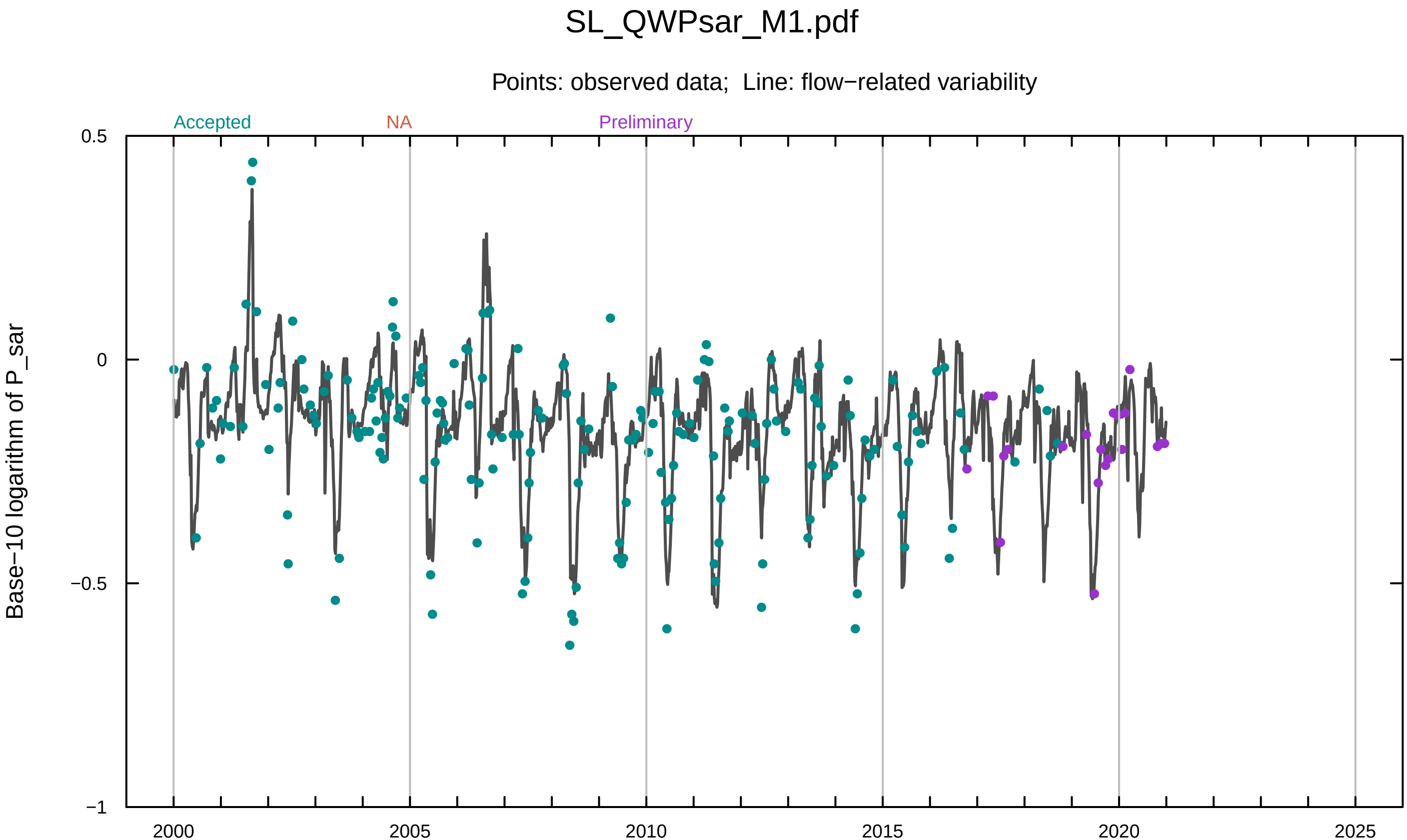


SL_QWPsar_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

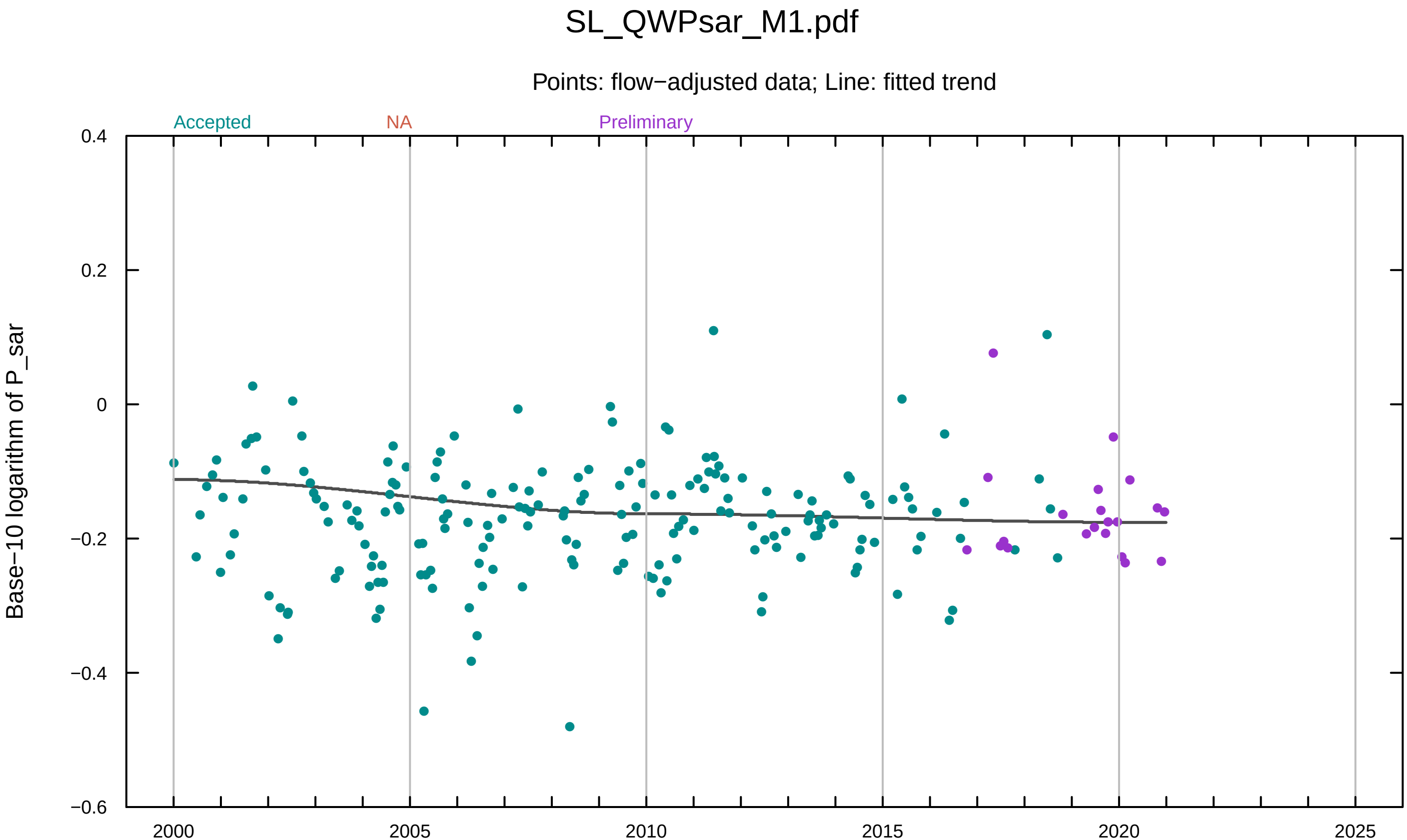


SL_QWPsar_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

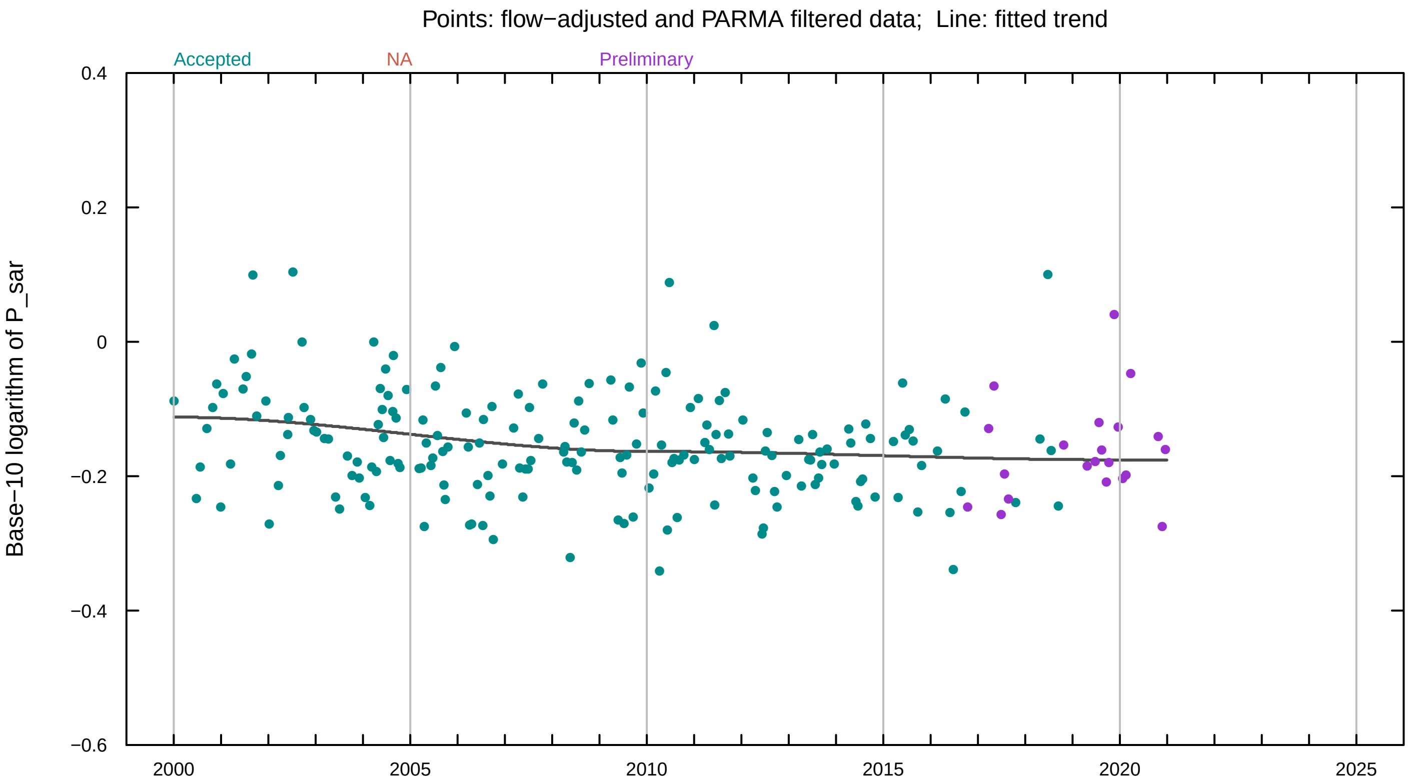

SL_QWPsar_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025



SL_QWPsar_M1.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
0.5
0
−0.5
−1
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

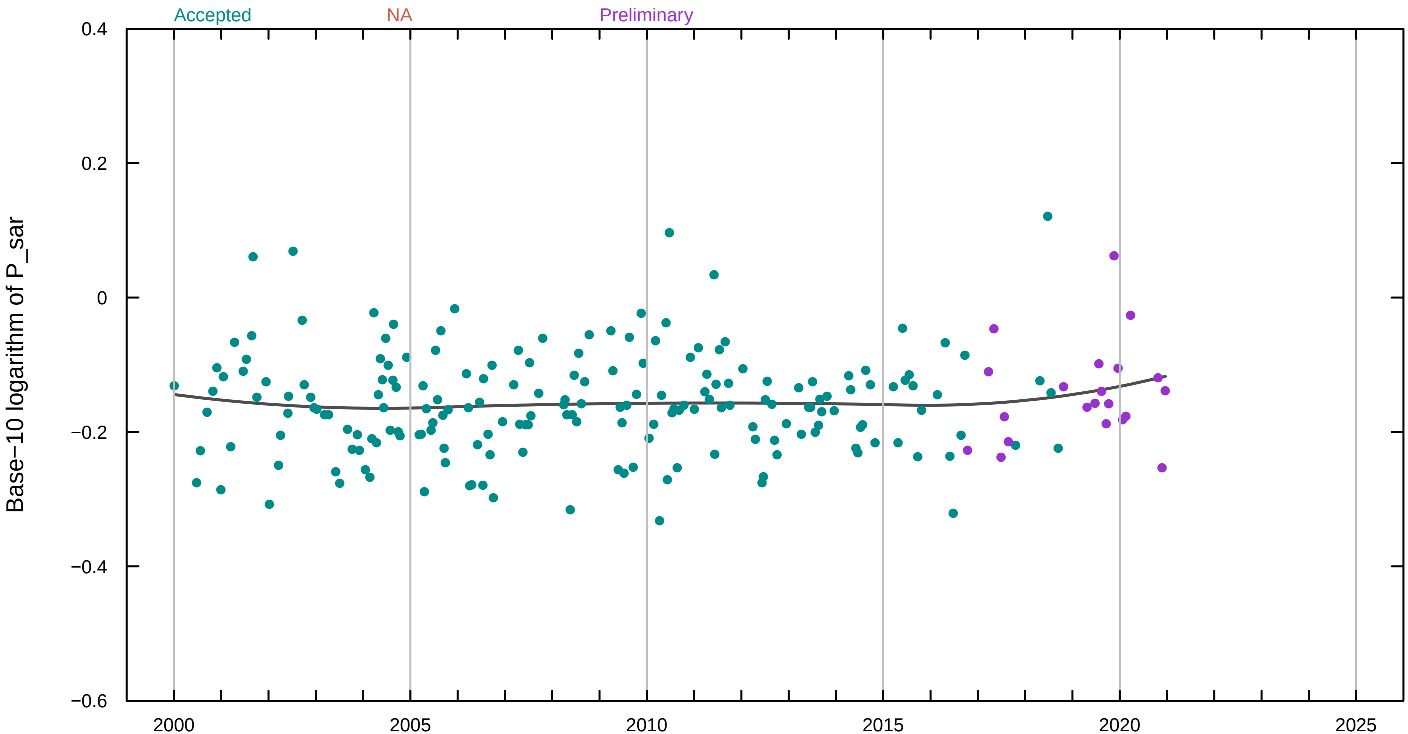

SL_QWPsar_M1.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
−0.6
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

SL_QWPsar_M1.pdf



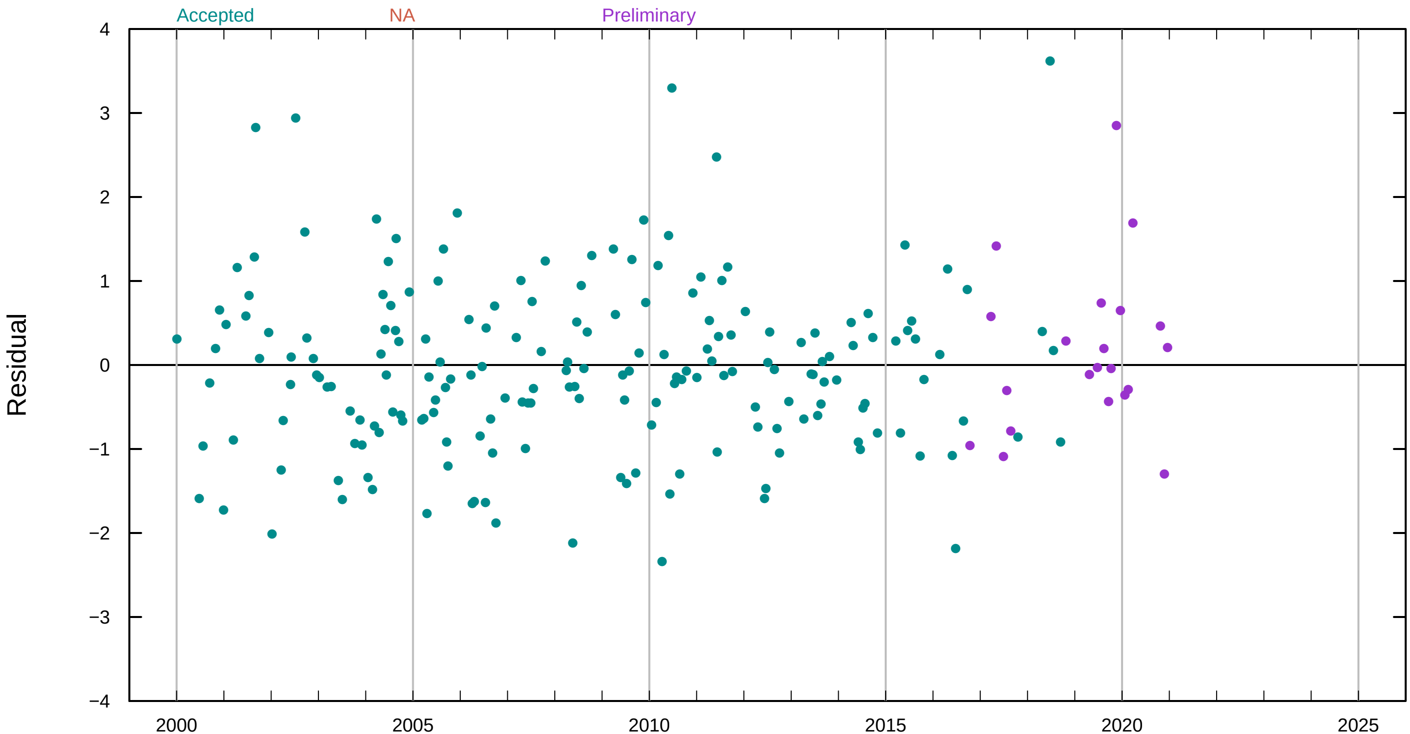
SL_QWPsar_M1.pdf

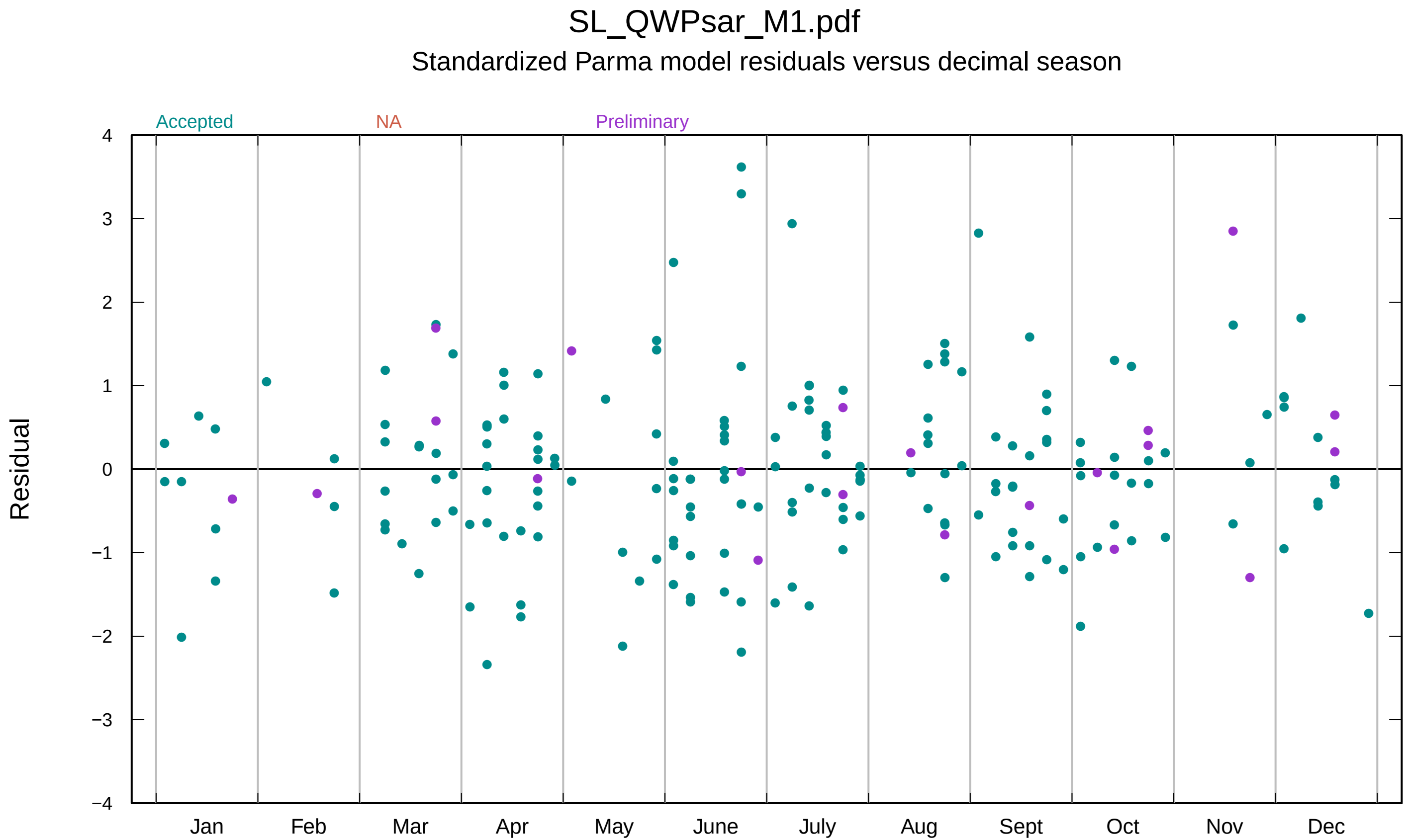
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline

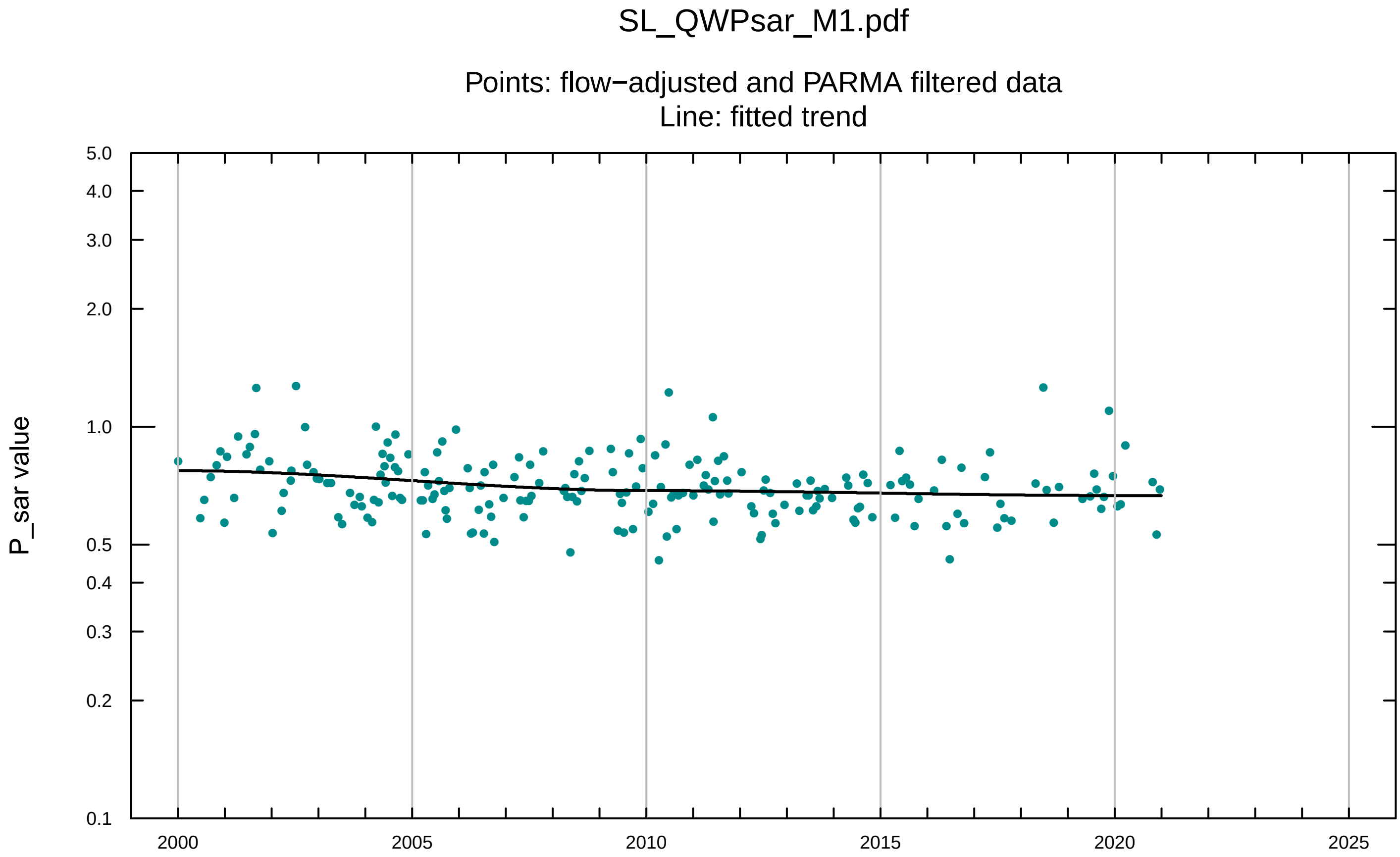


SL_QWPsar_M1.pdf

Standardized PARMA model residuals versus decimal year




SL_QWPsar_M1.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec



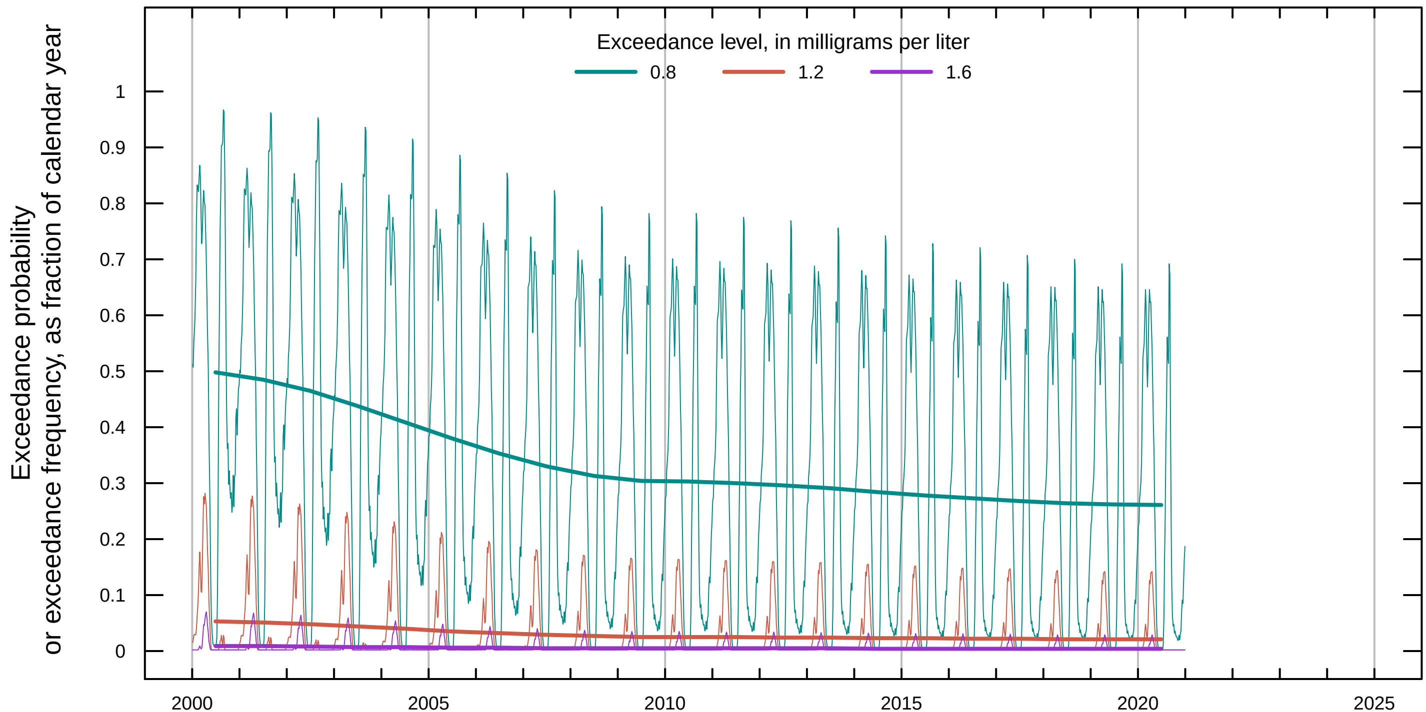
SL_QWPsar_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

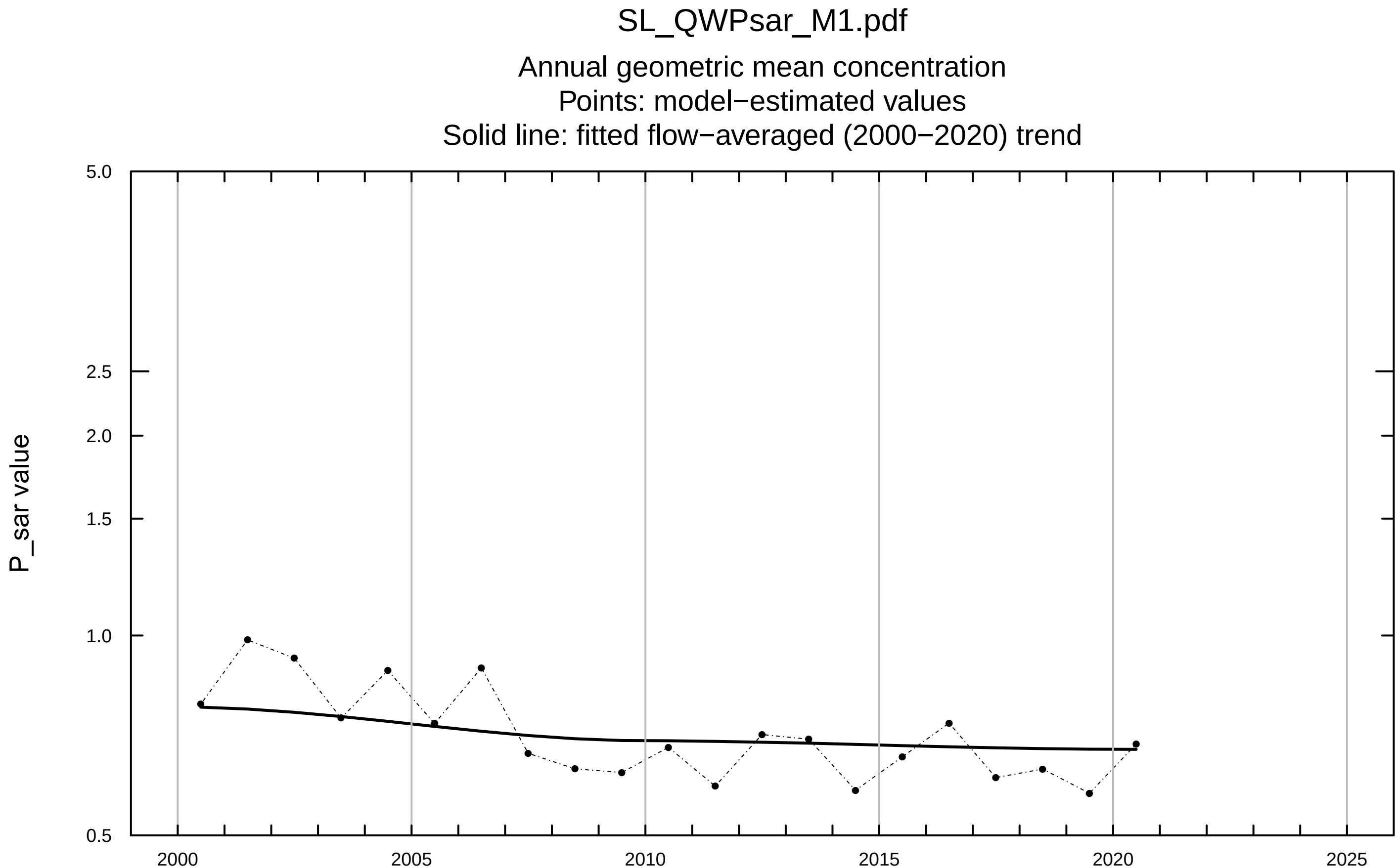
SL_QWPsar_M1.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

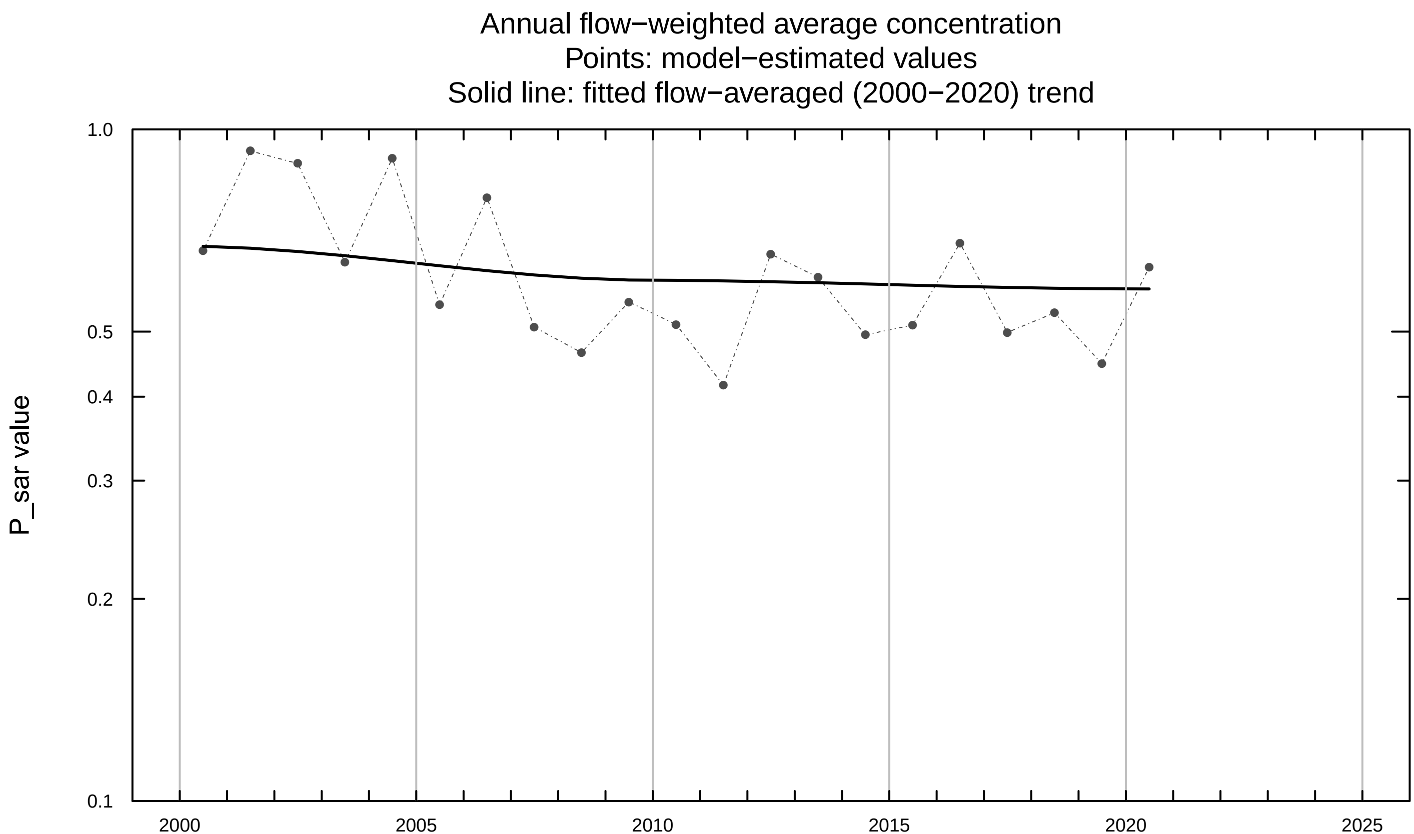
Heavy line: Expected annual flow−averaged exceedance frequency

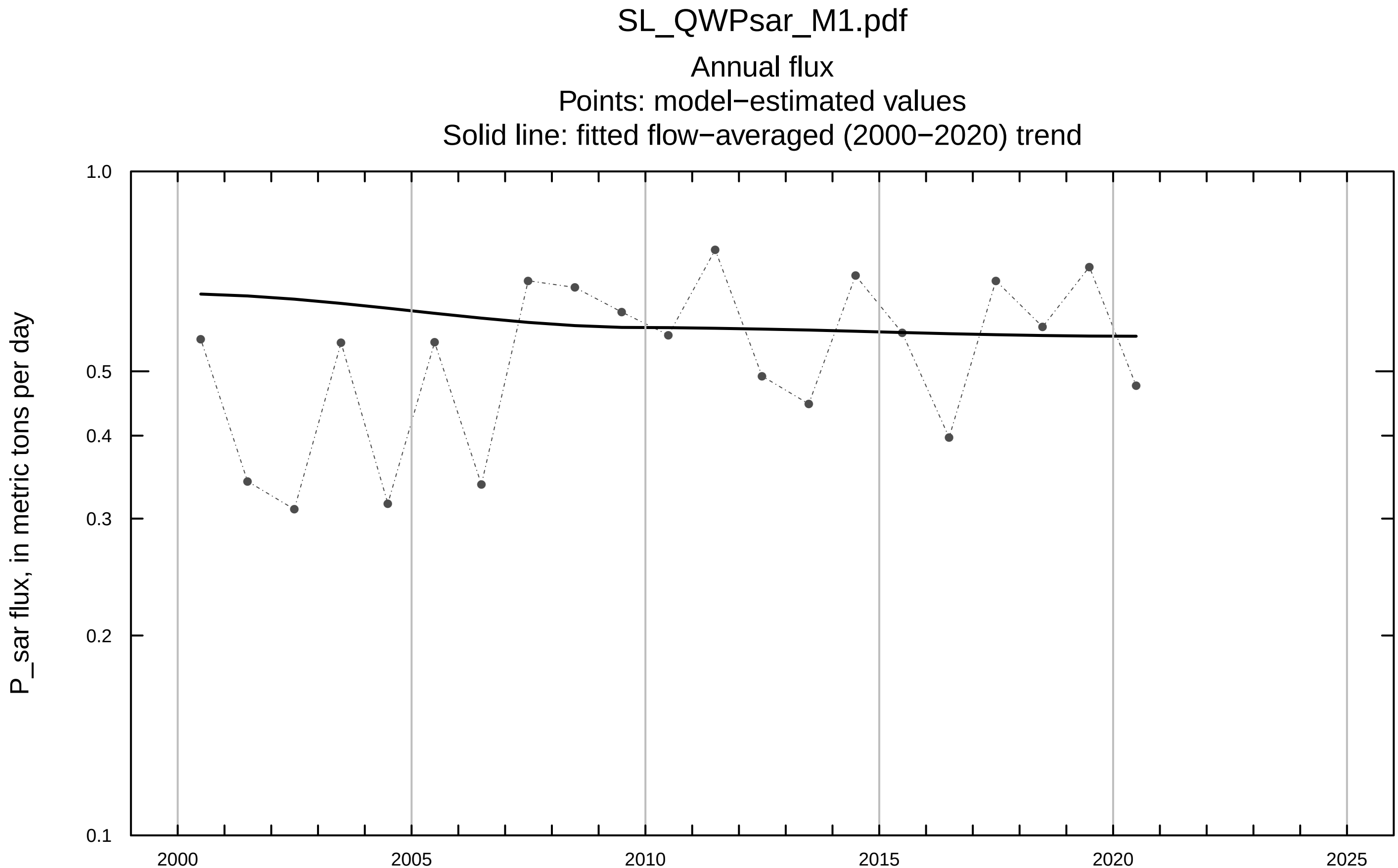




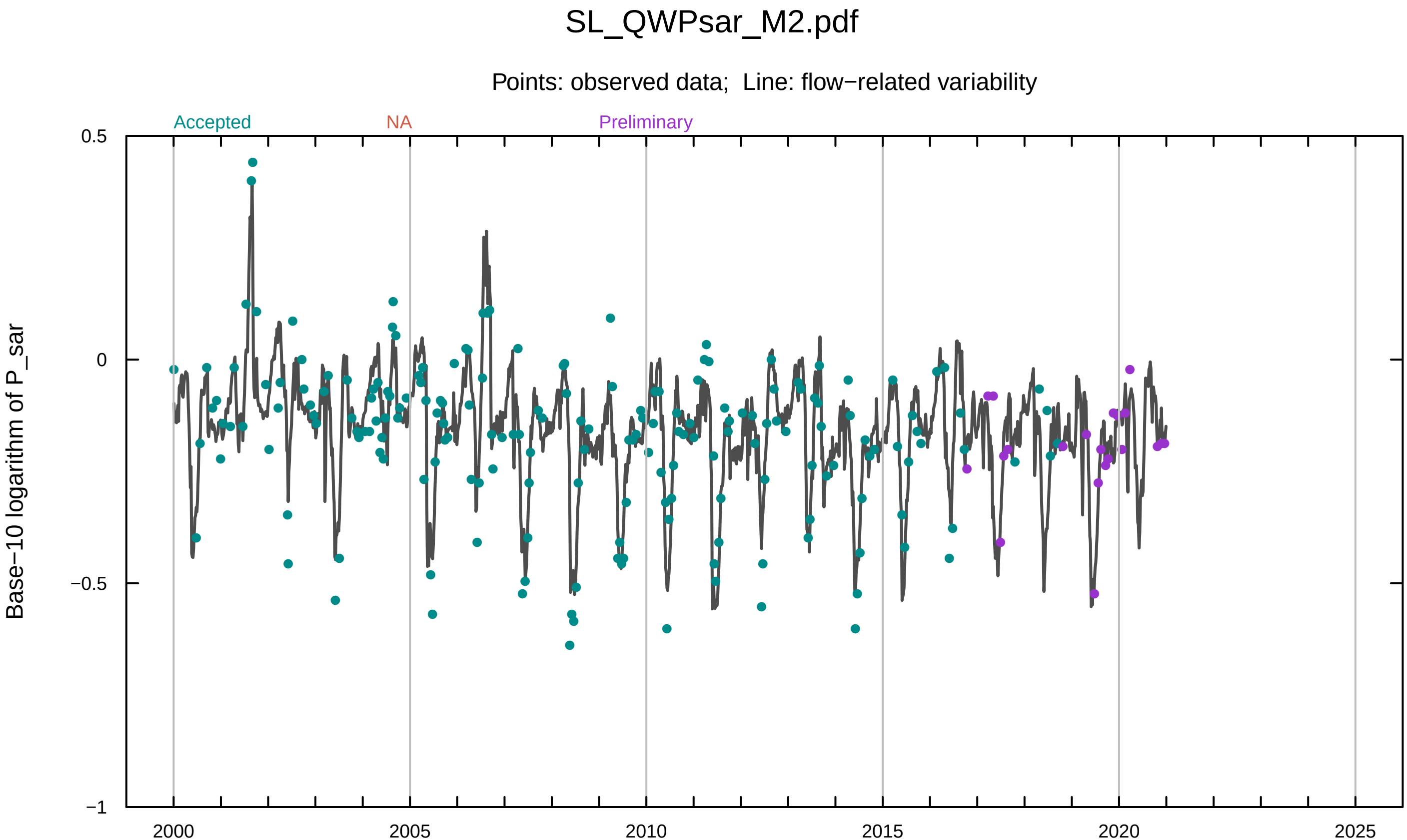
SL_QWPsar_M1.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

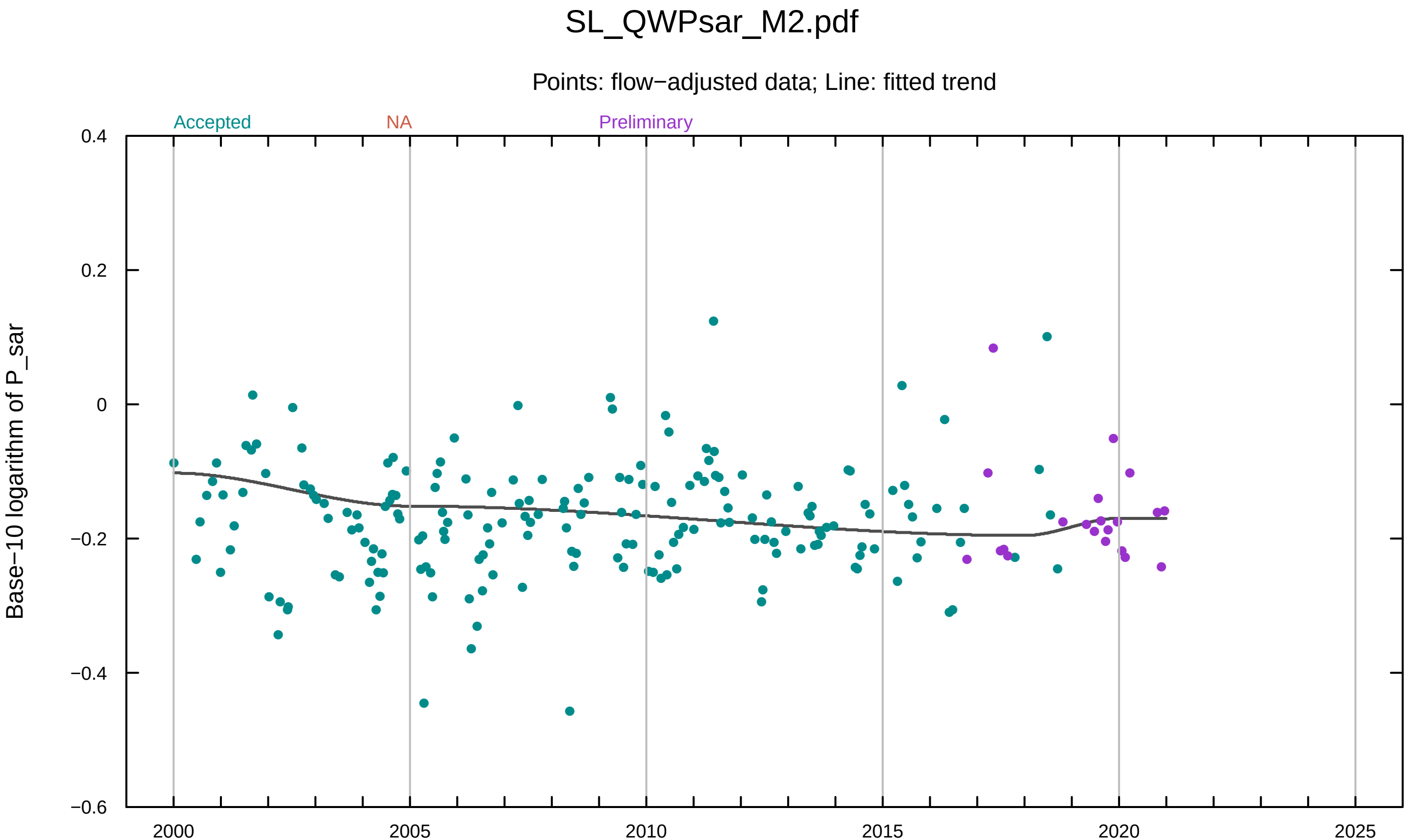
SL_QWPsar_M1.pdf

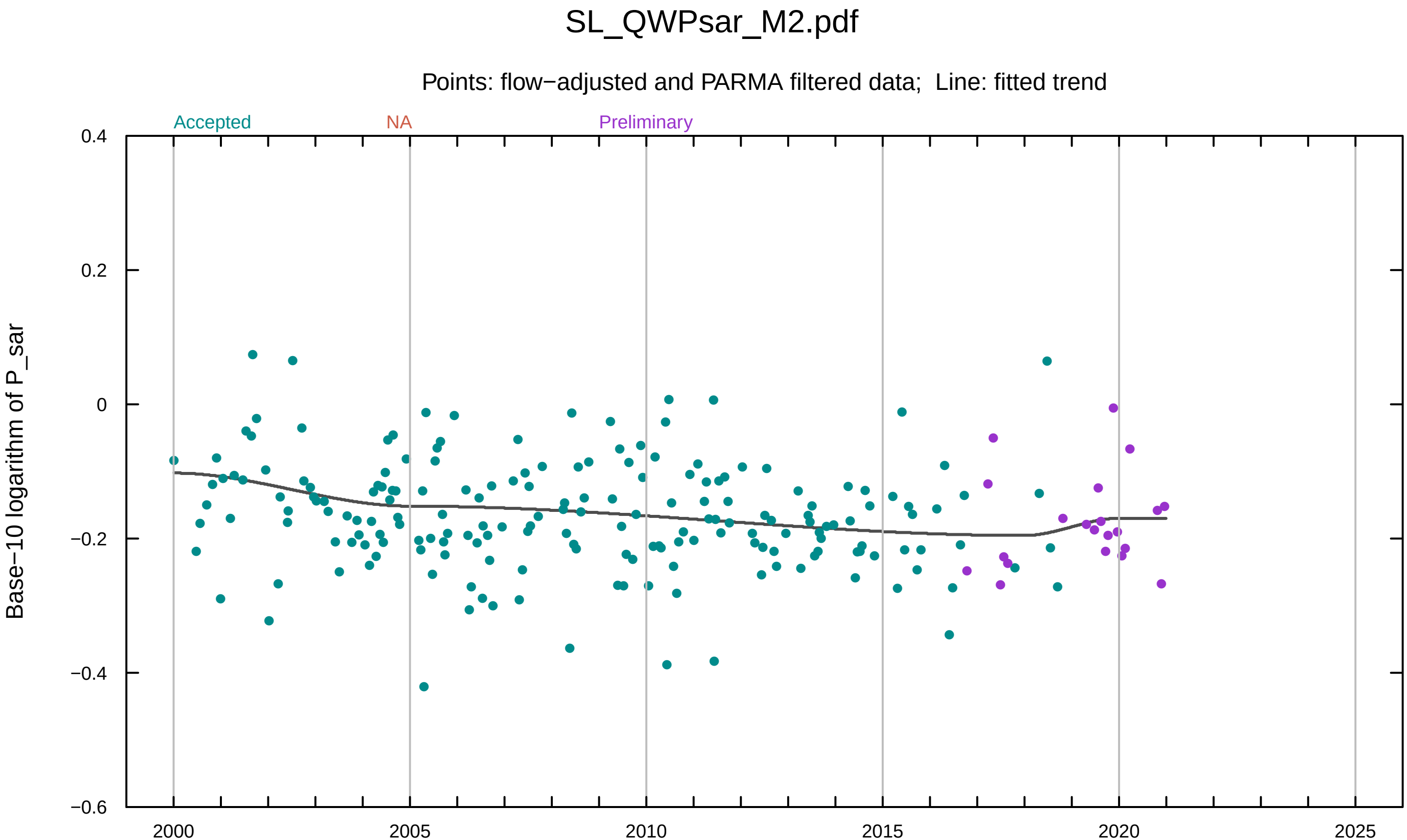




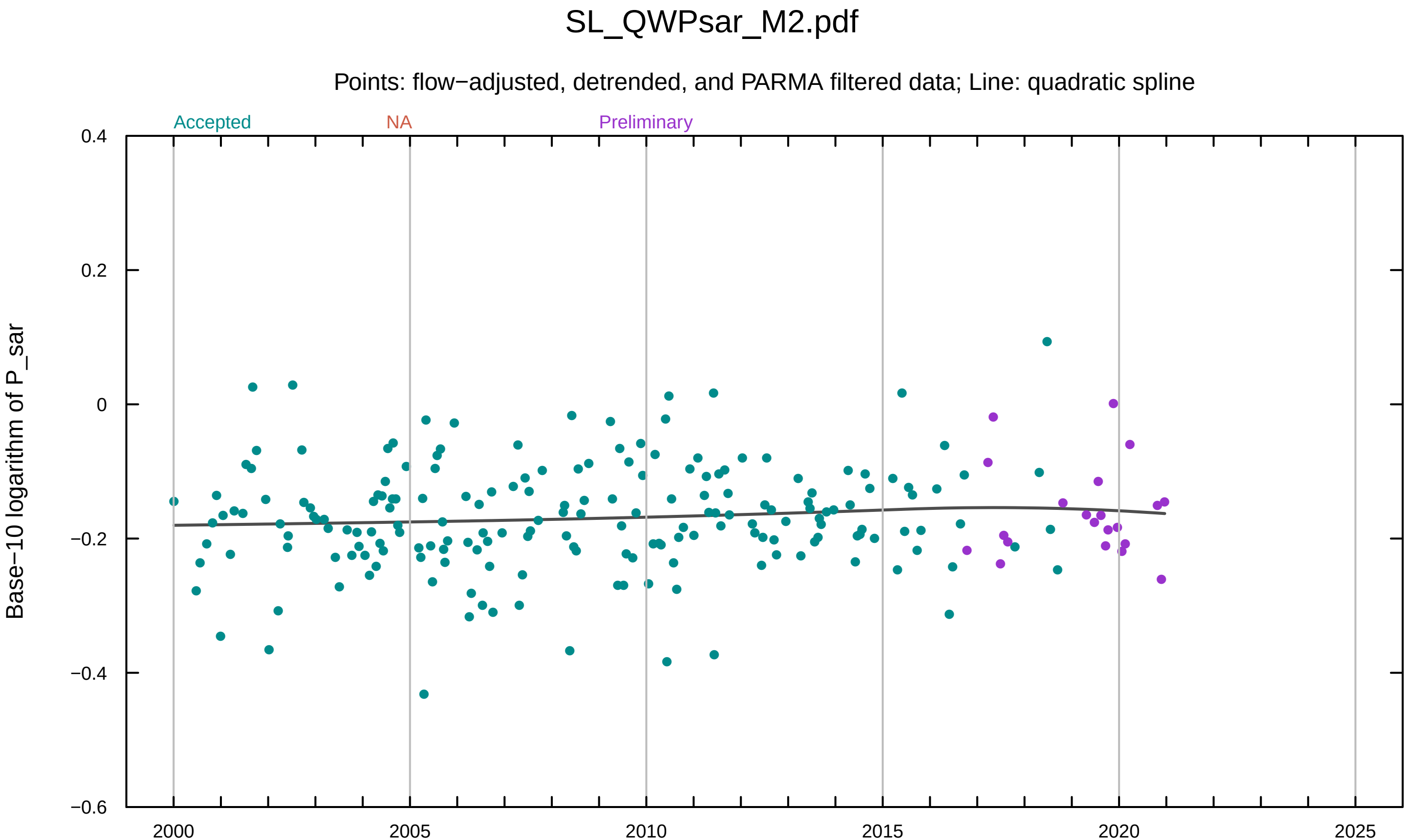
SL_QWPsar_M1.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

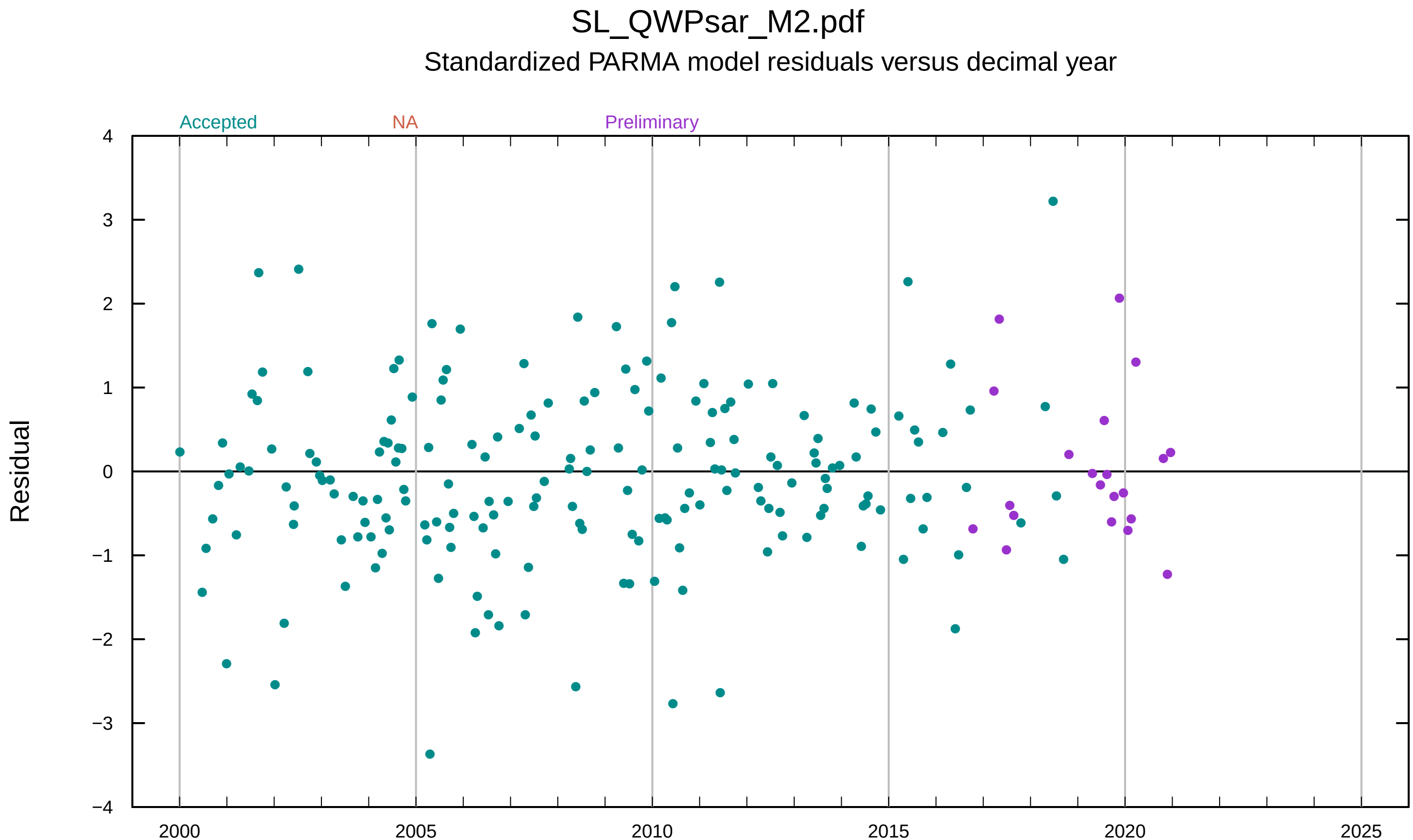

SL_QWPsar_M2.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
0.5
0
−0.5
−1
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

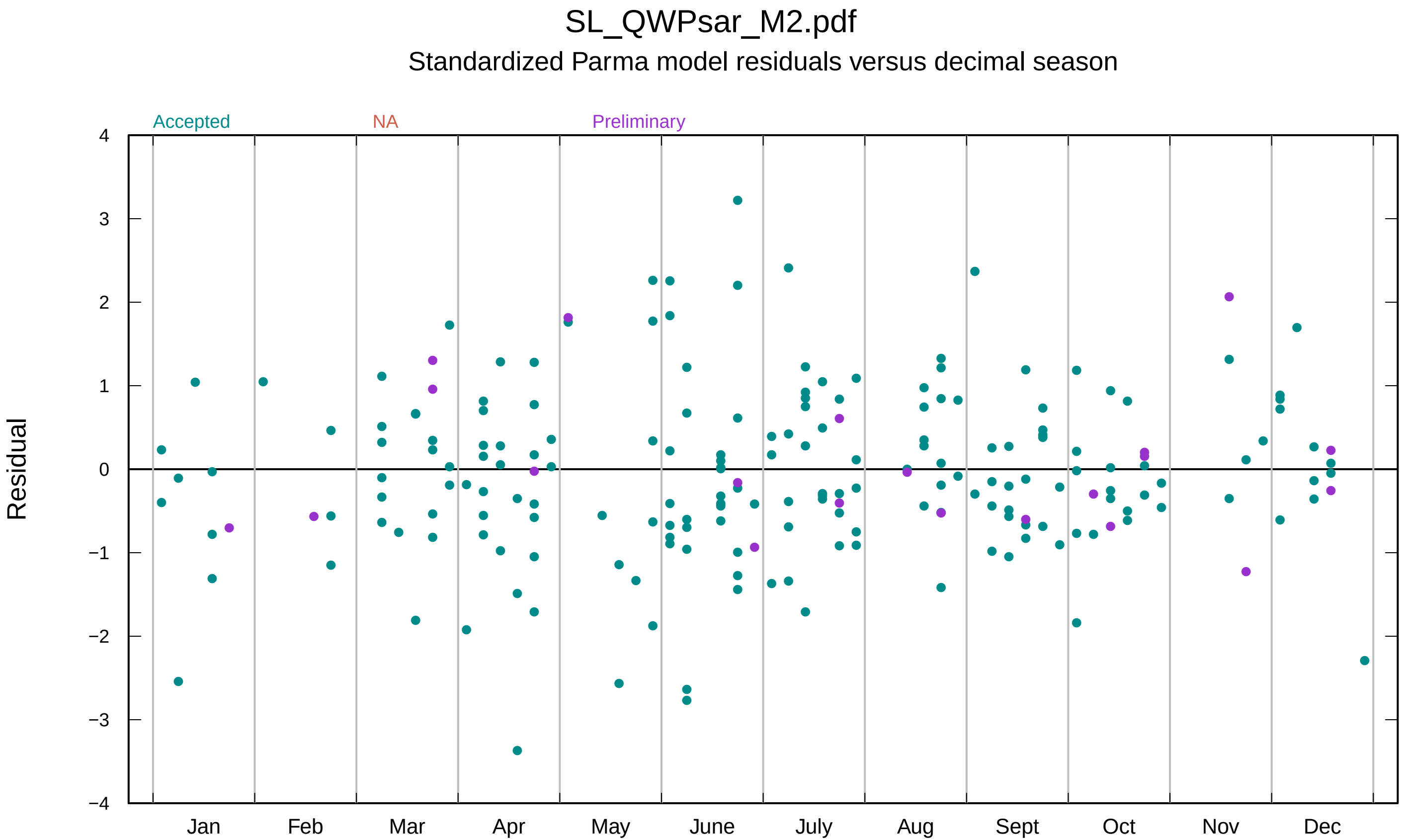

SL_QWPsar_M2.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025



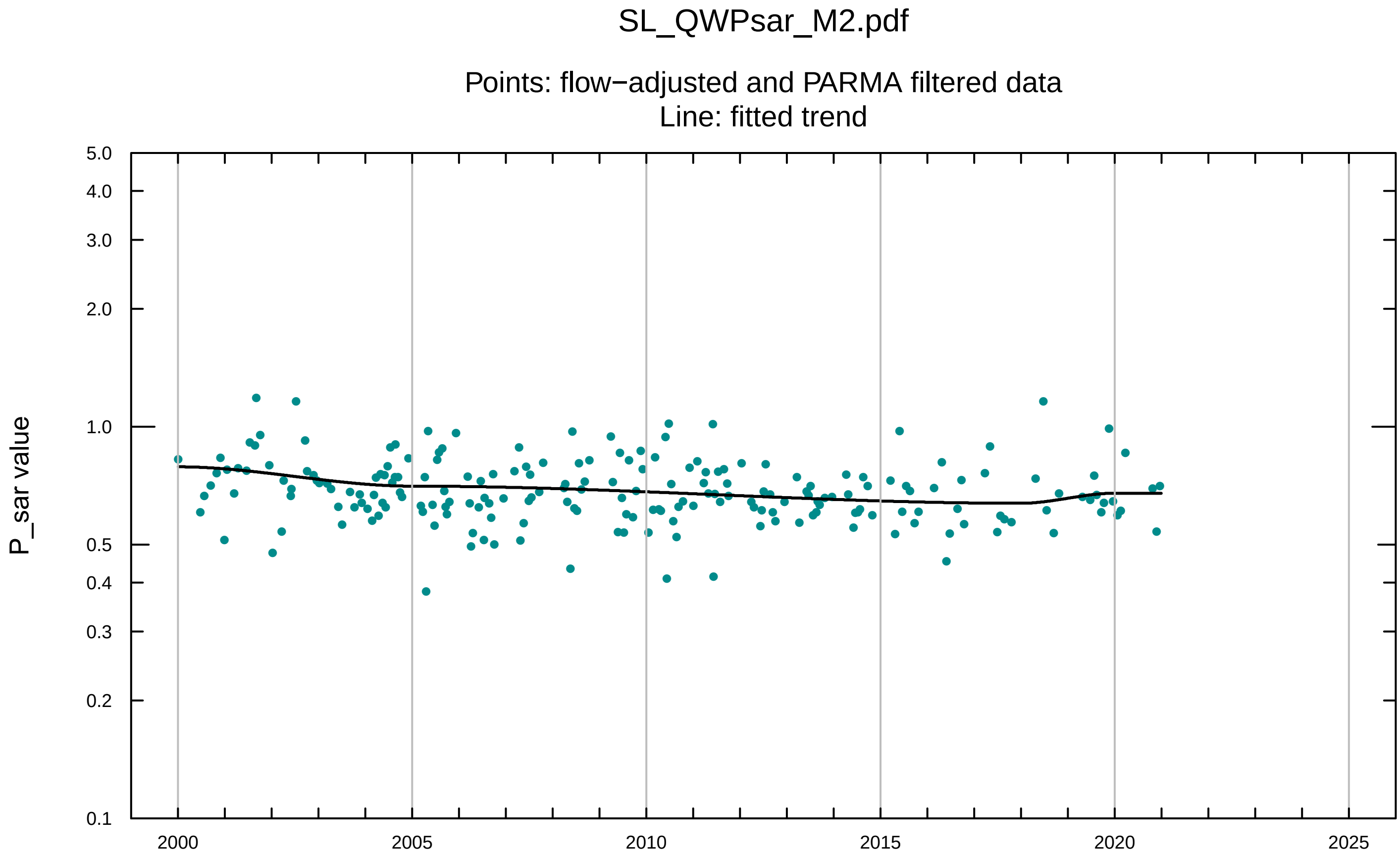
SL_QWPsar_M2.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025

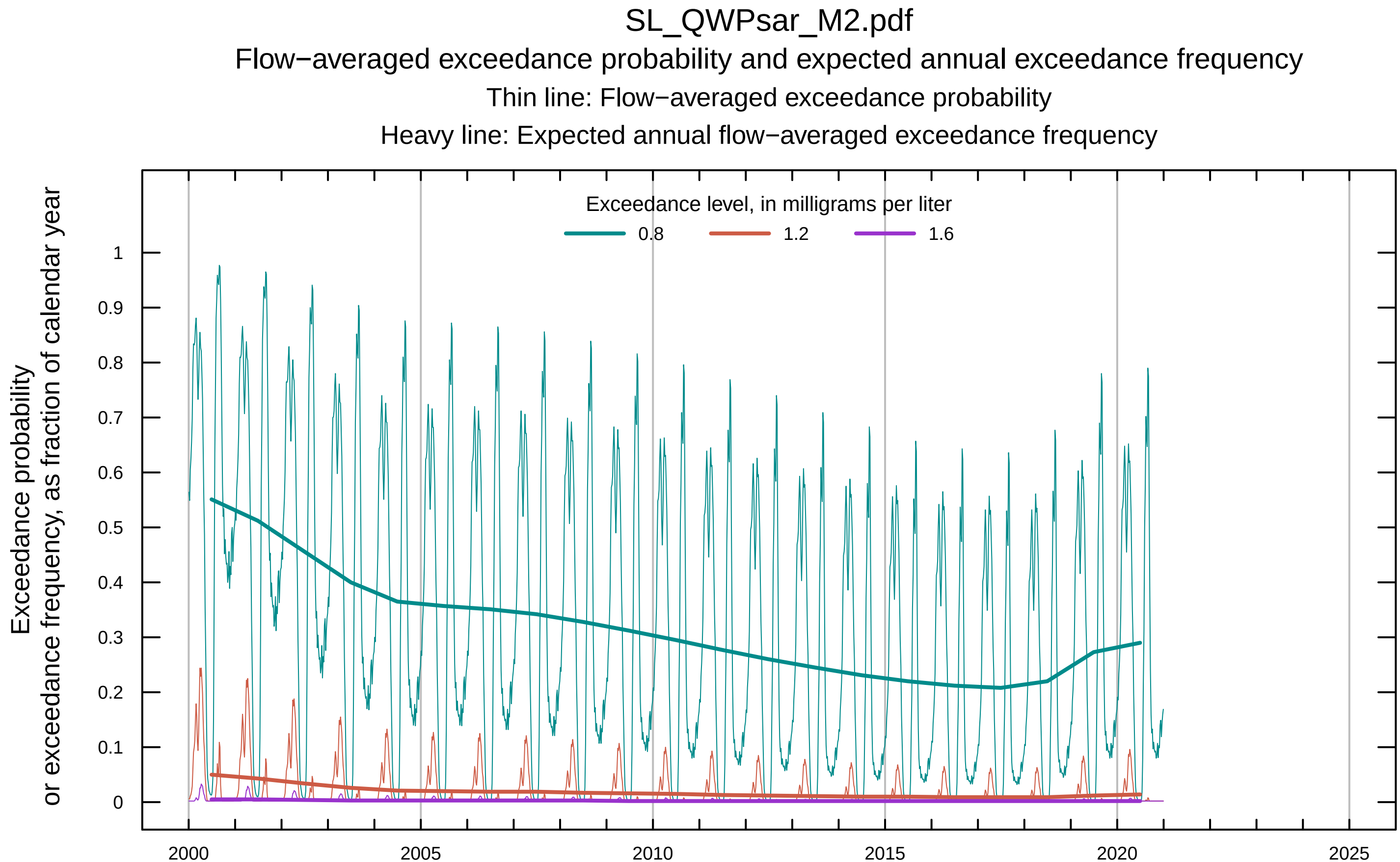

SL_QWPsar_M2.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025


SL_QWPsar_M2.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025



SL_QWPsar_M2.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

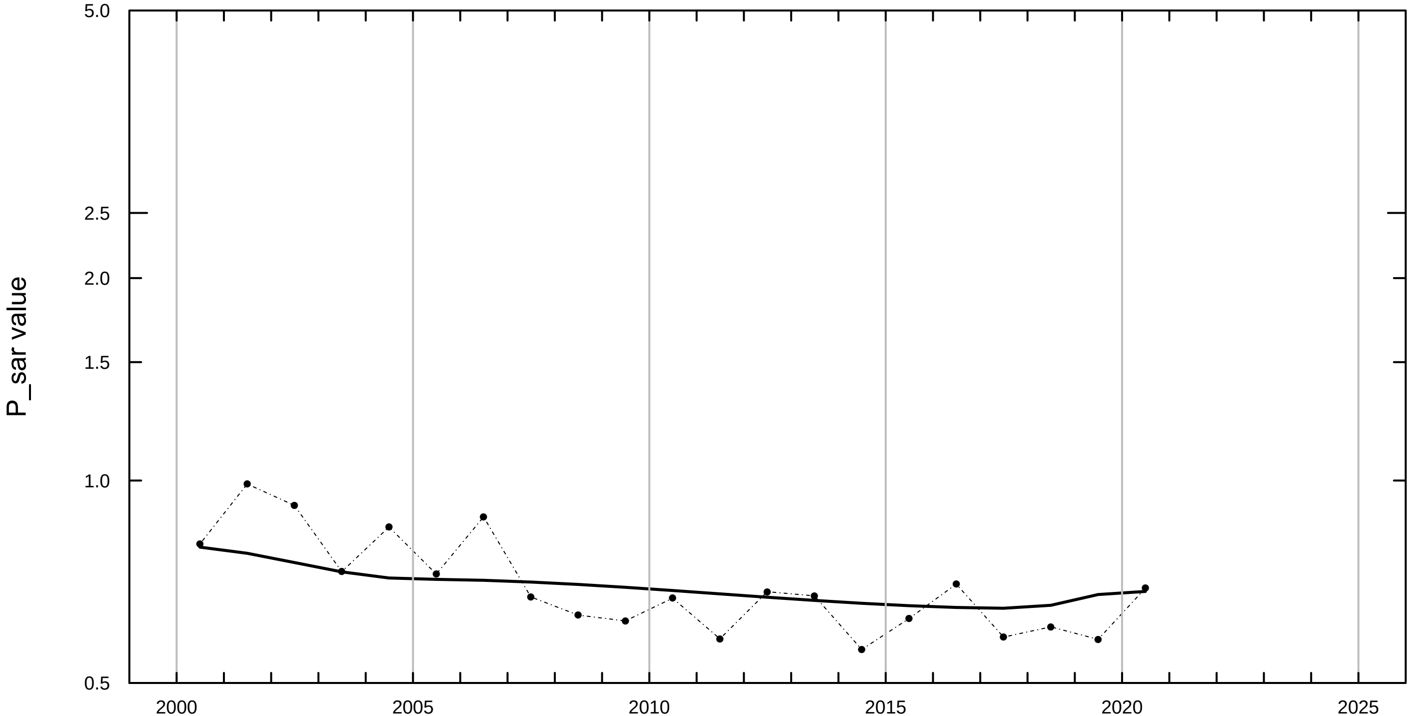

SL_QWPsar_M2.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

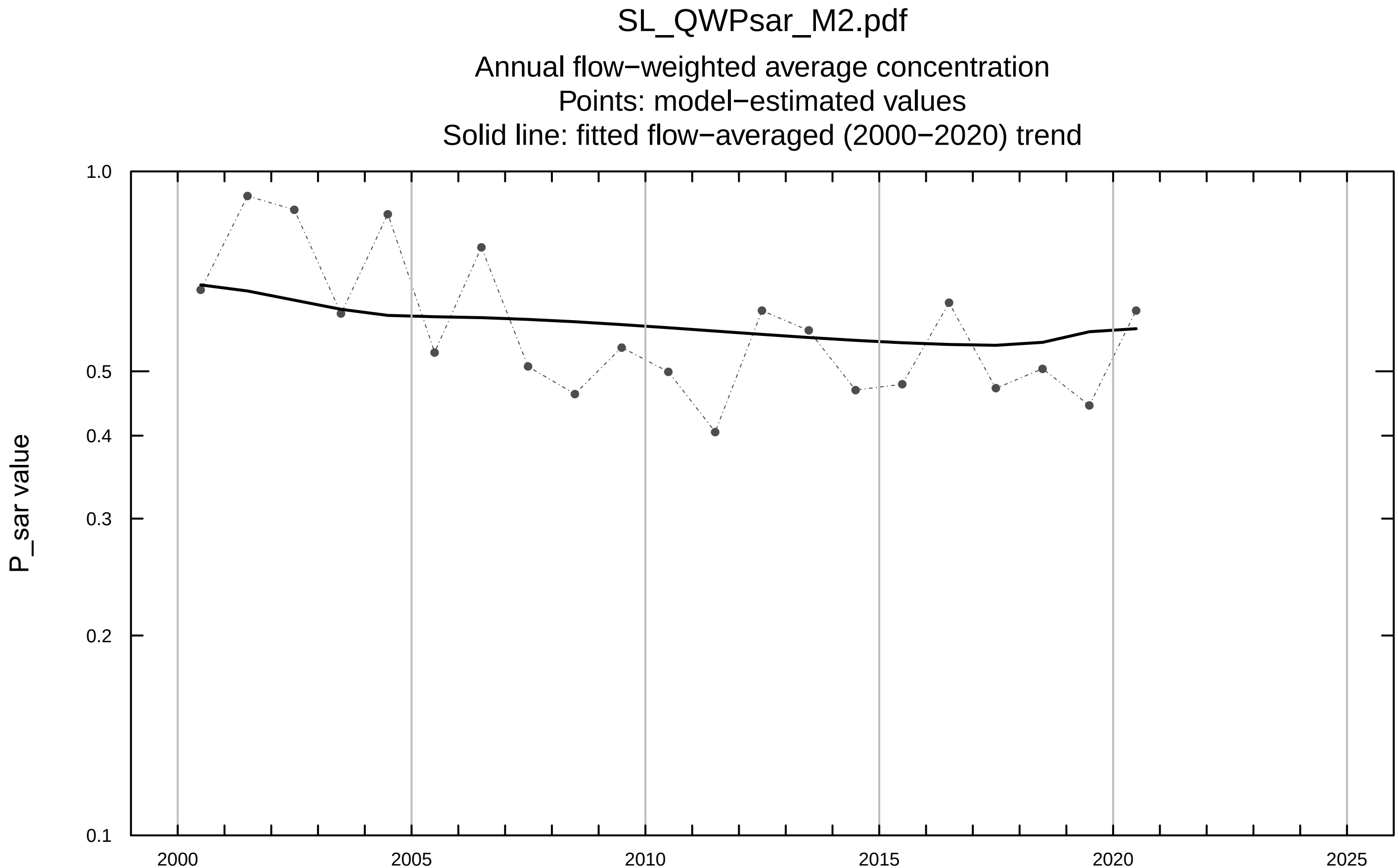


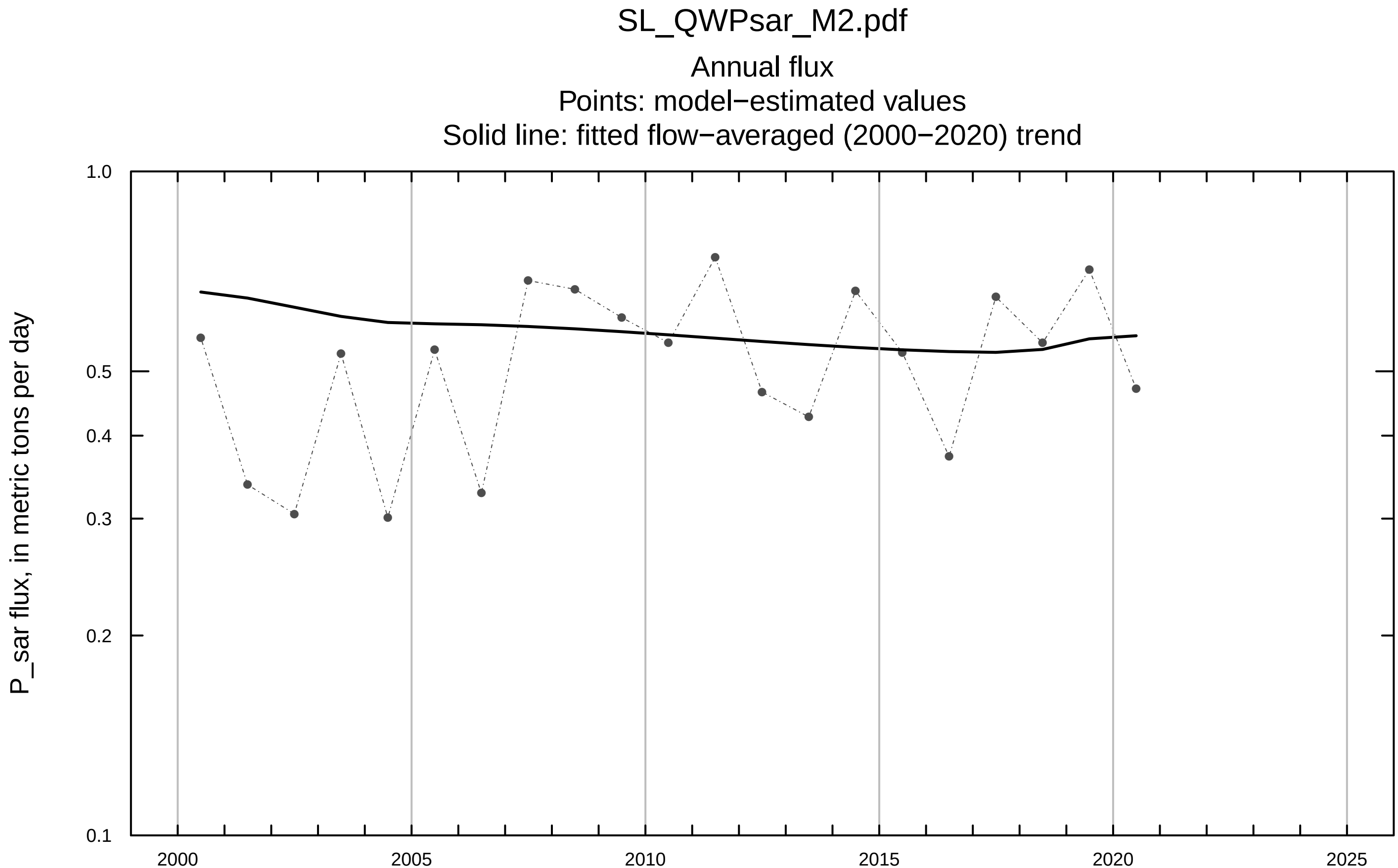
SL_QWPsar_M2.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025

SL_QWPsar_M2.pdf

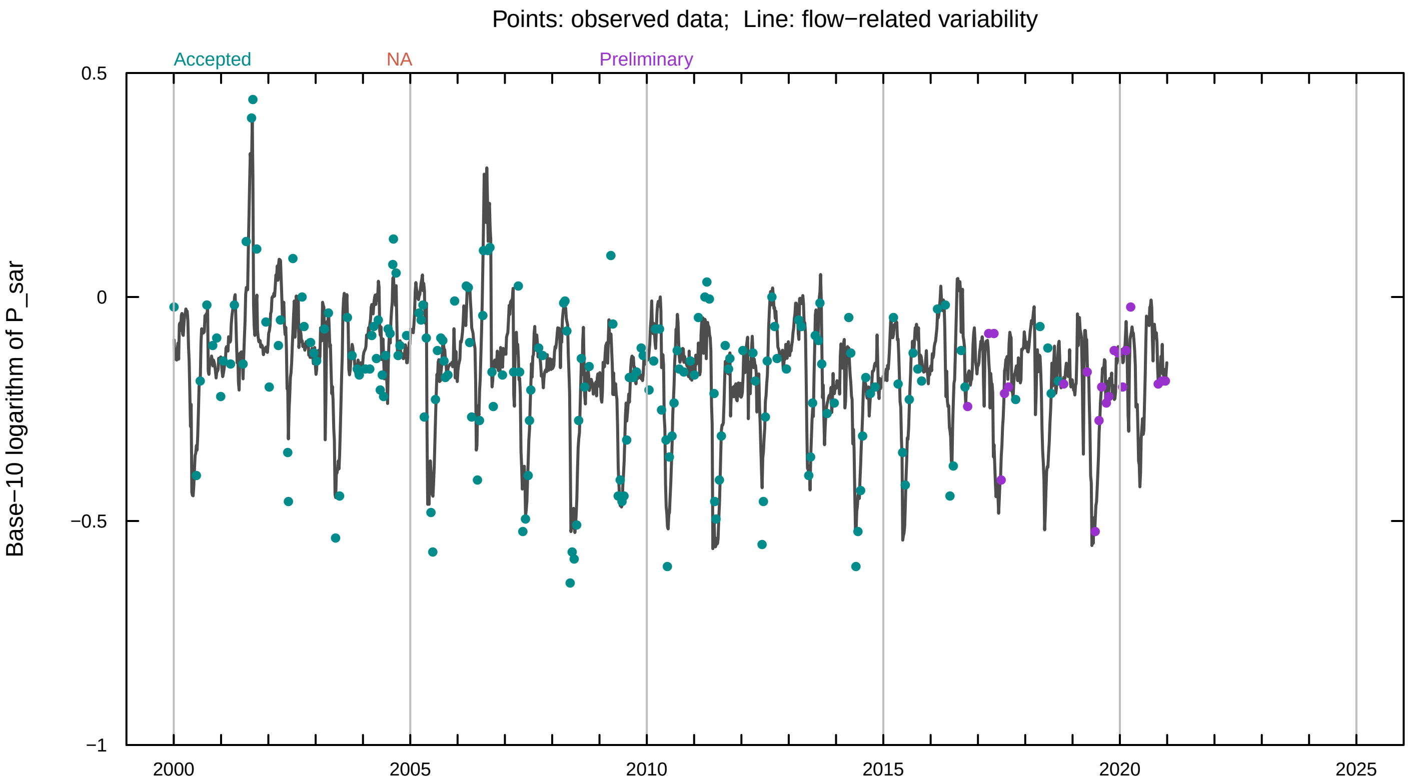
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend

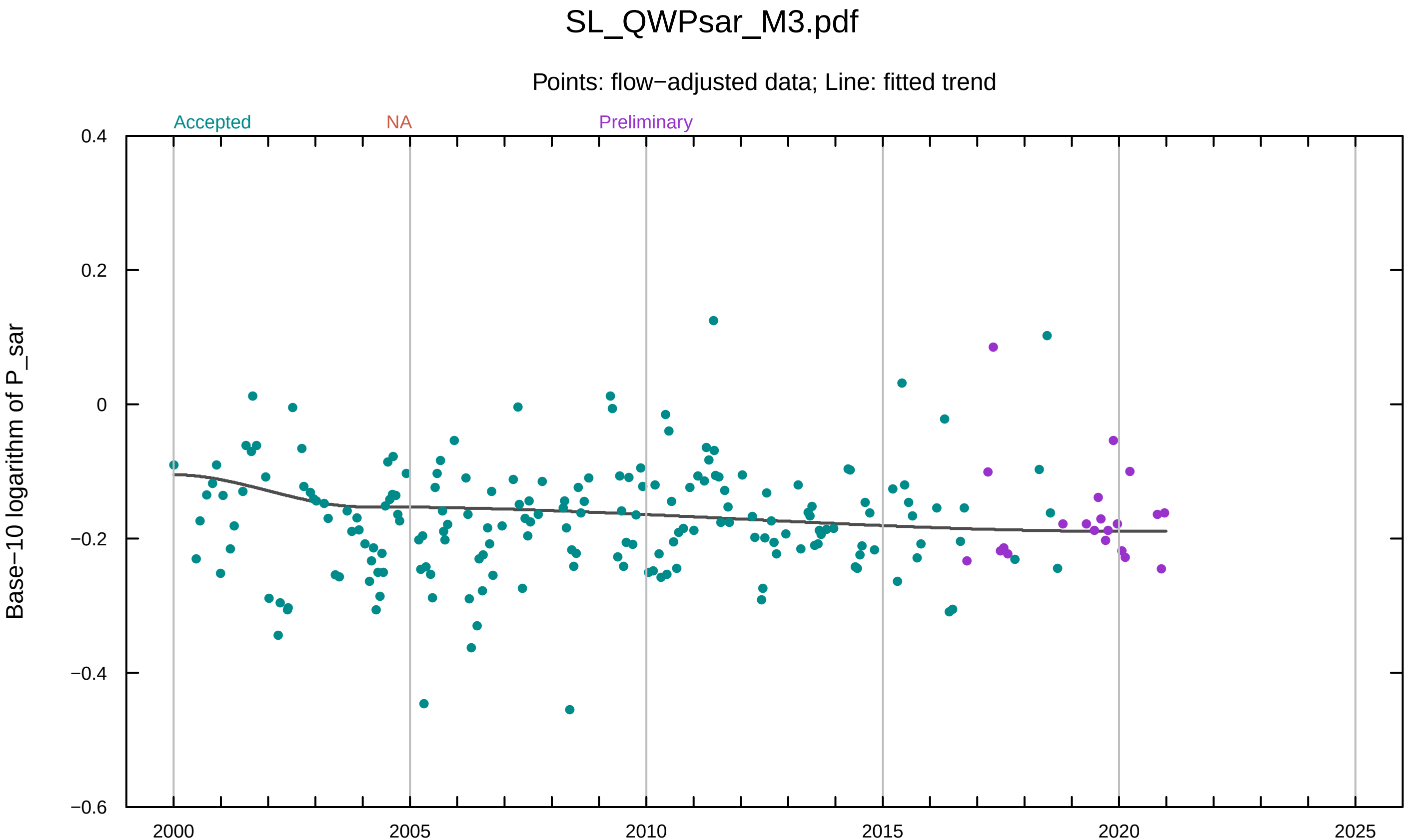



SL_QWPsar_M2.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

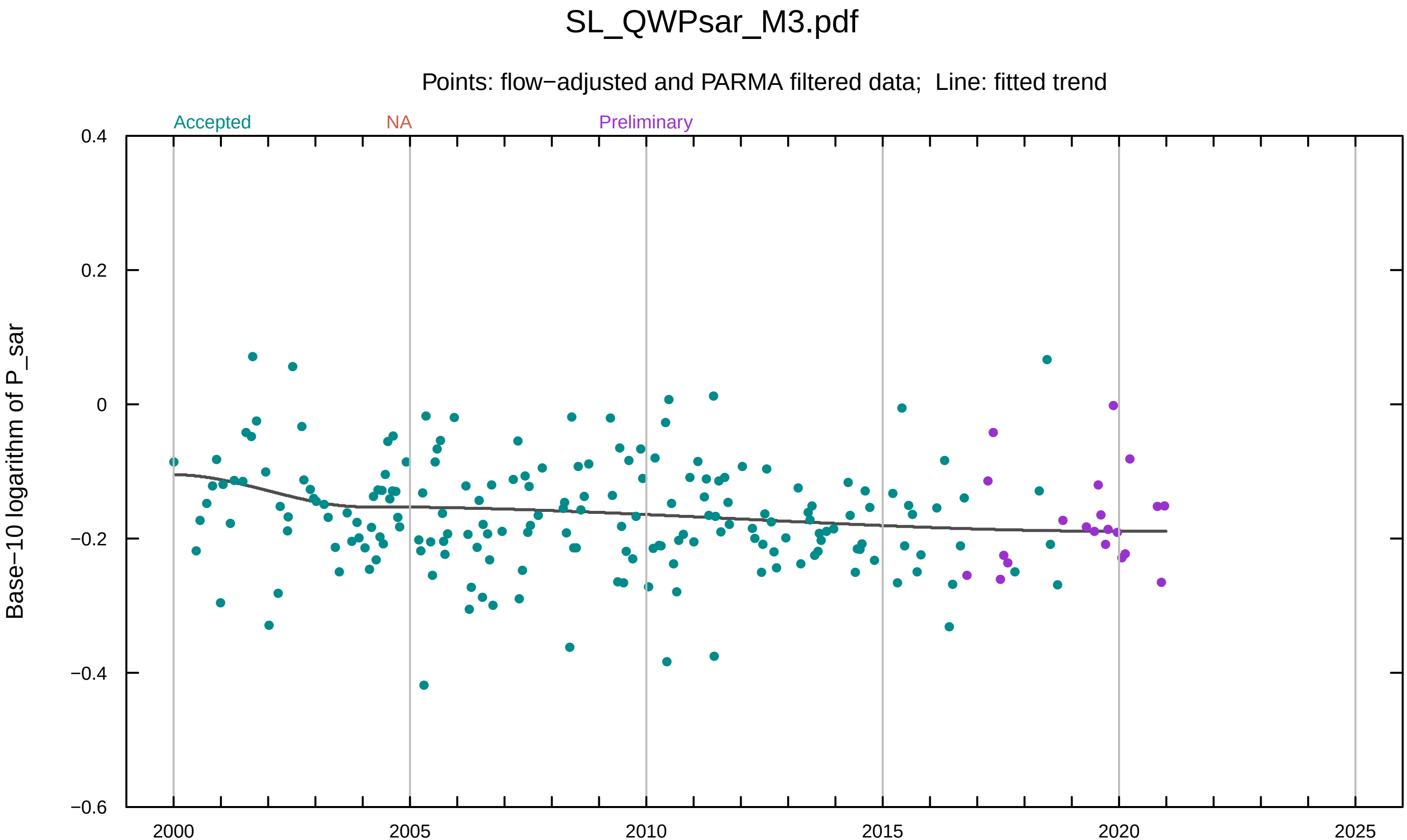

SL_QWPsar_M2.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

SL_QWPsar_M3.pdf

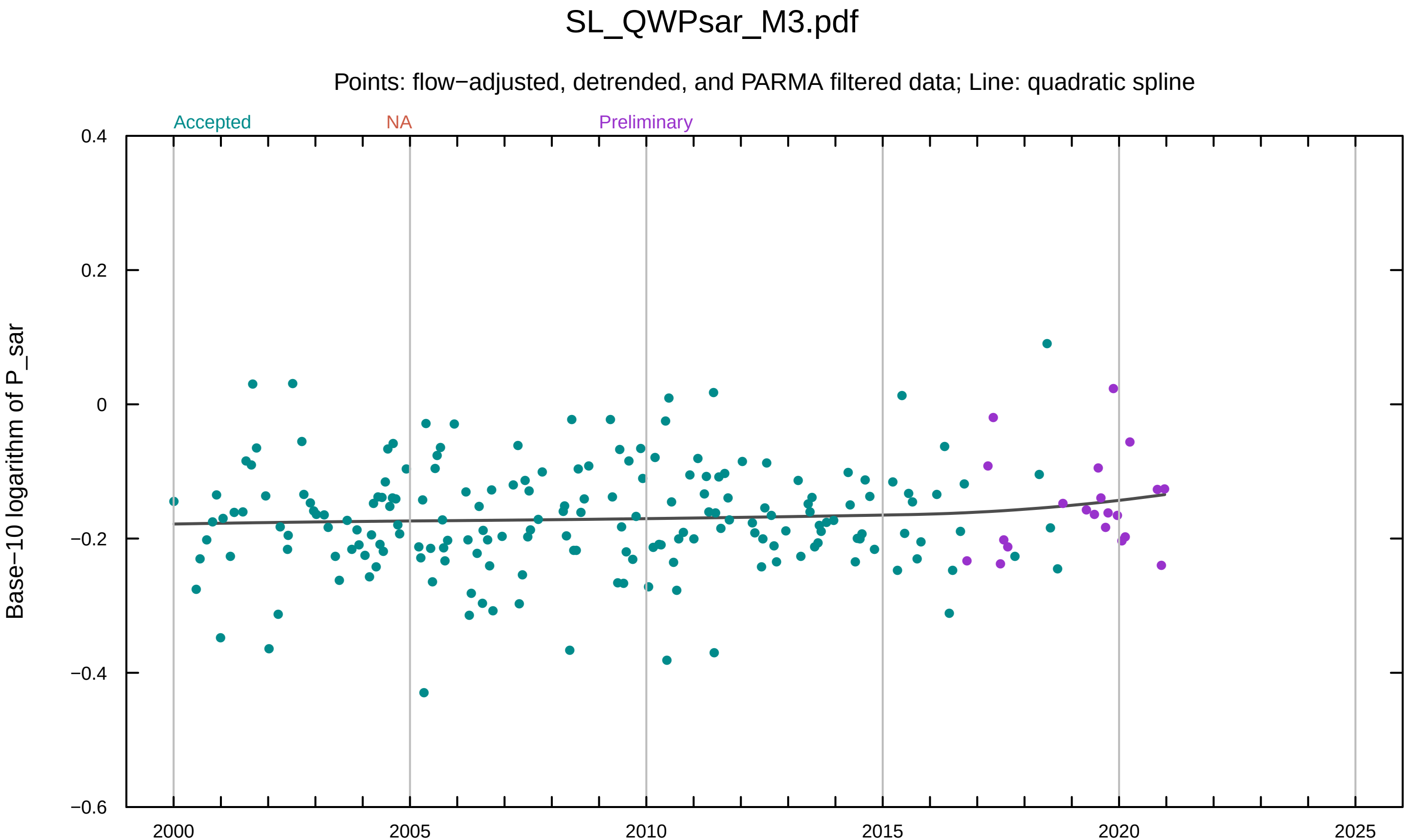




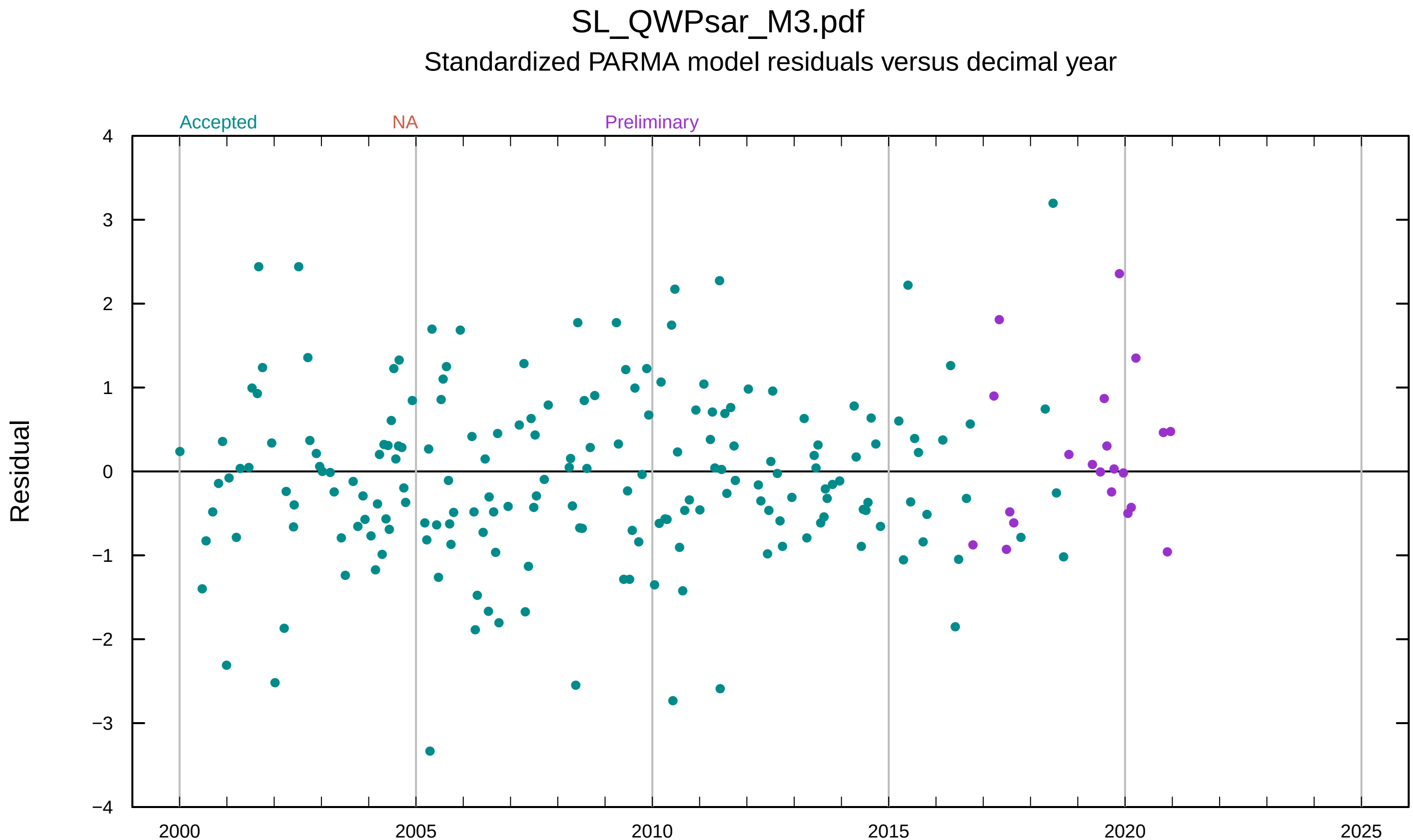
SL_QWPsar_M3.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025



SL_QWPsar_M3.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
0.4
0.2
0
−0.2
−0.4
−0.6
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025



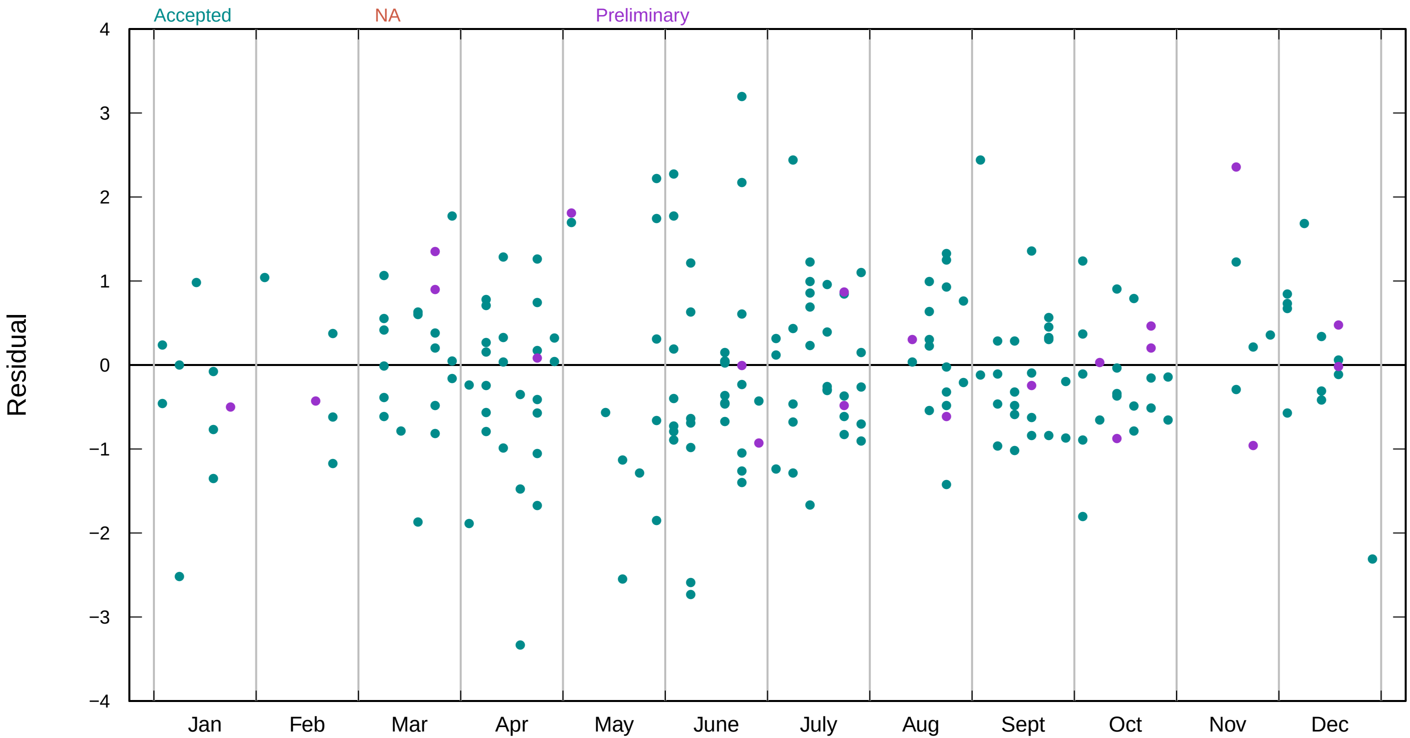
SL_QWPsar_M3.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025



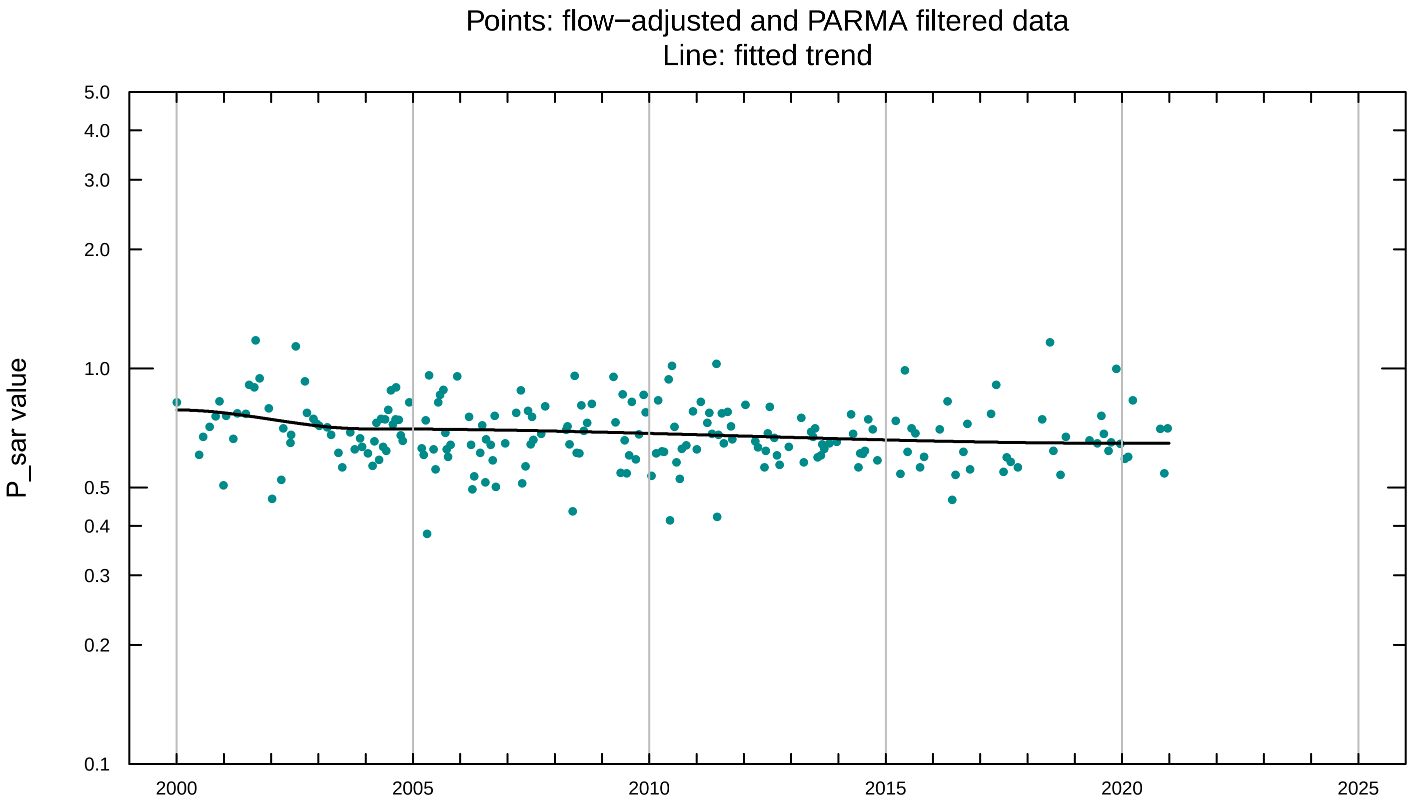
SL_QWPsar_M3.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025

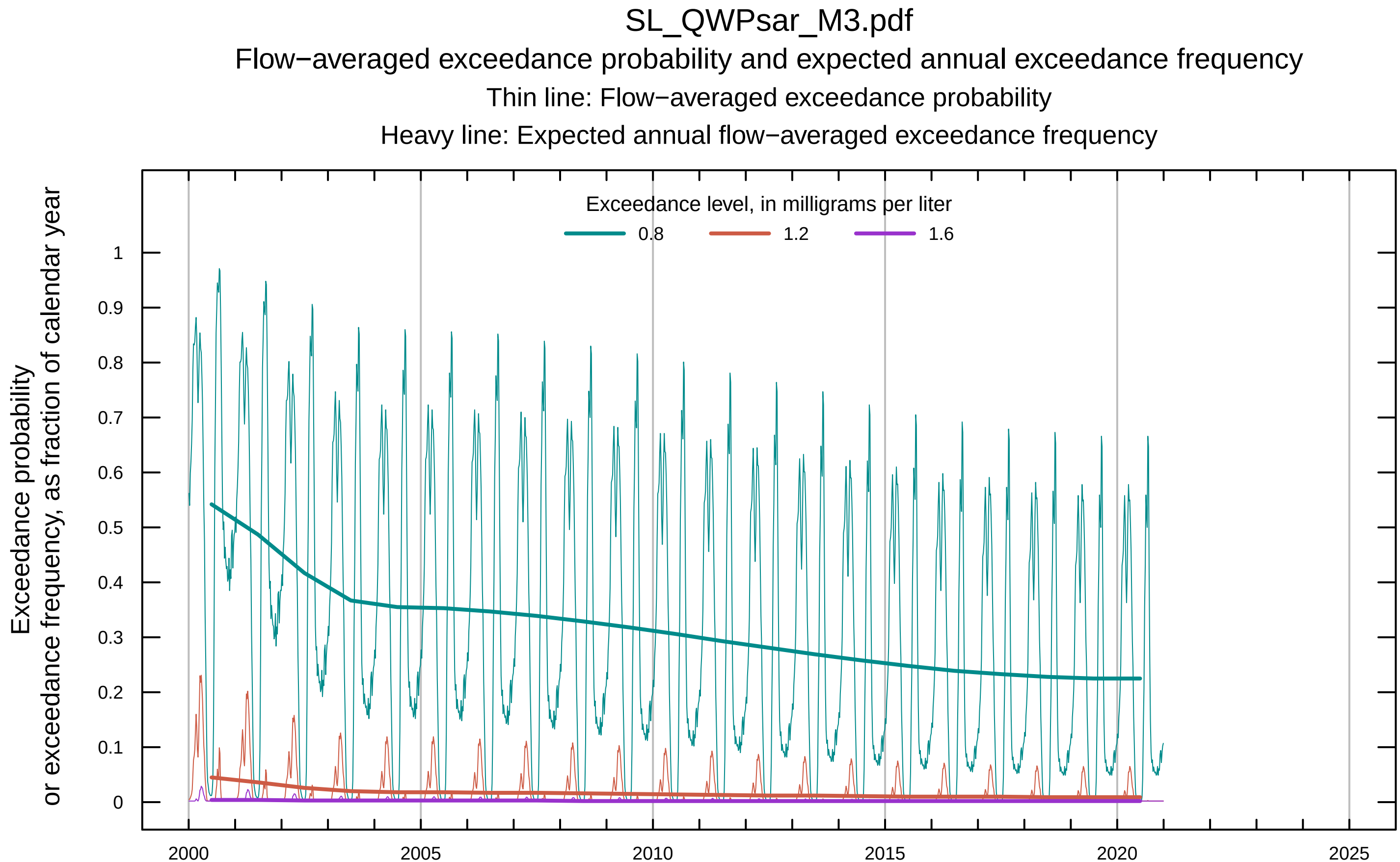
SL_QWPsar_M3.pdf

Standardized Parma model residuals versus decimal season

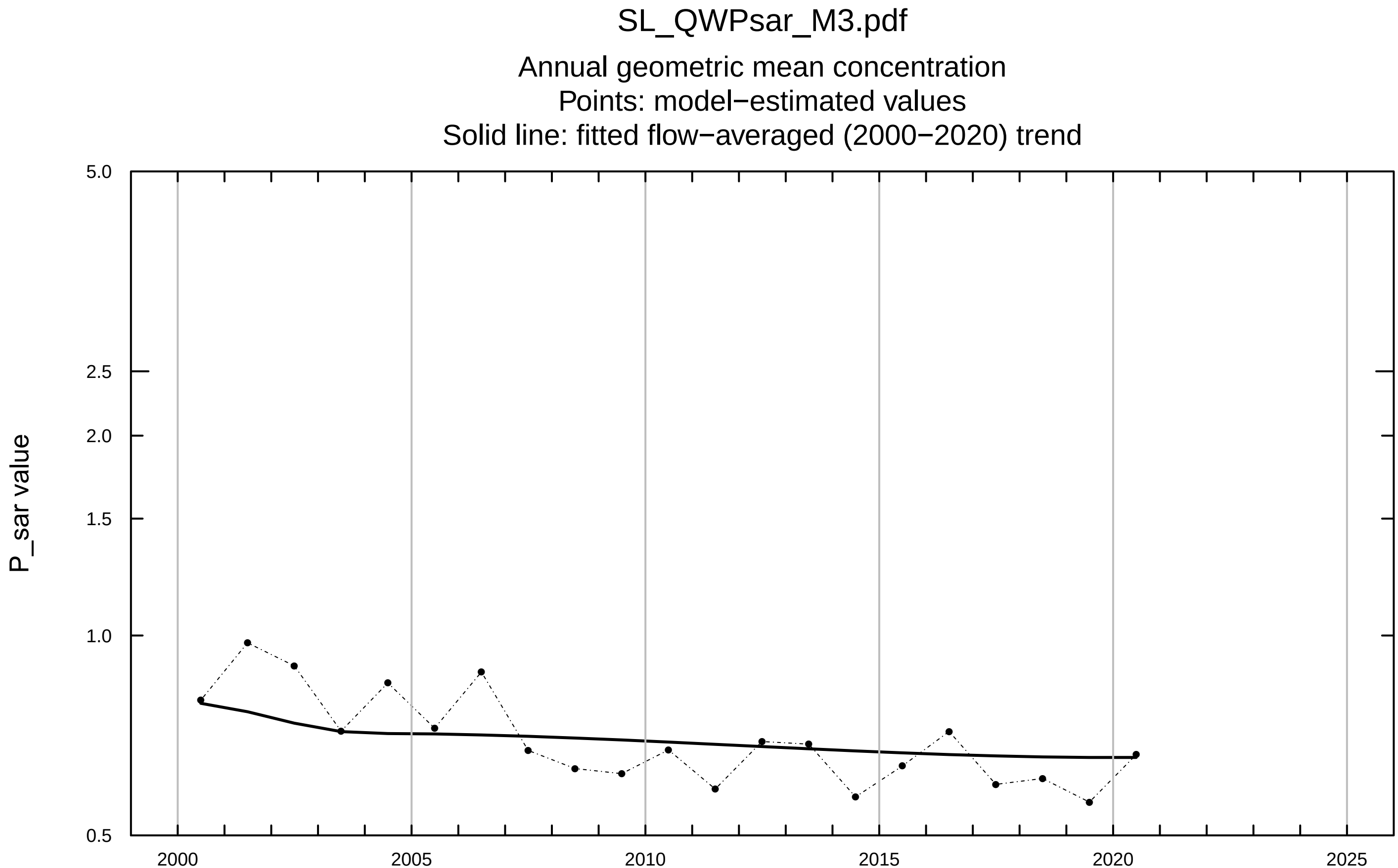


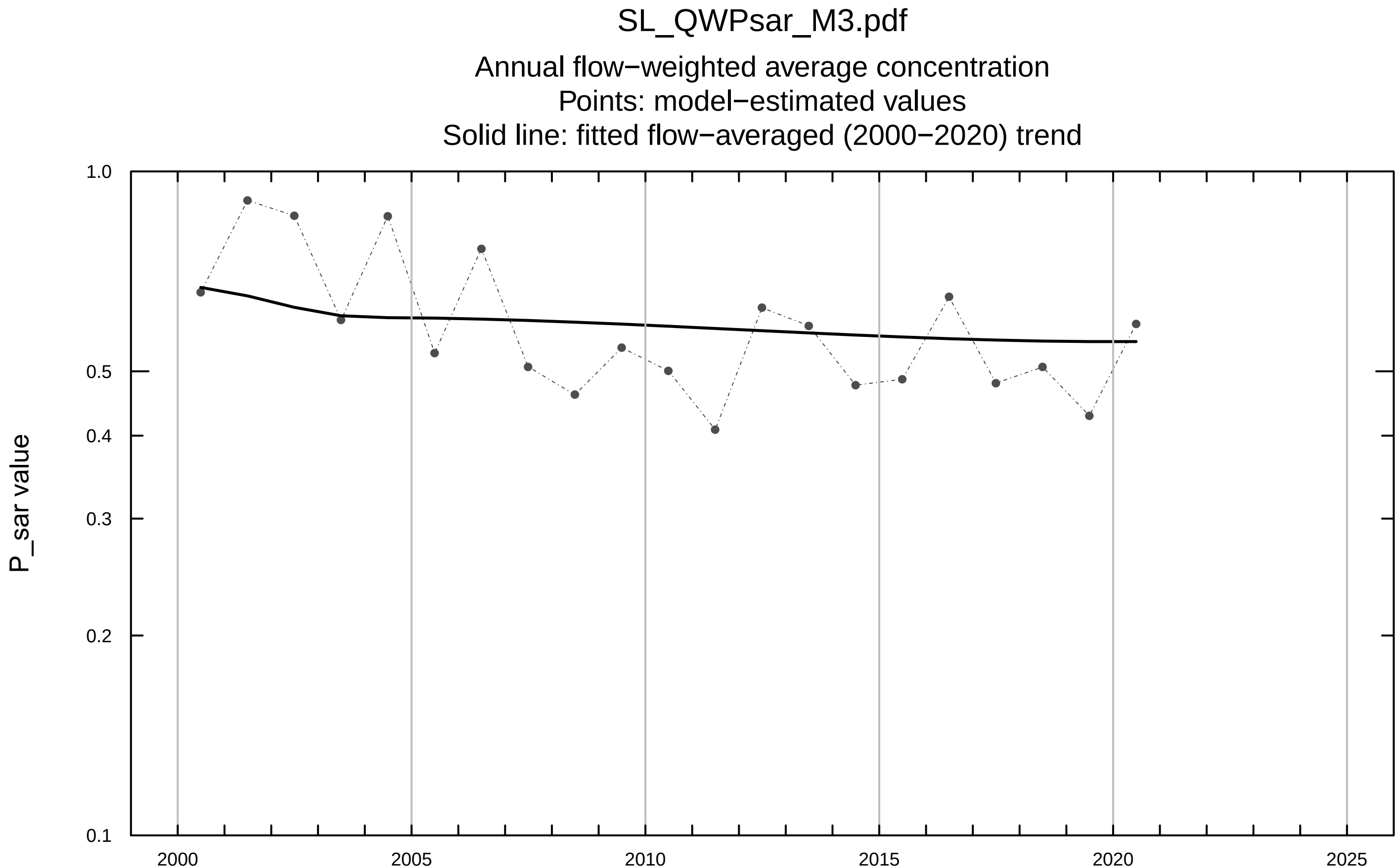
SL_QWPsar_M3.pdf

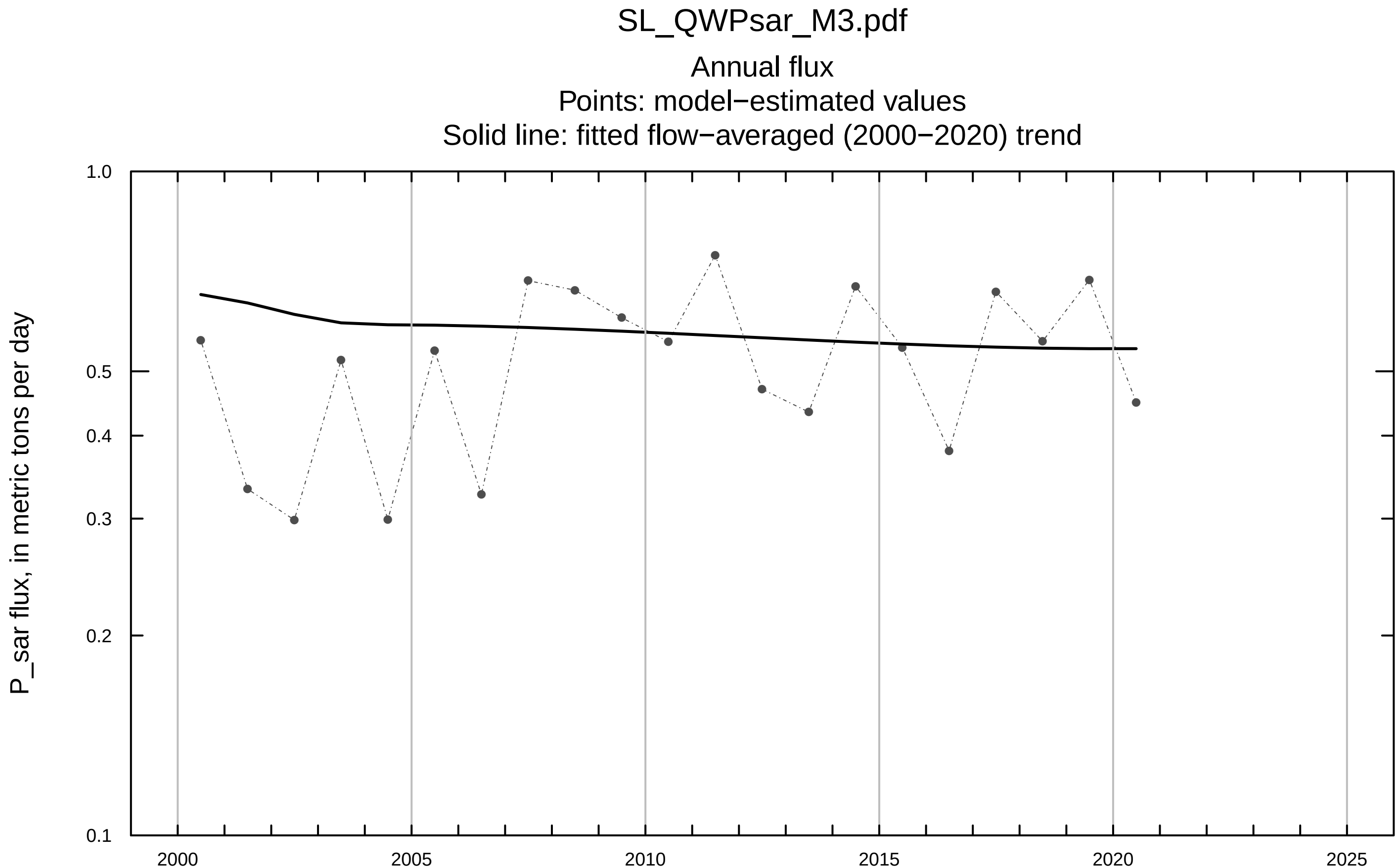




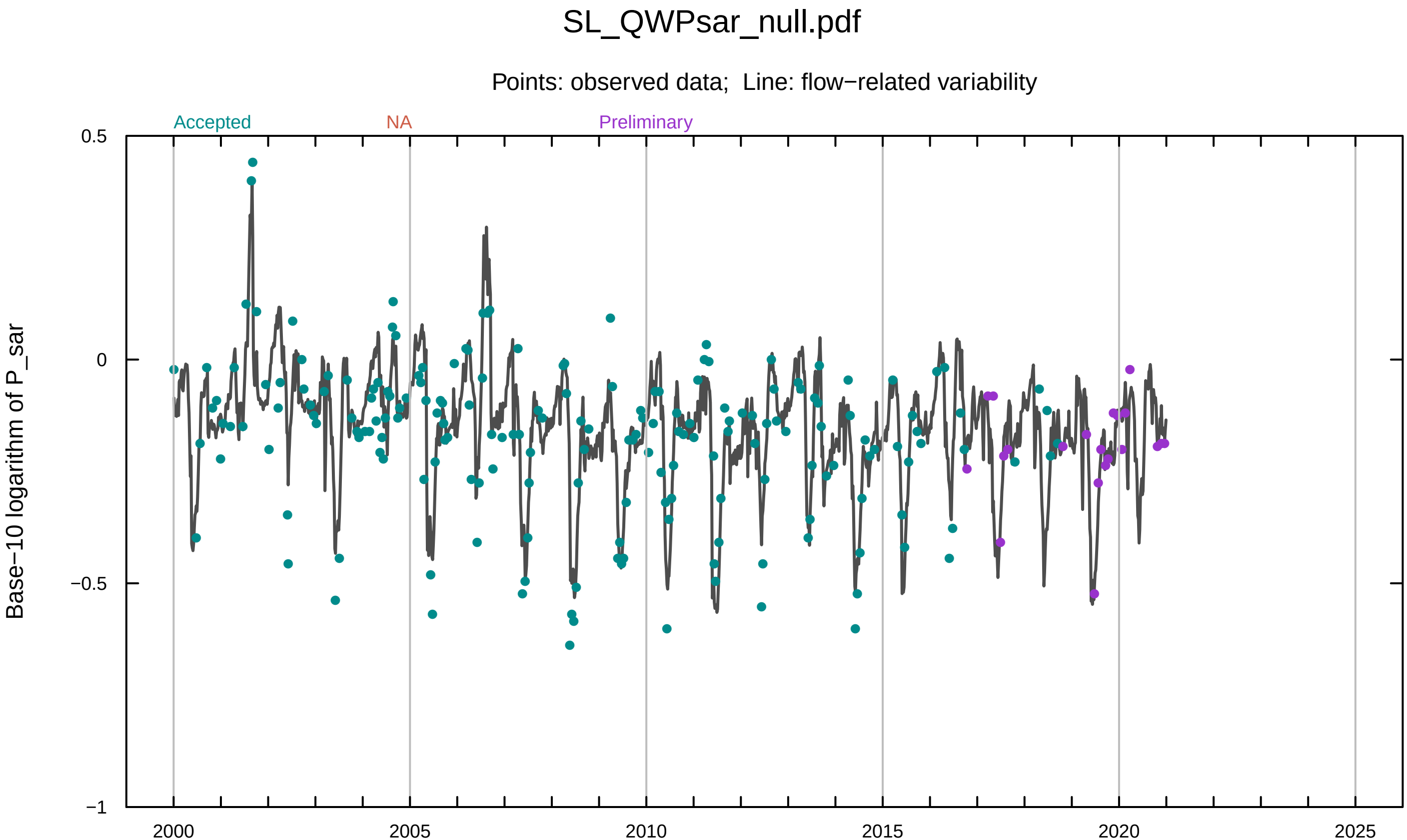
SL_QWPsar_M3.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025


SL_QWPsar_M3.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

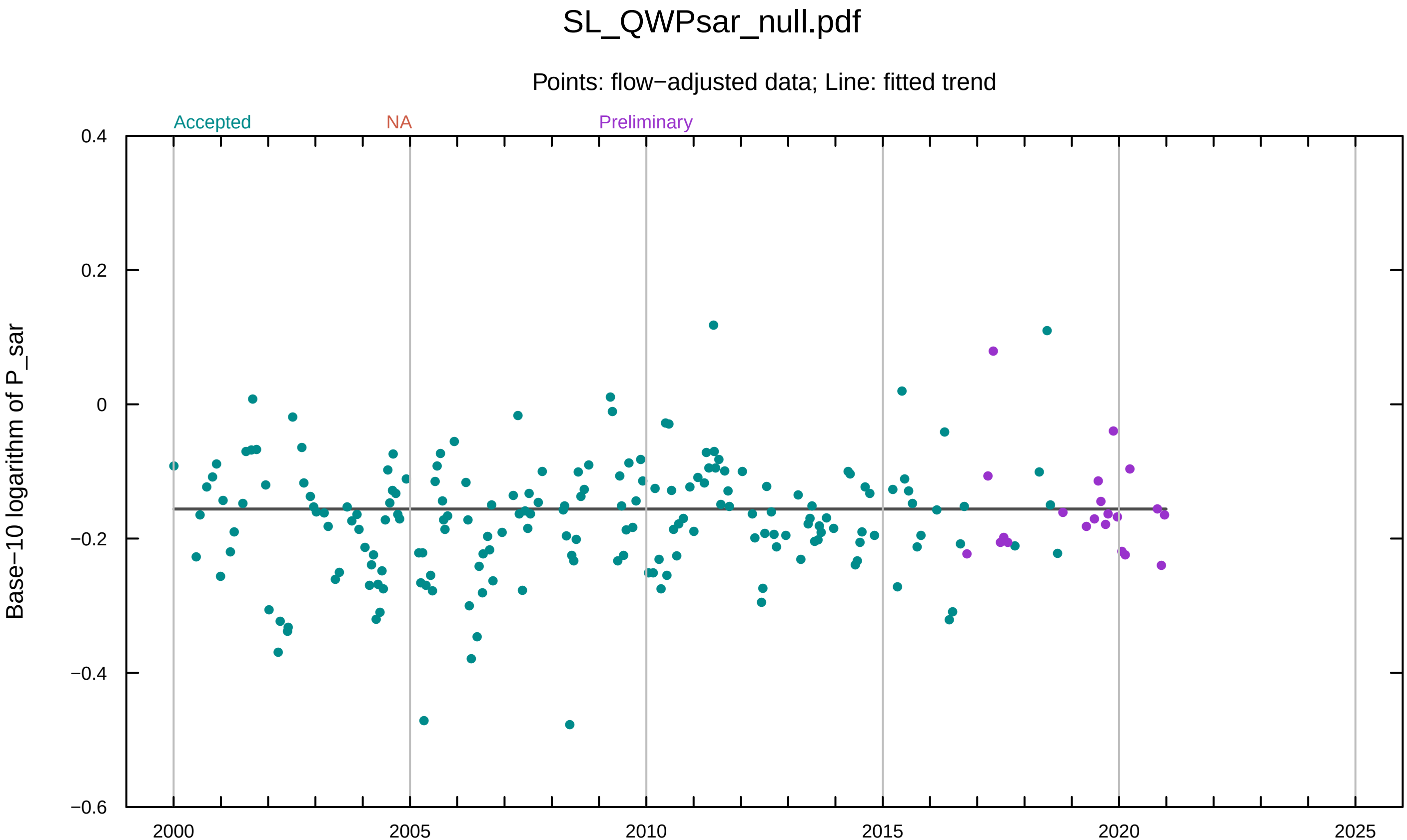

SL_QWPsar_M3.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

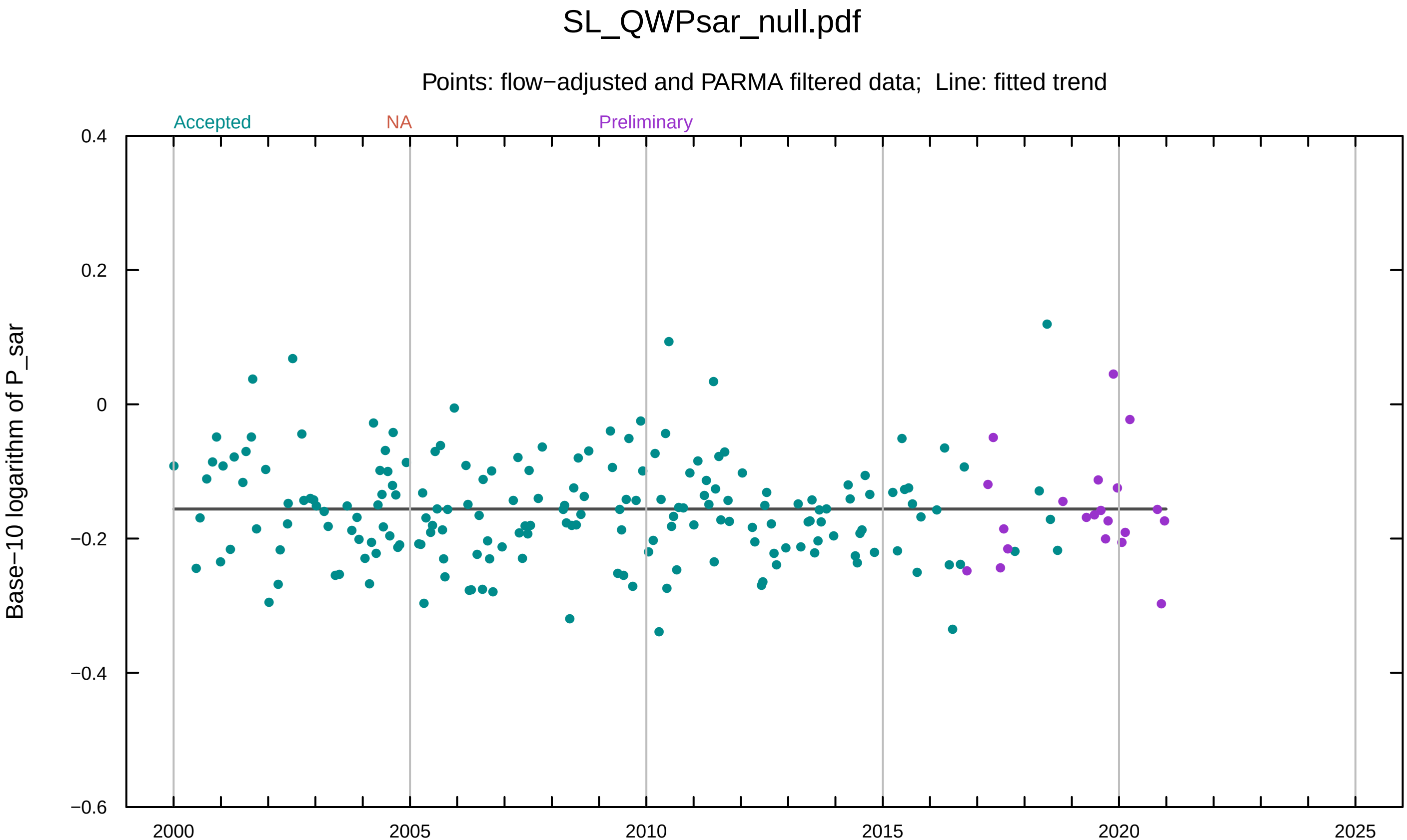


SL_QWPsar_M3.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

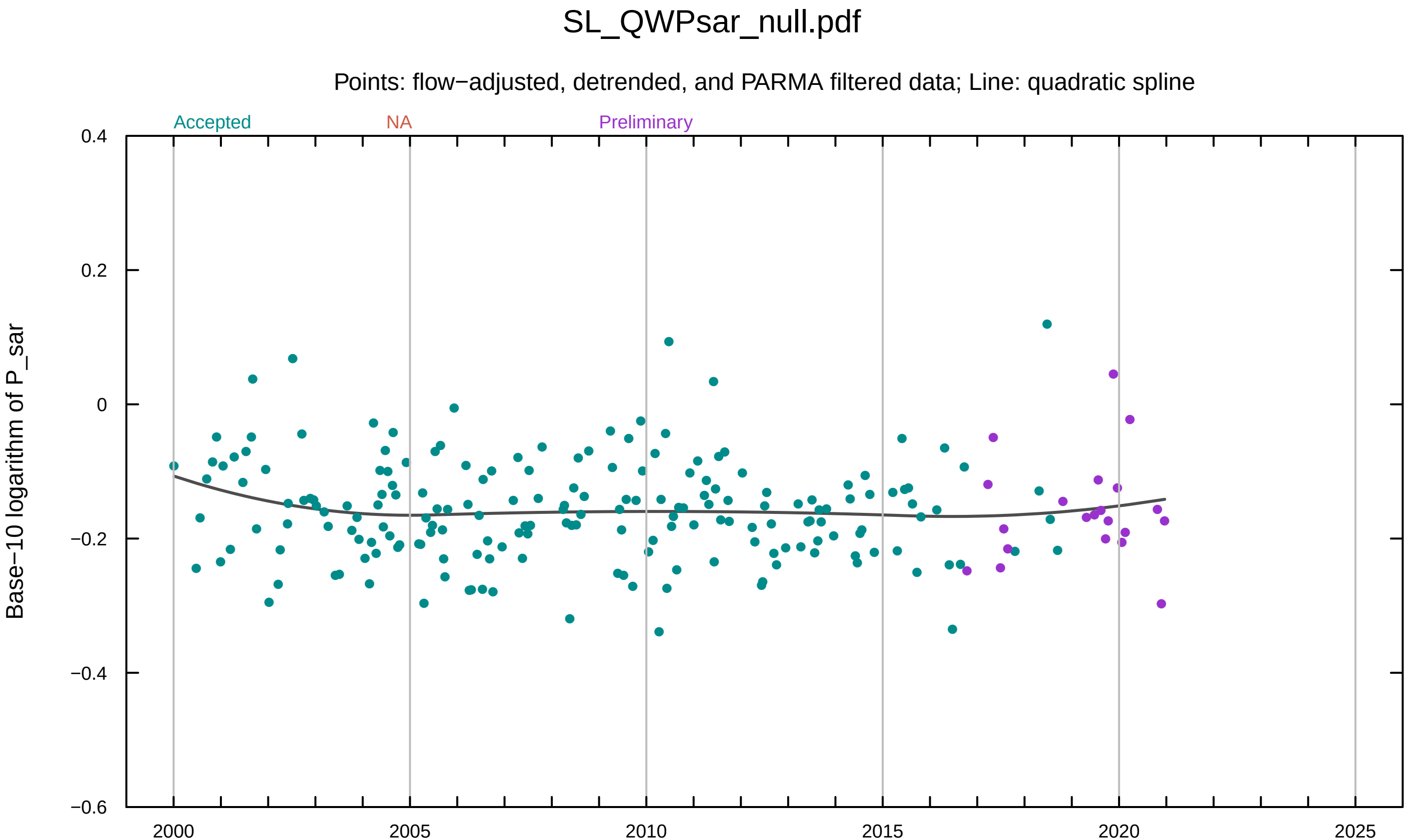


SL_QWPsar_null.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
0.5
0
−0.5
−1
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

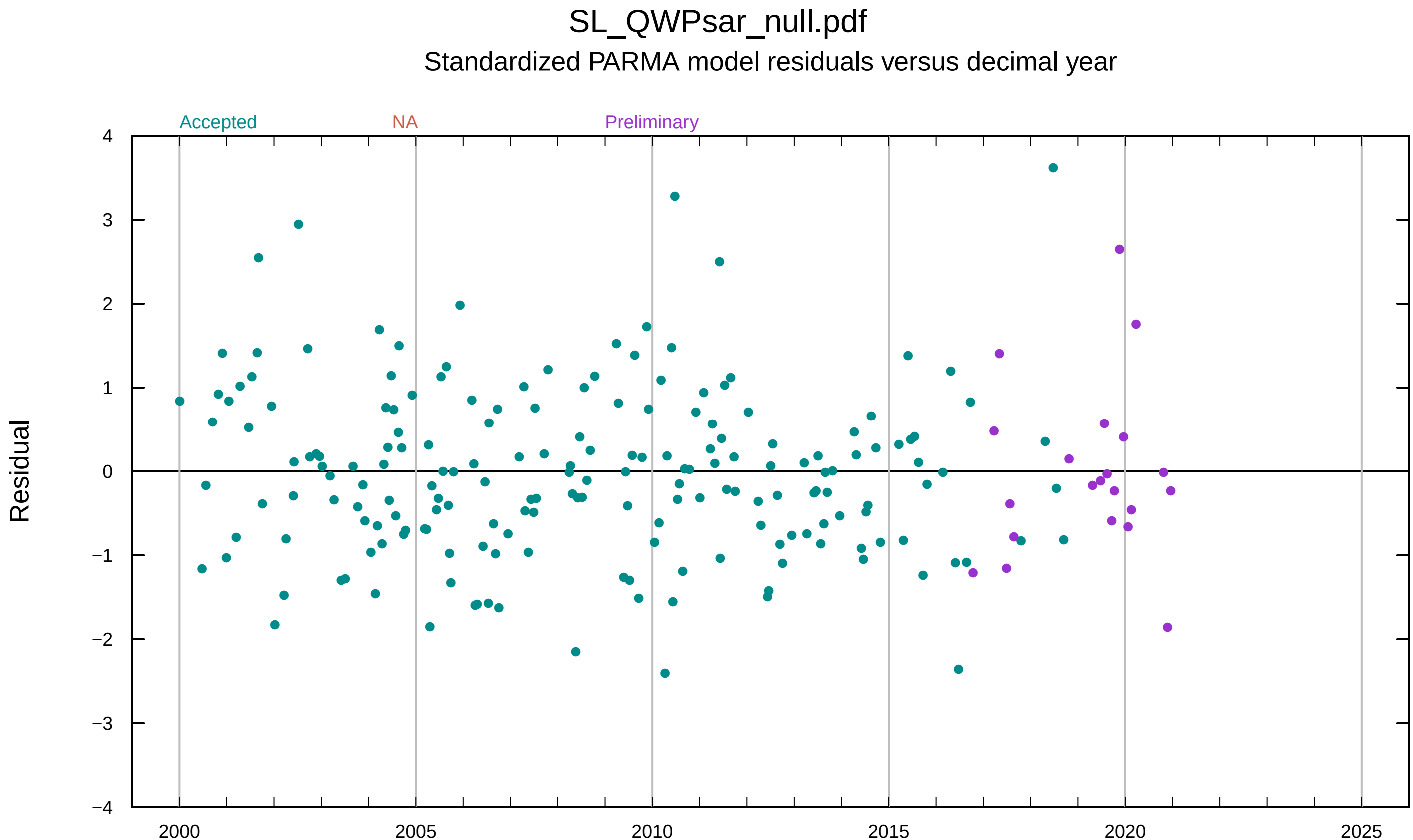

SL_QWPsar_null.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025

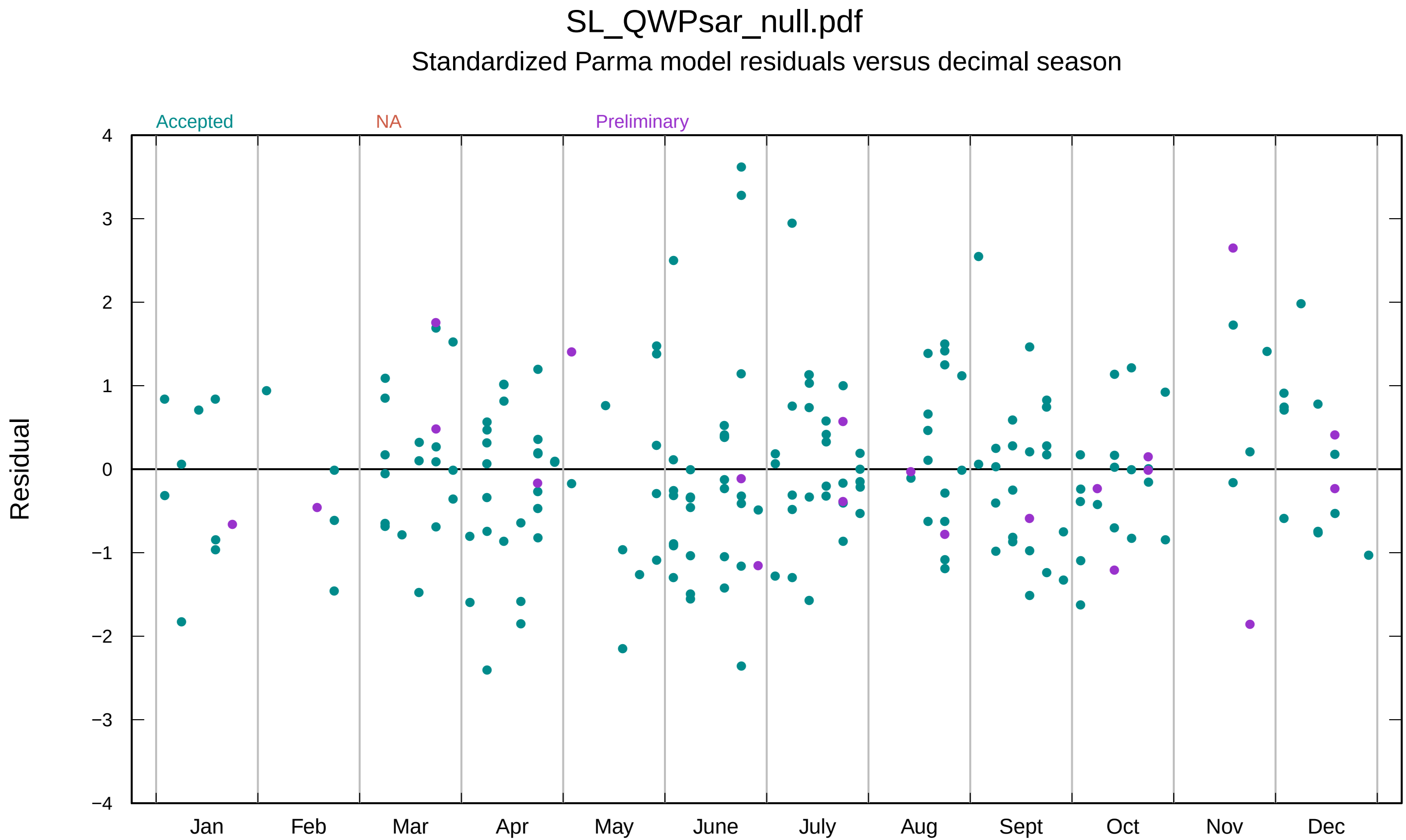


SL_QWPsar_null.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025

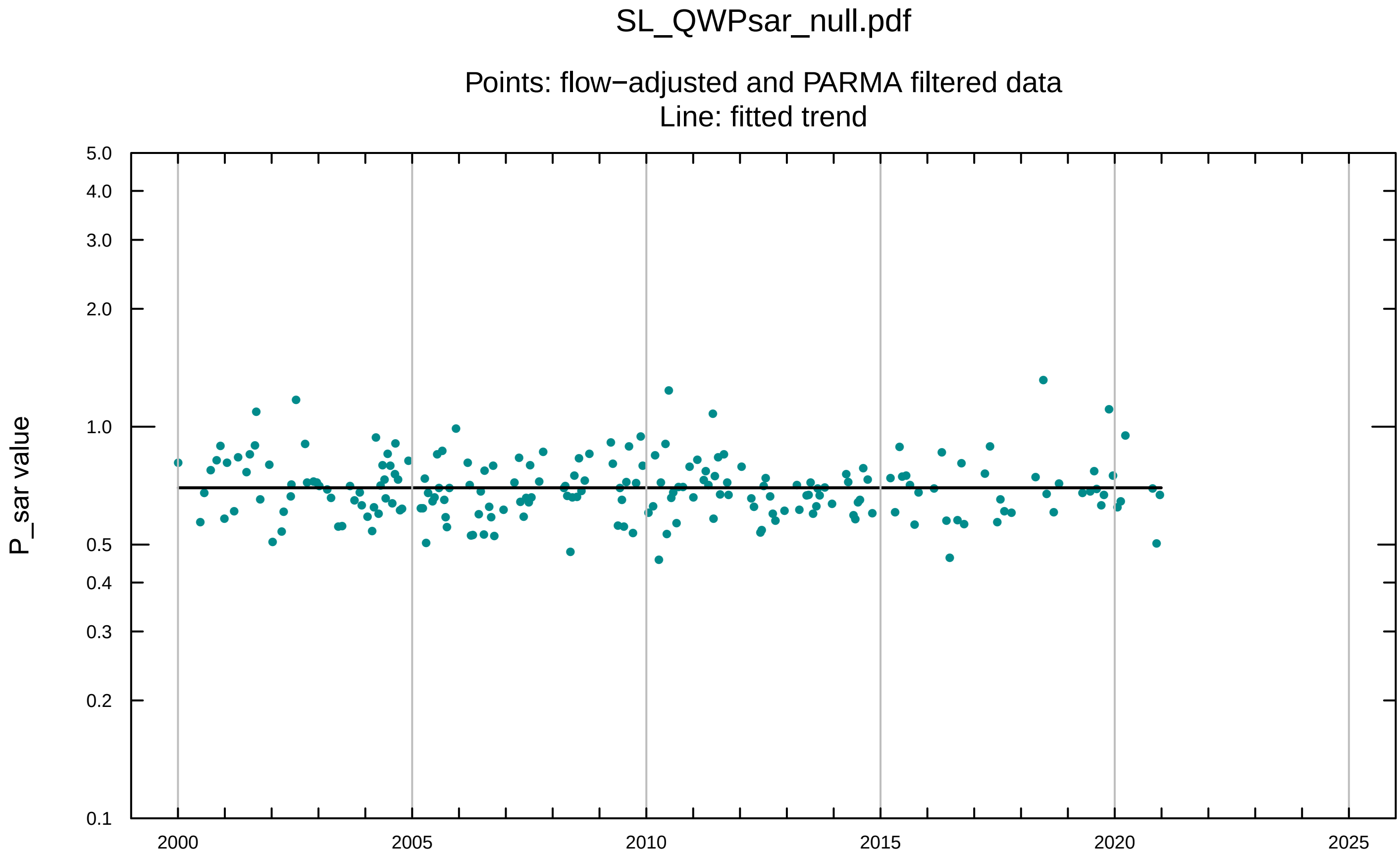


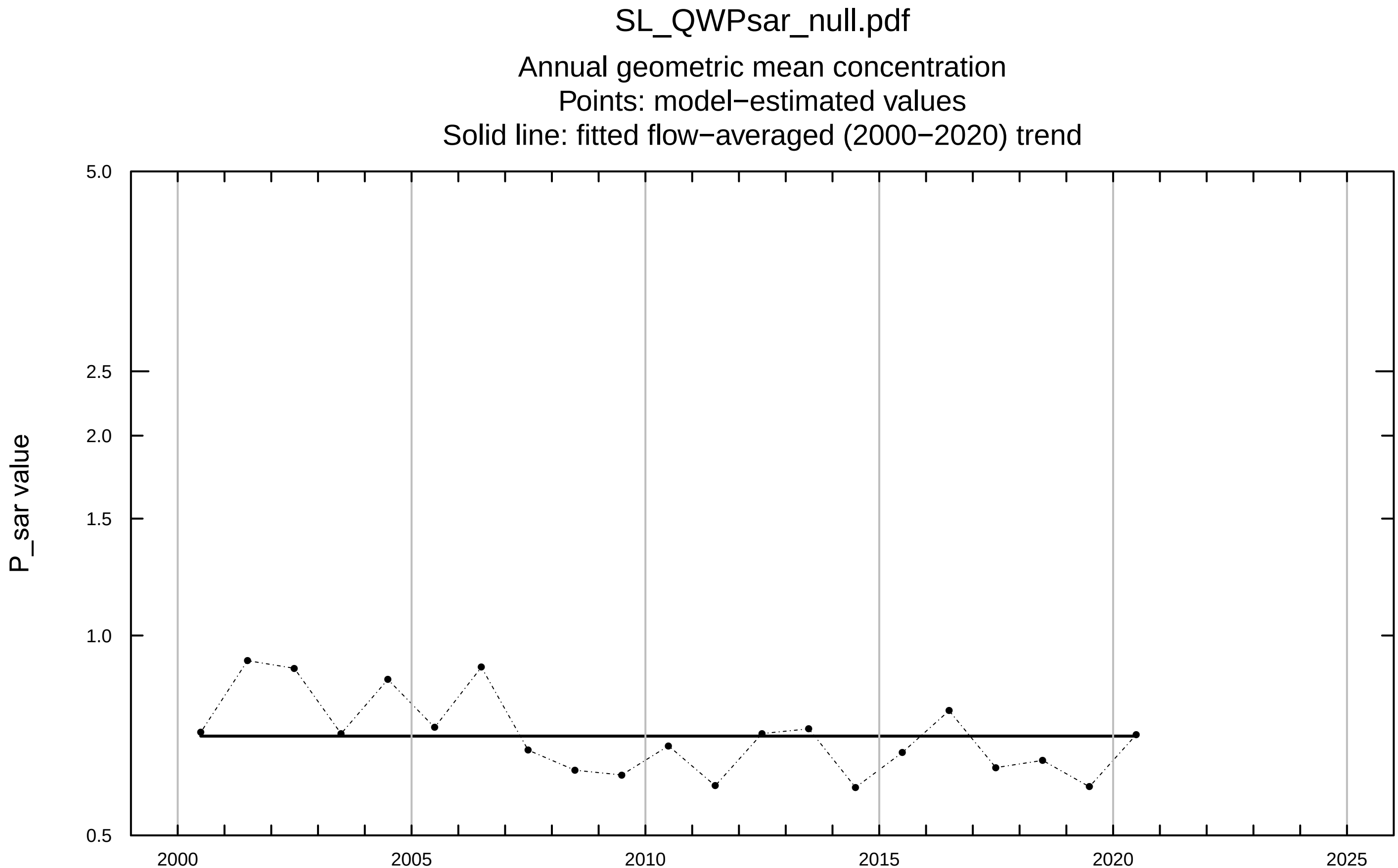
SL_QWPsar_null.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.4
0.2
0
−0.2
−0.4
−0.6
2000
2005
2010
2015
2020
2025


SL_QWPsar_null.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025

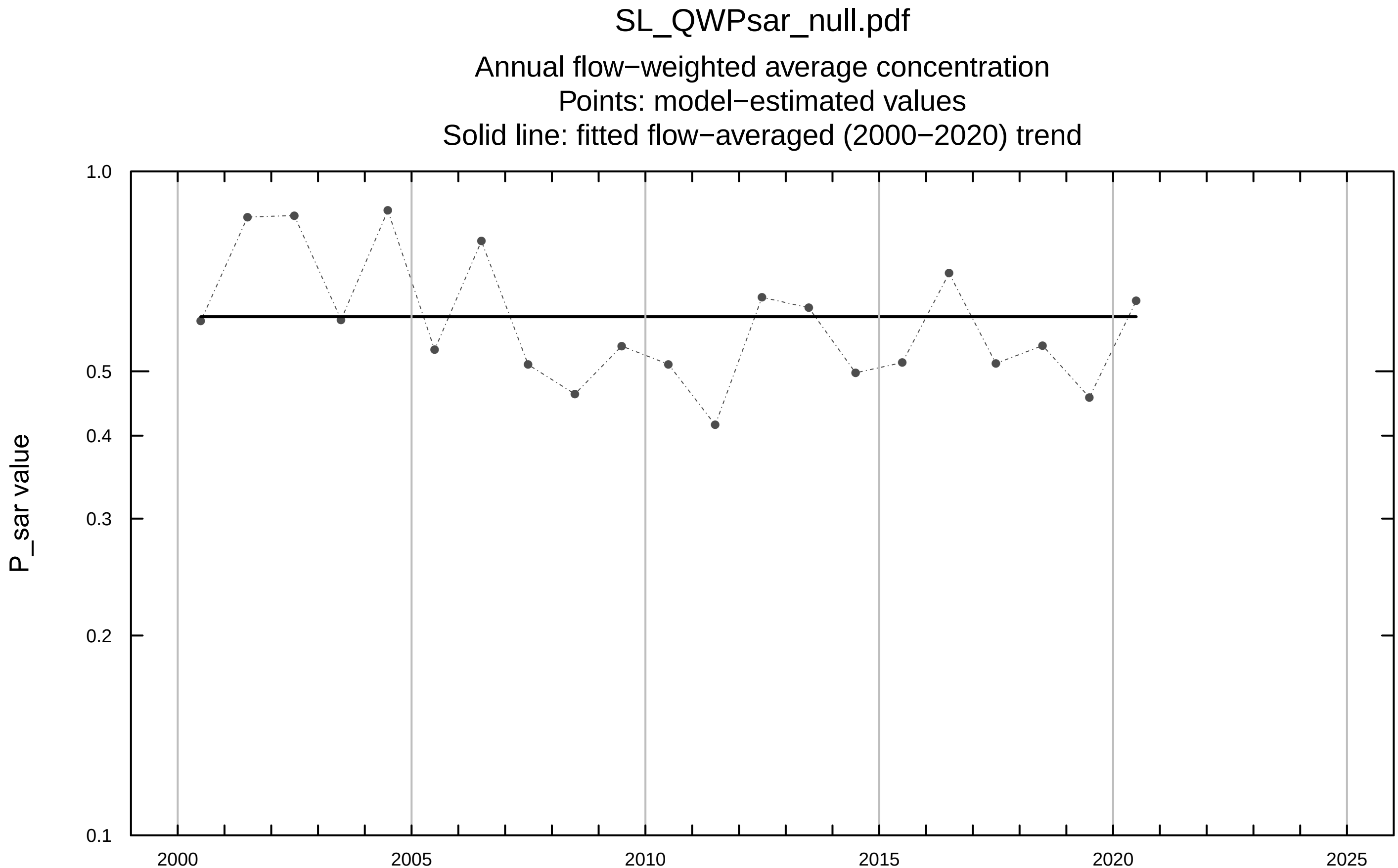


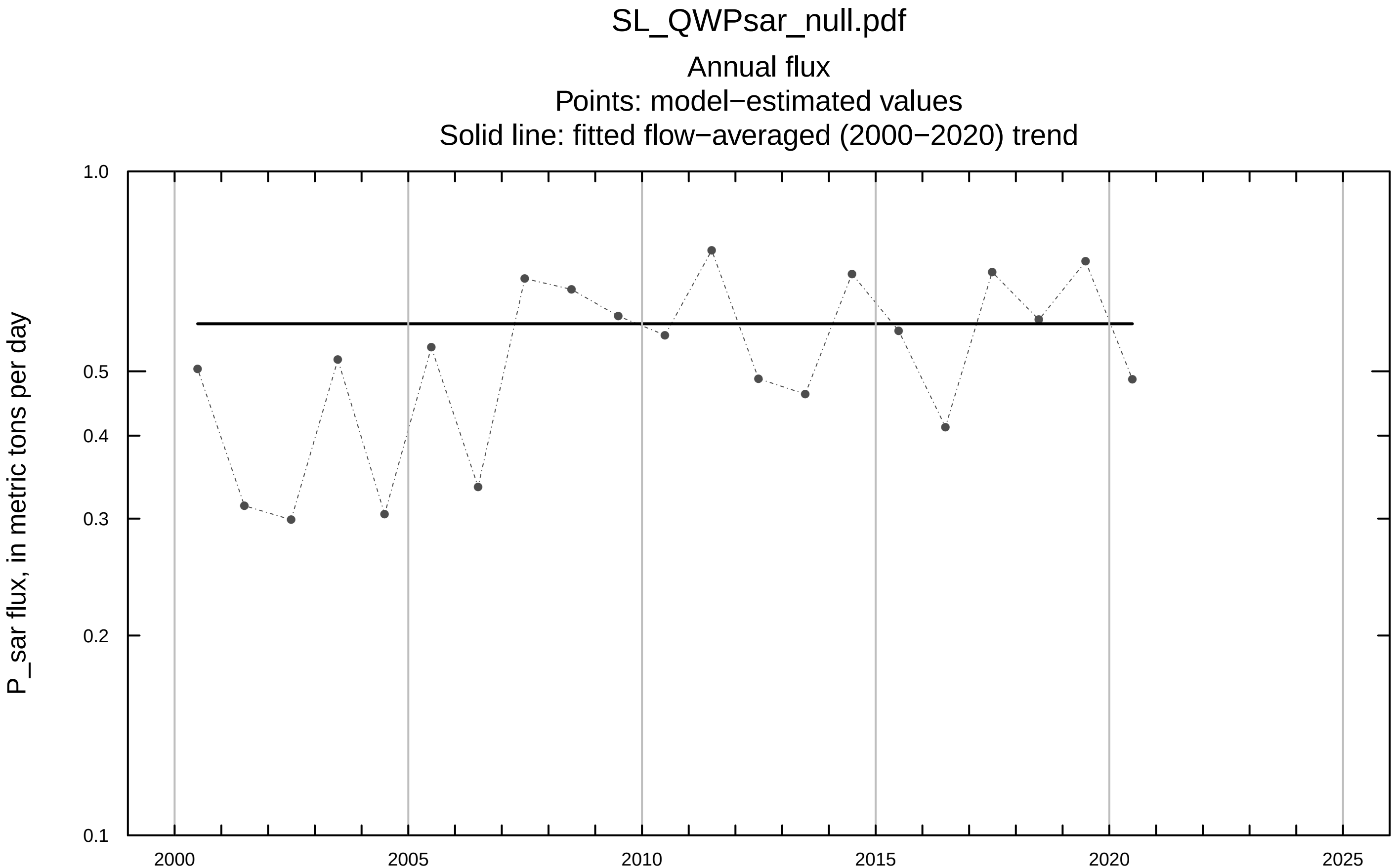
SL_QWPsar_null.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec


SL_QWPsar_null.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025



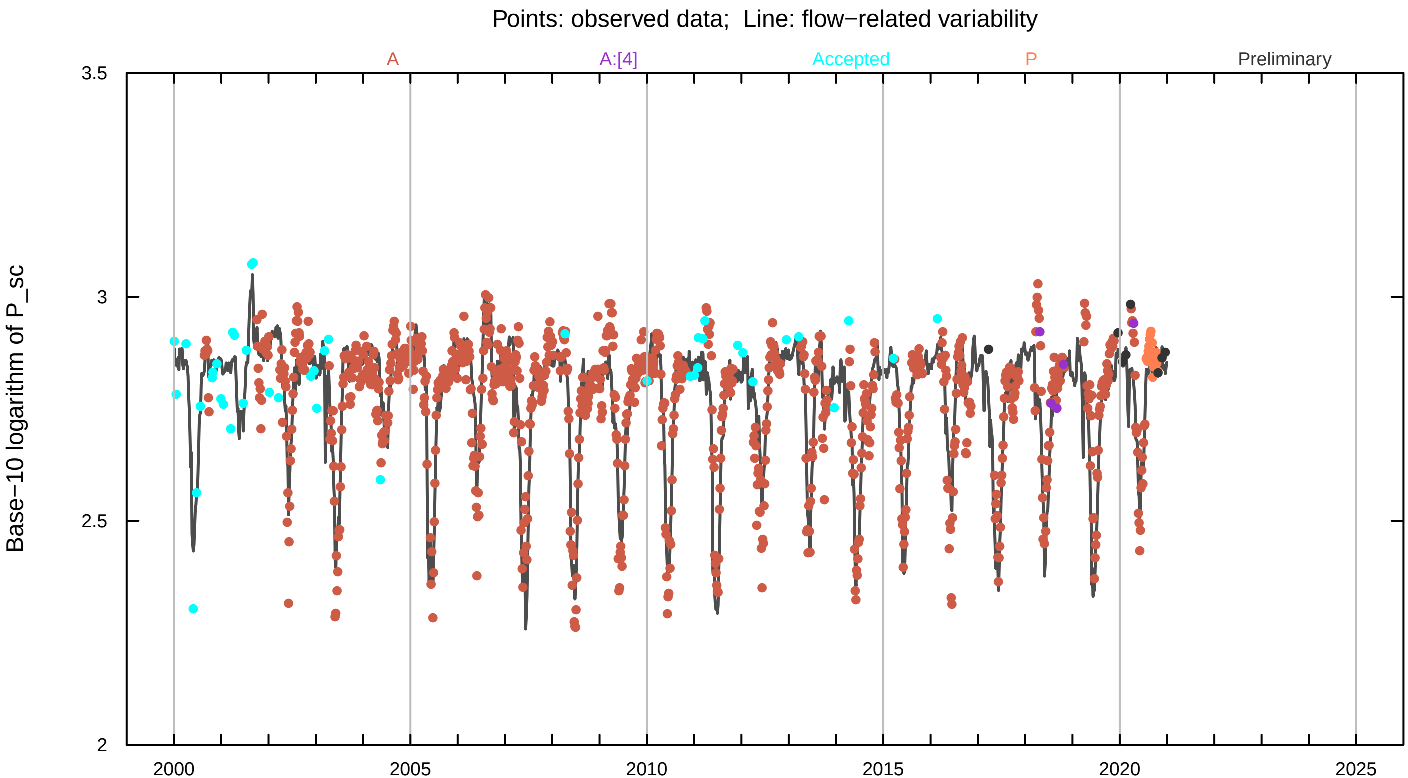
SL_QWPsar_null.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

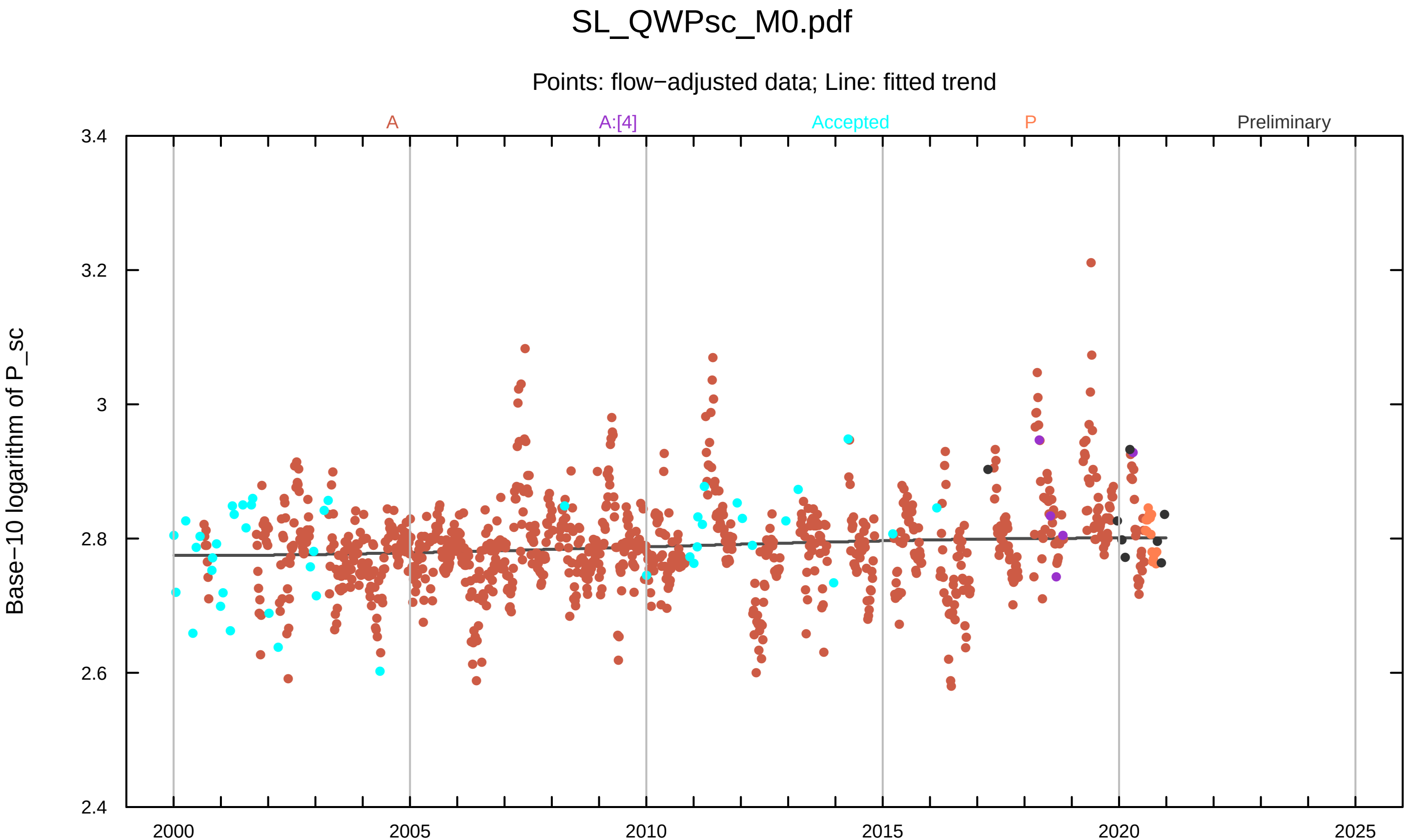

SL_QWPsar_null.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

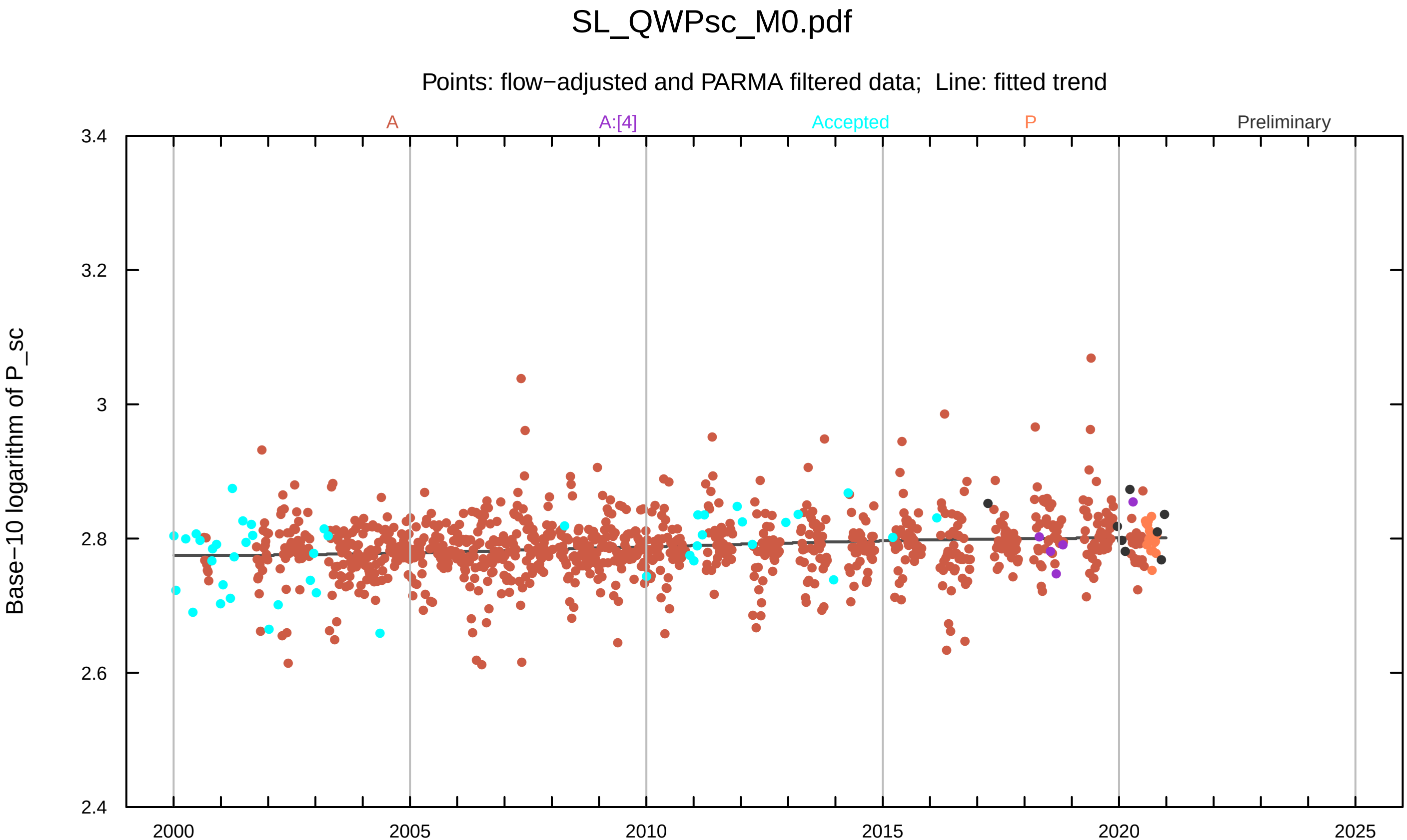


SL_QWPsar_null.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

SL_QWPsc_M0.pdf



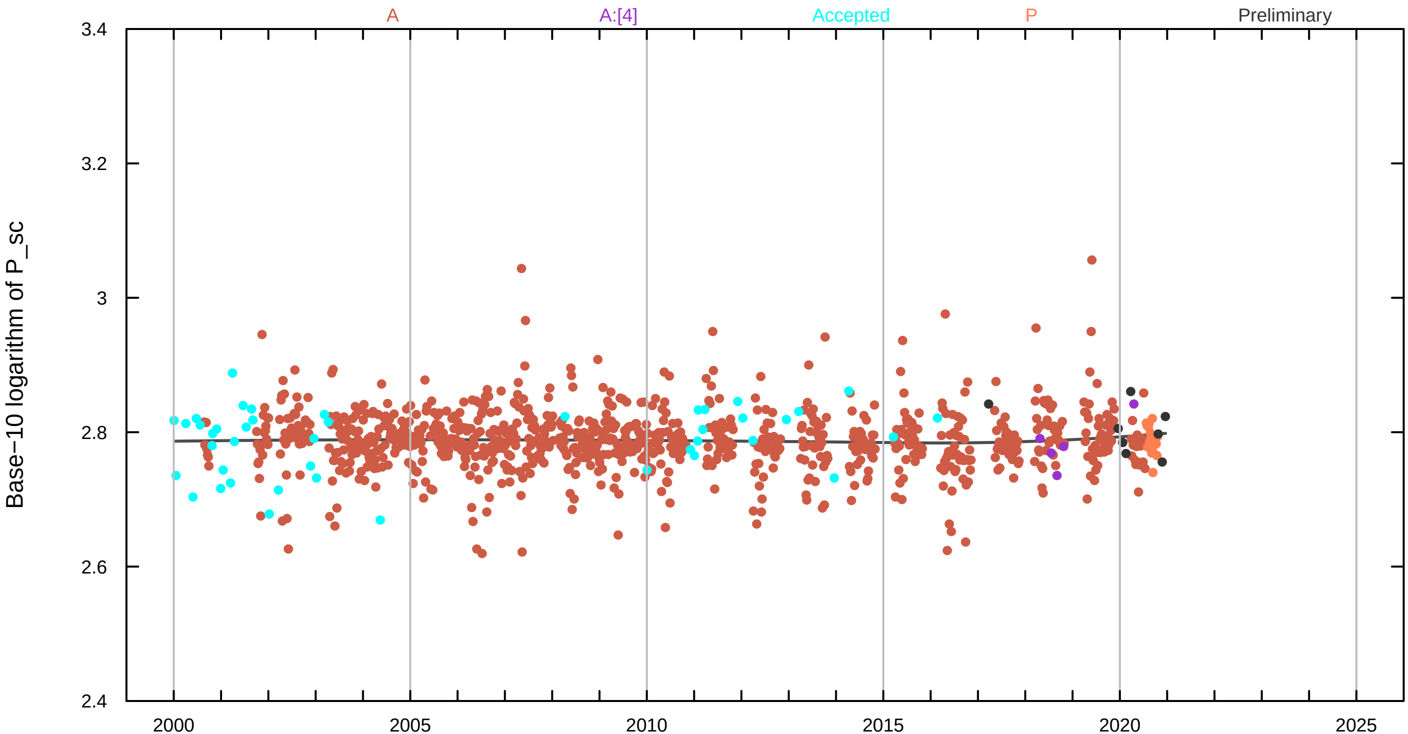

SL_QWPsc_M0.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

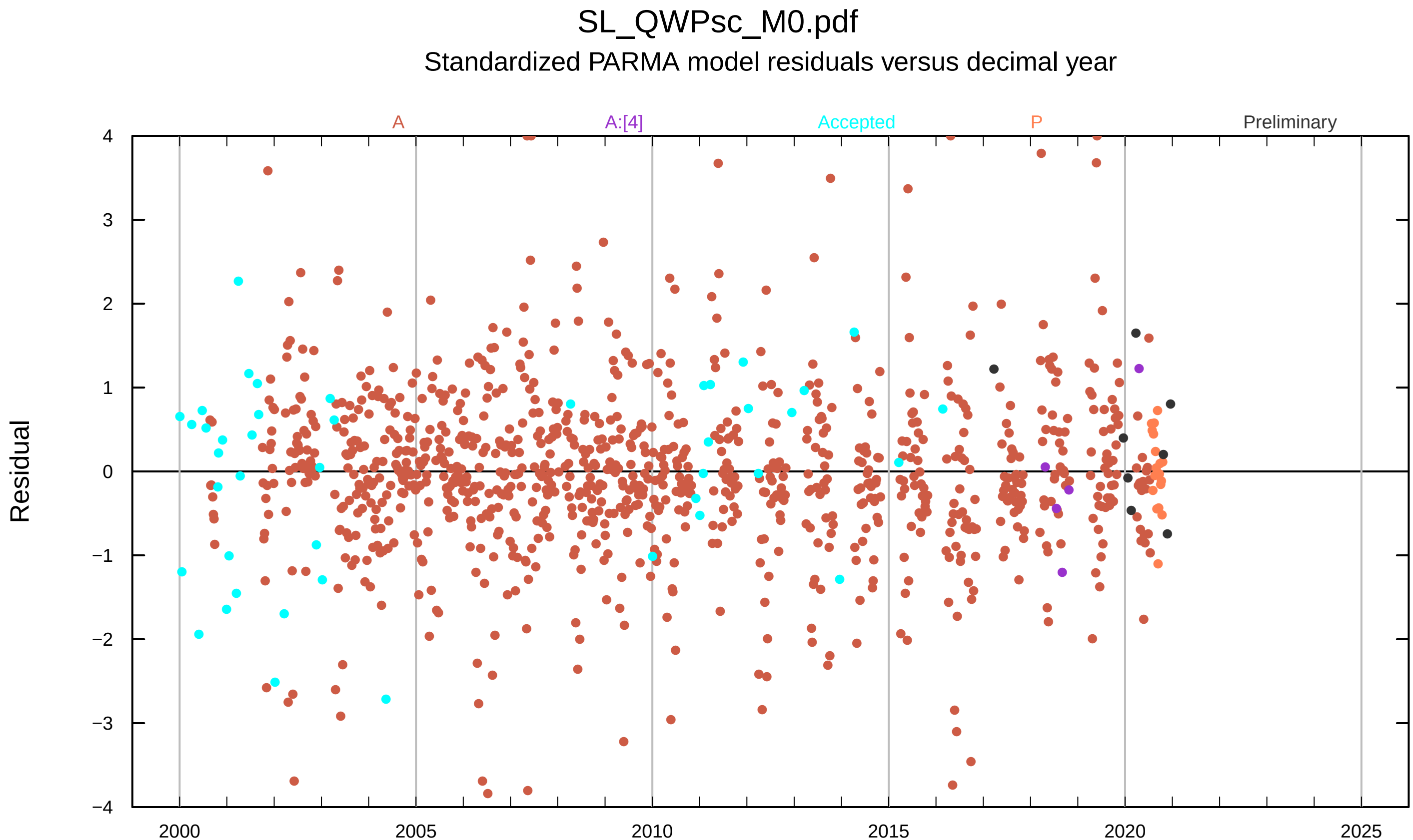


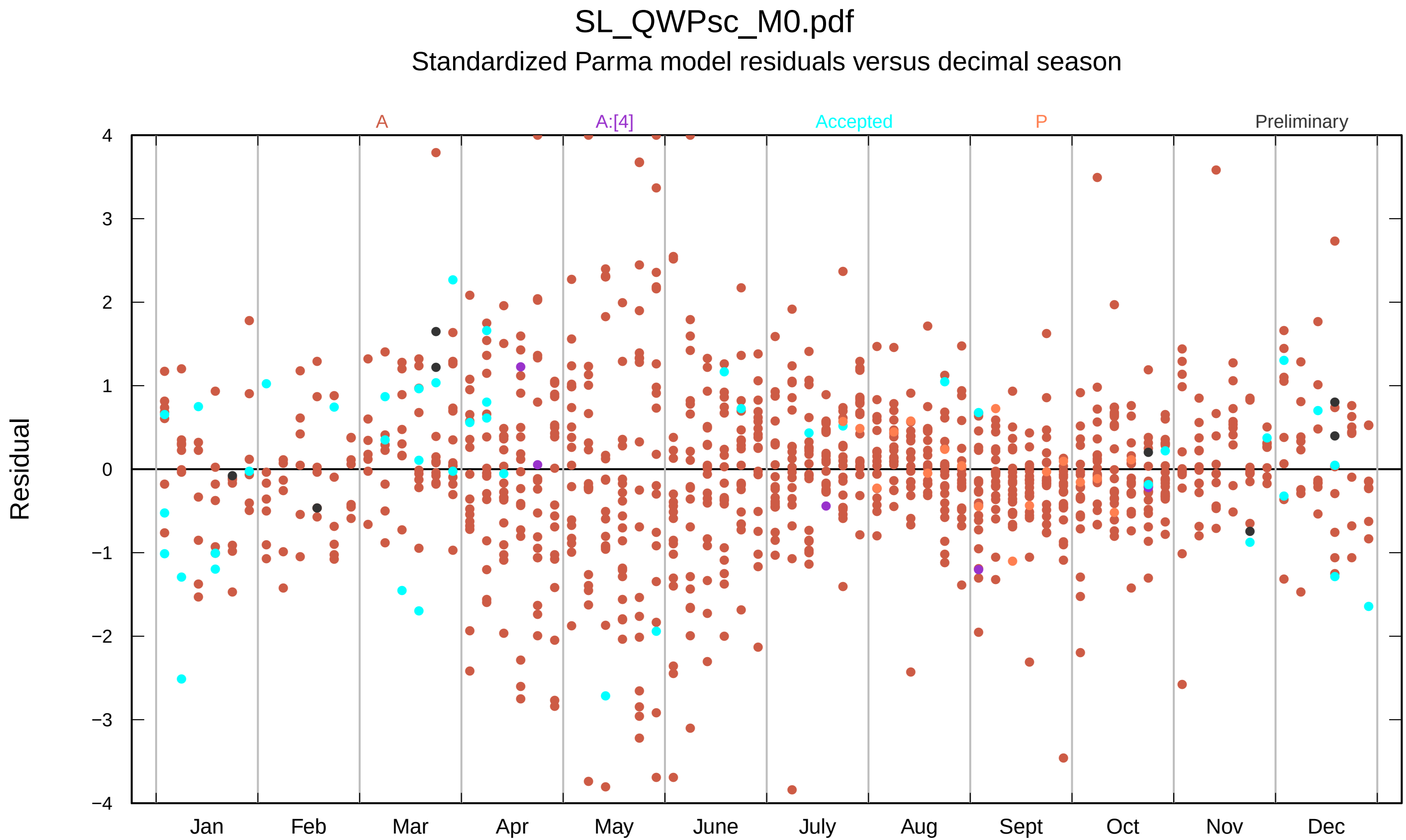
SL_QWPsc_M0.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

SL_QWPsc_M0.pdf

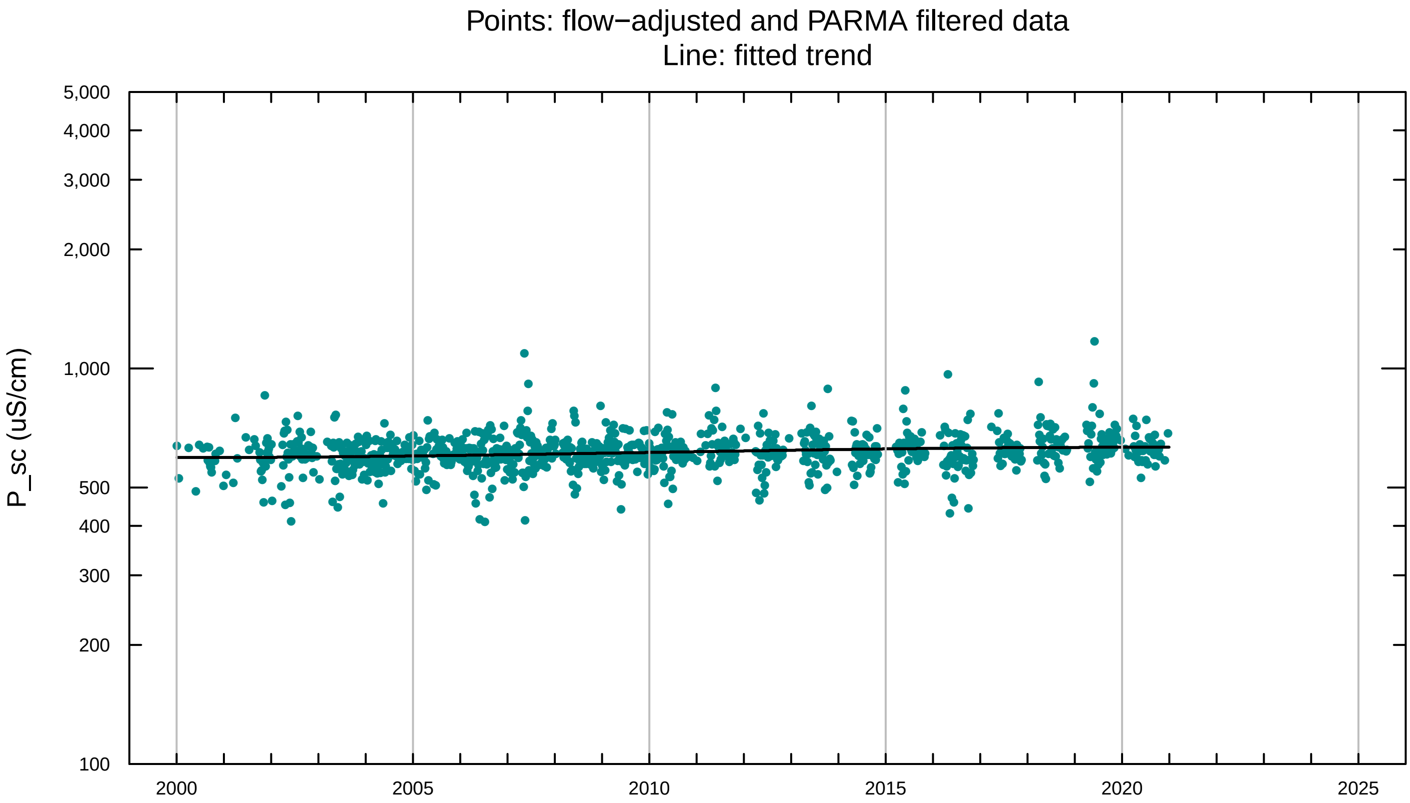
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline




SL_QWPsc_M0.pdf
Standardized PARMA model residuals versus decimal year
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025


SL_QWPsc_M0.pdf
Standardized Parma model residuals versus decimal season
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

SL_QWPsc_M0.pdf

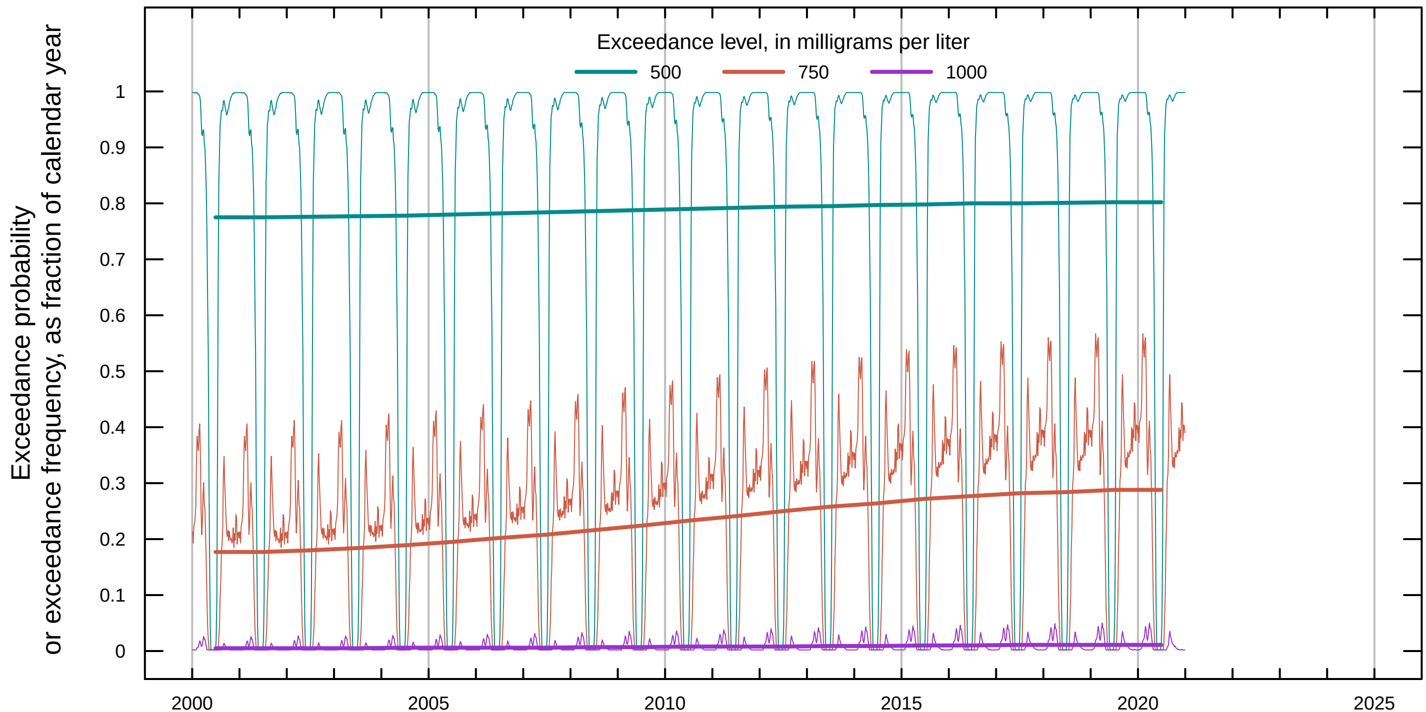


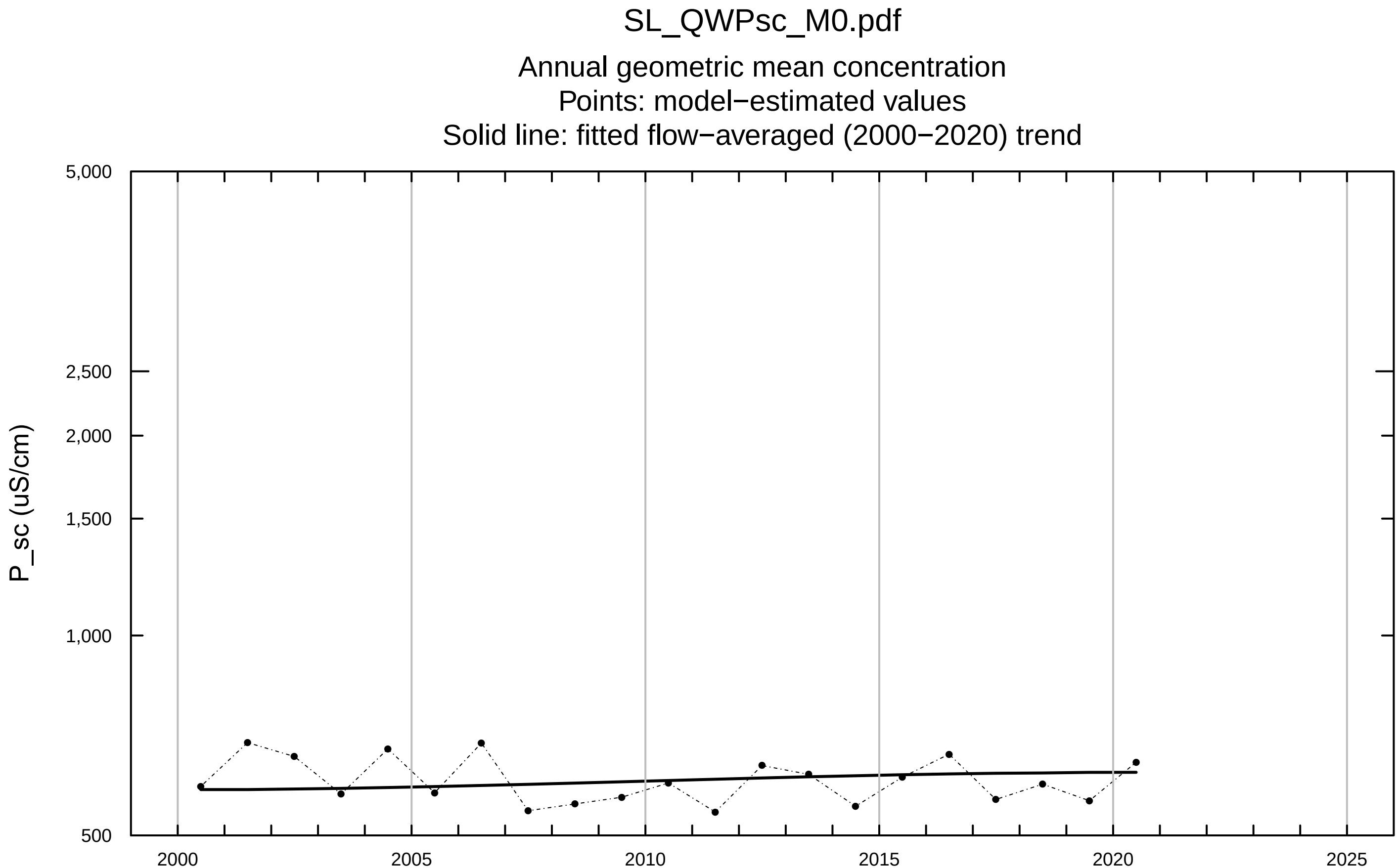
SL_QWPsc_M0.pdf

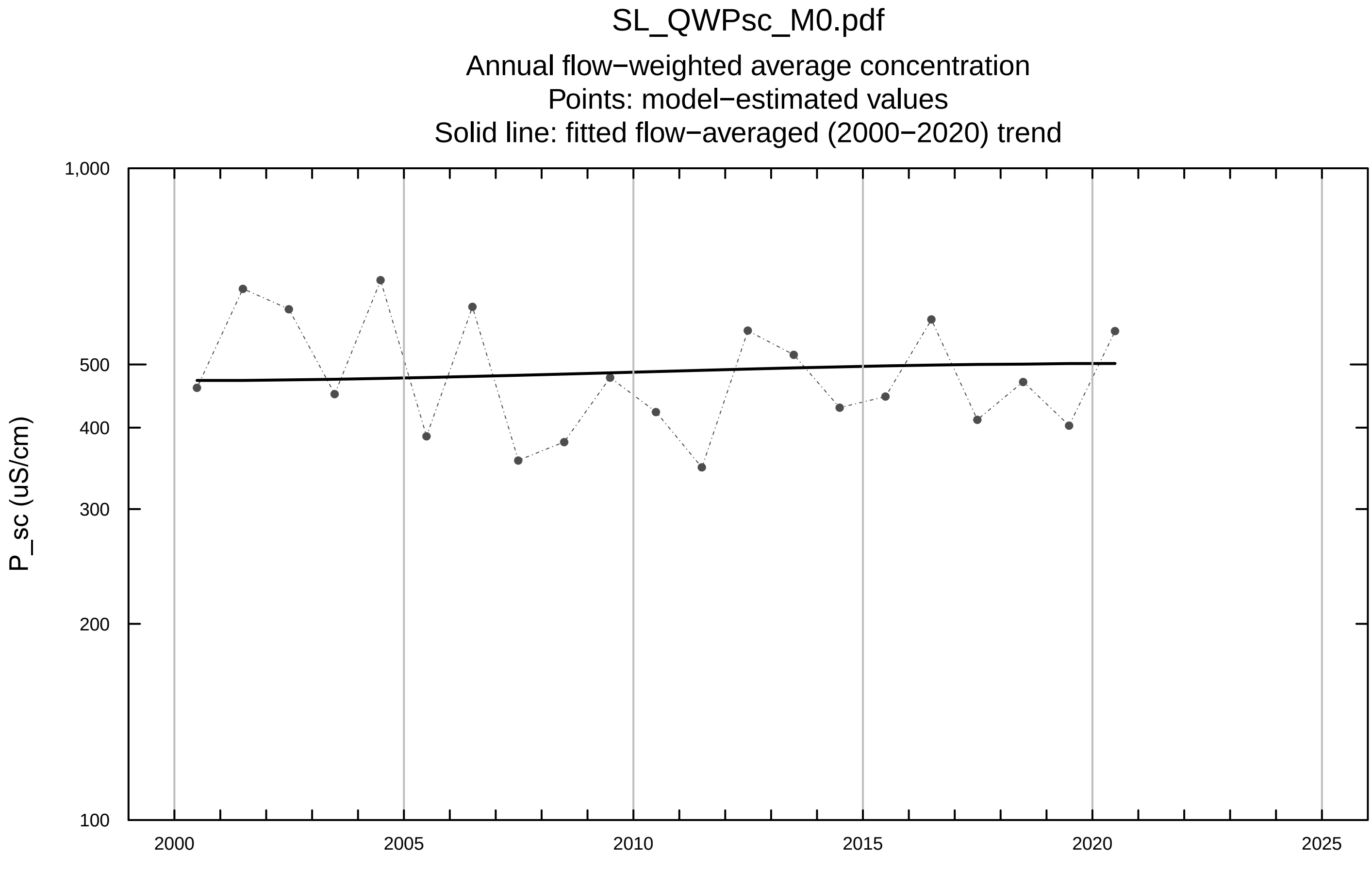
Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

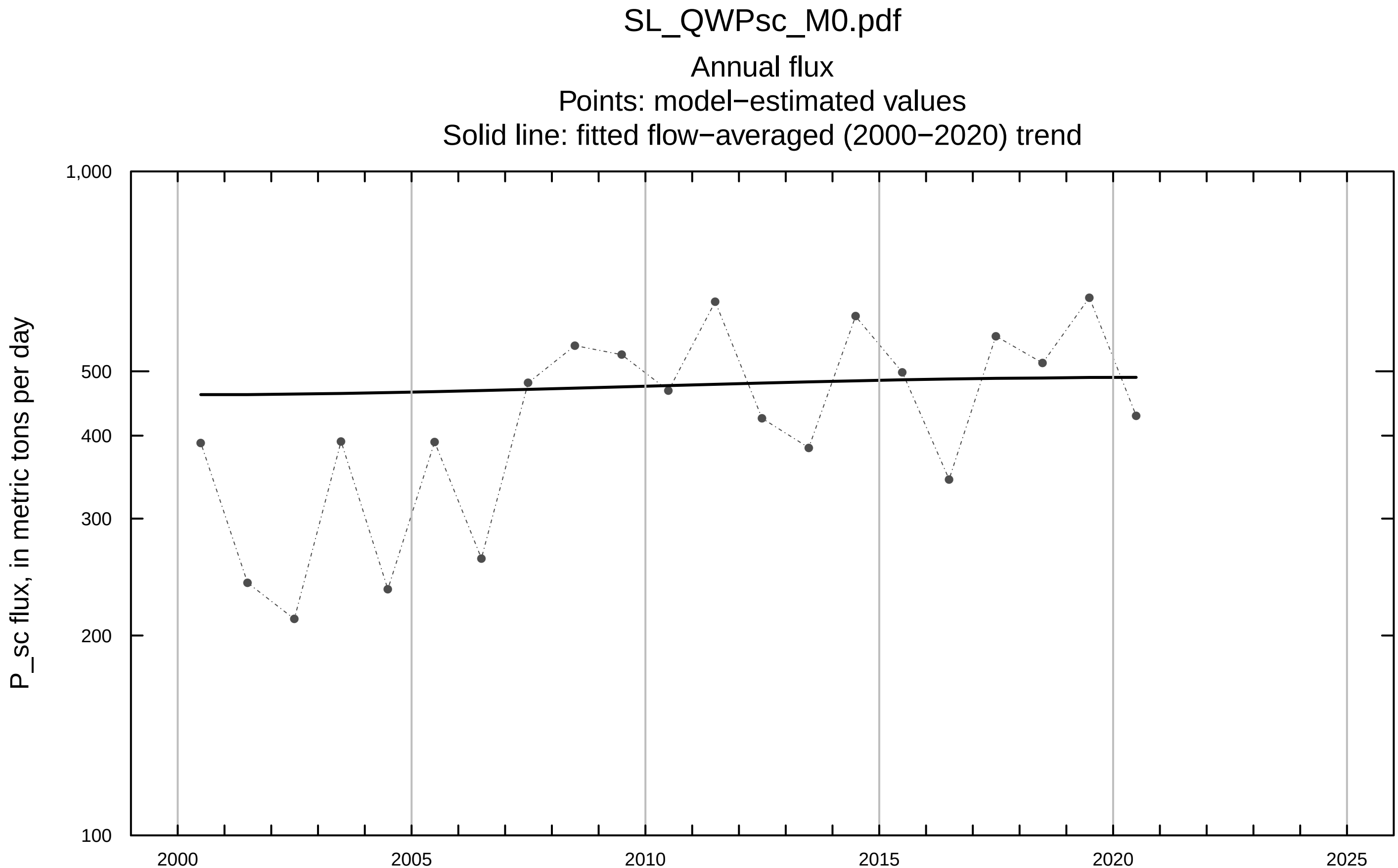
Heavy line: Expected annual flow−averaged exceedance frequency

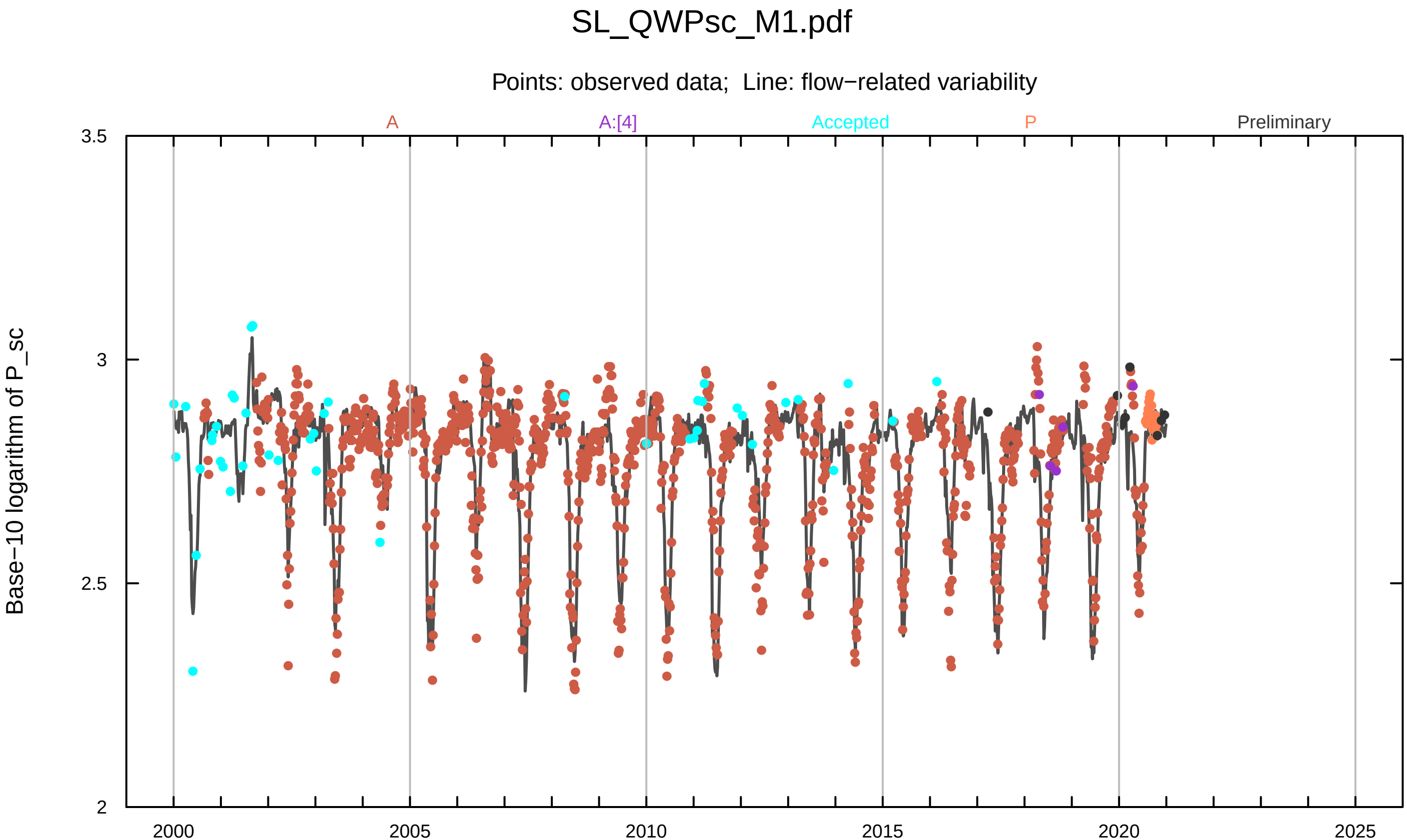



SL_QWPsc_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025

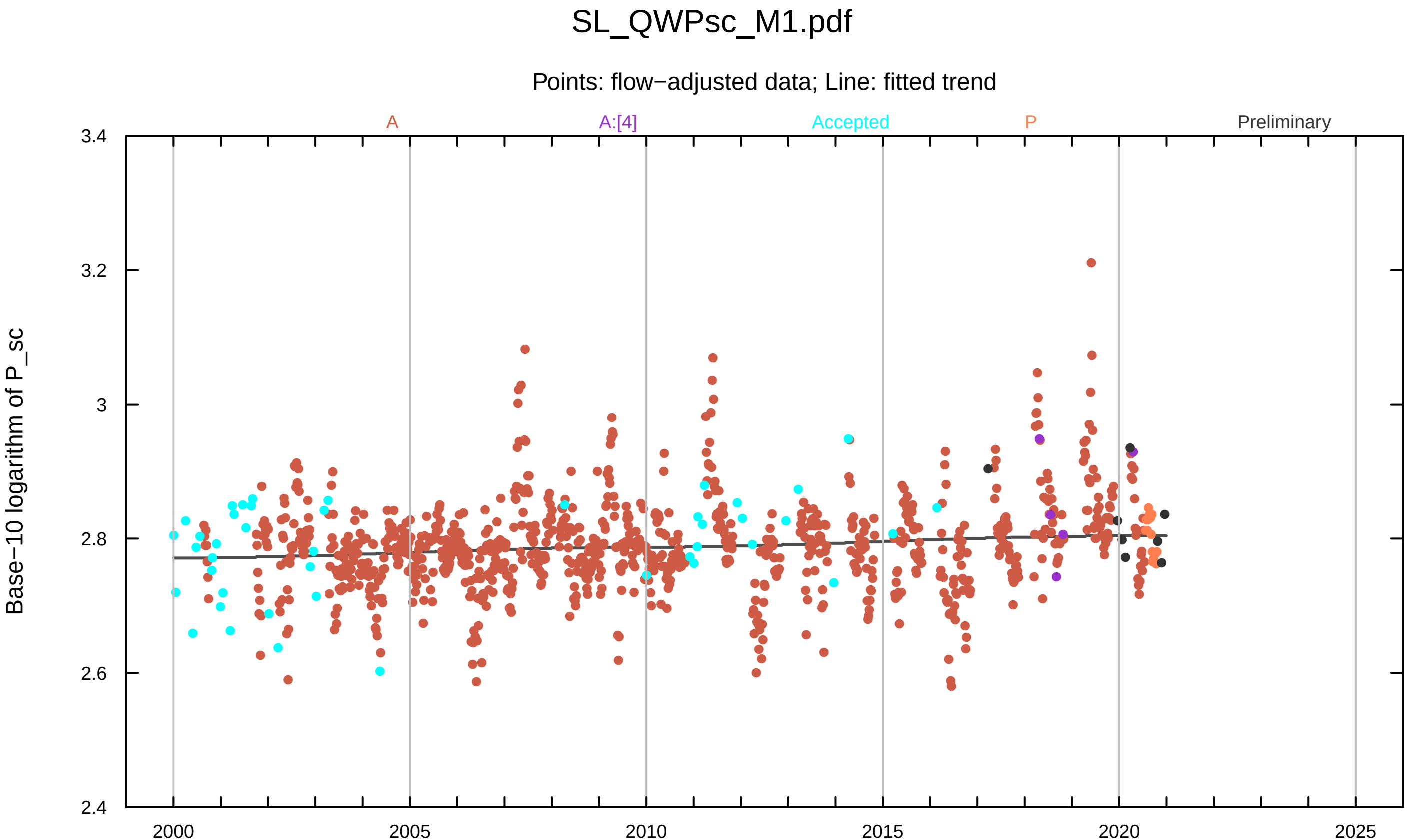


SL_QWPsc_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

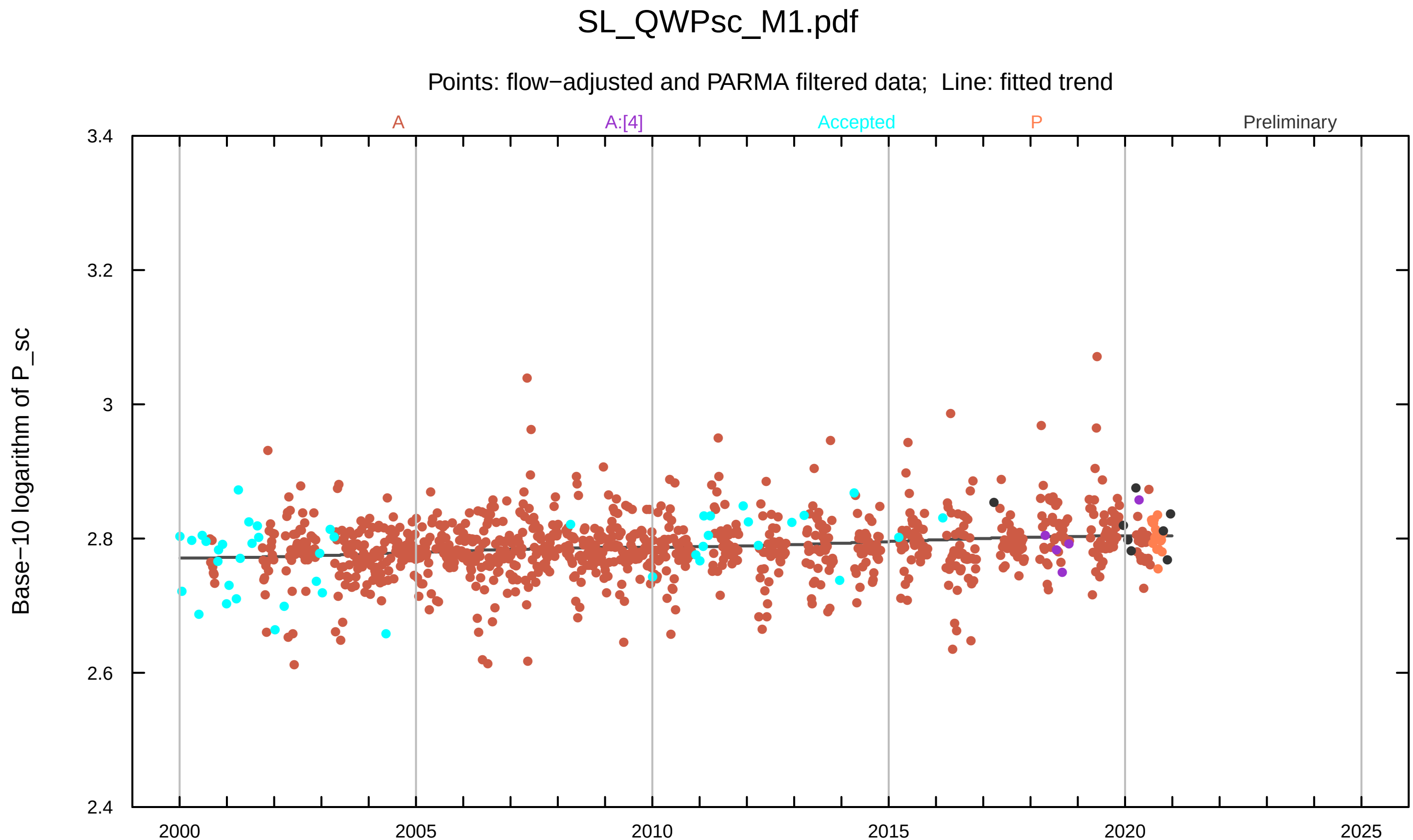

SL_QWPsc_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

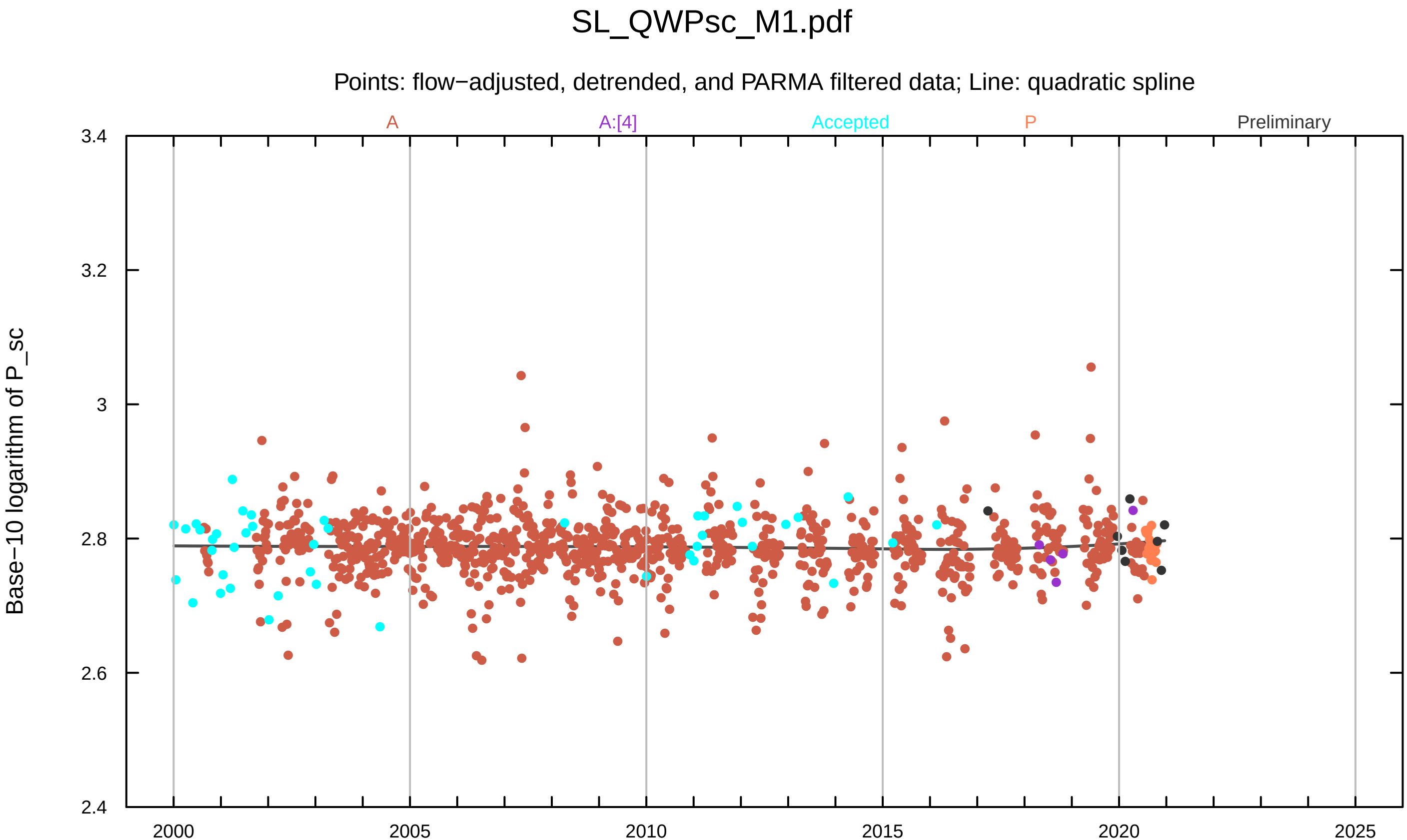


SL_QWPsc_M1.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.5
3
2.5
2
2000
2005
2010
2015
2020
2025



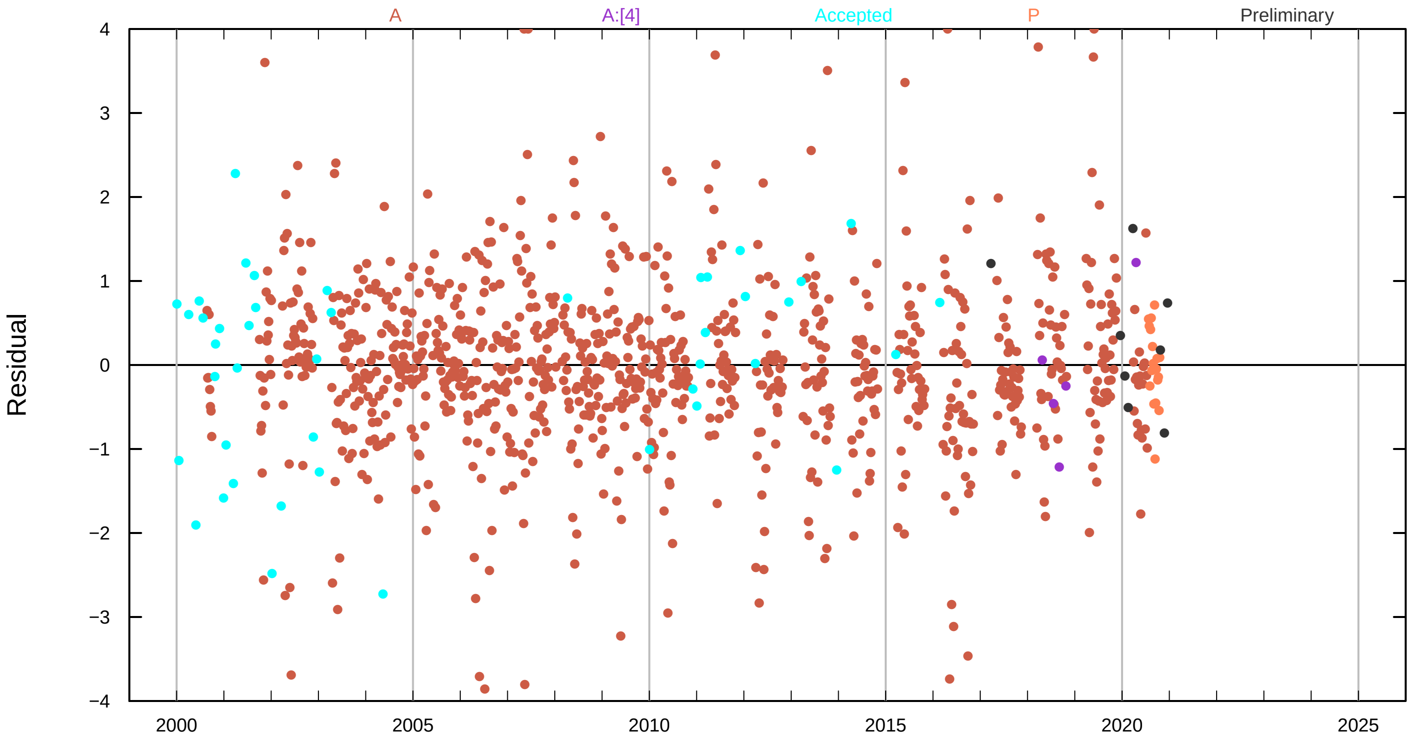
SL_QWPsc_M1.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

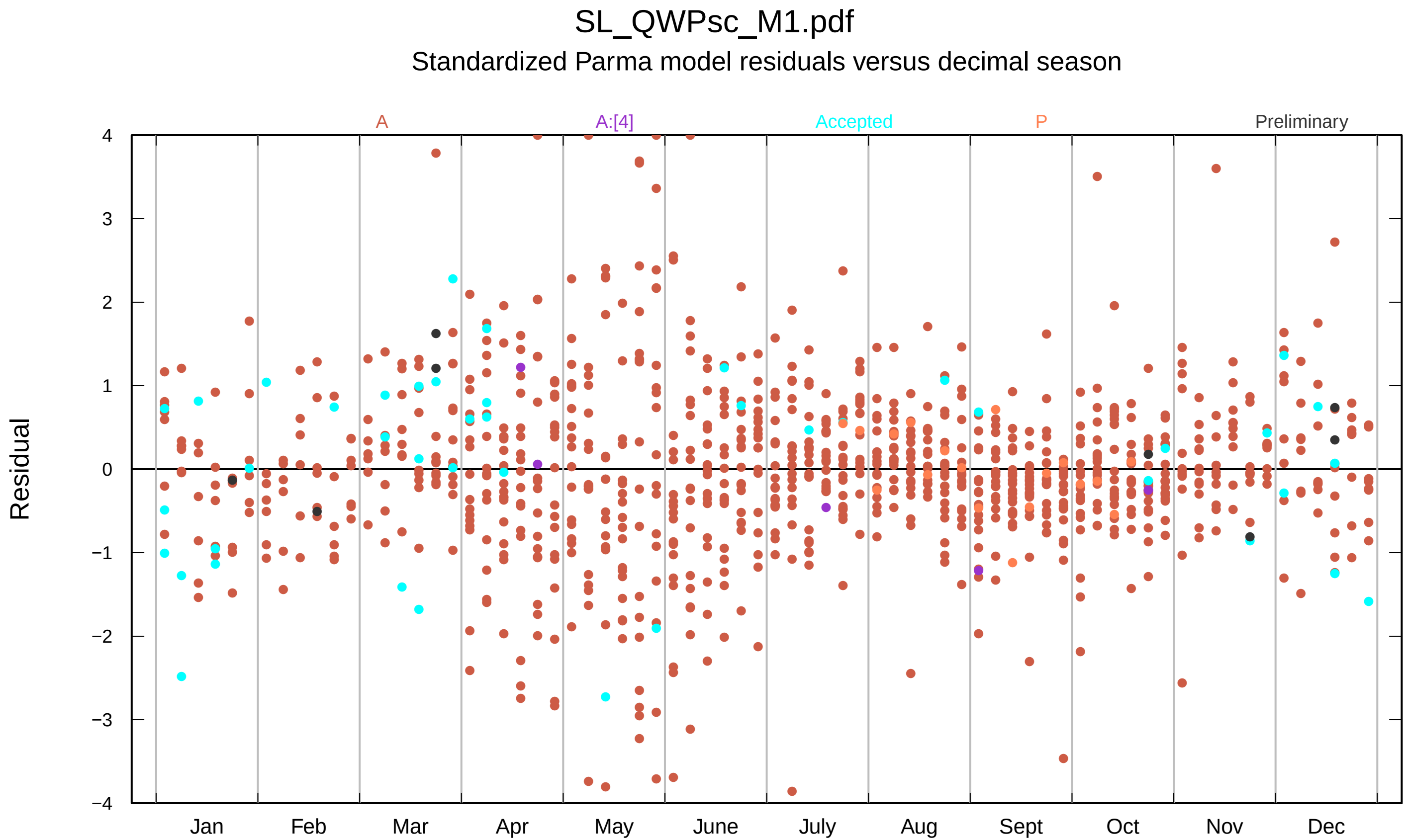

SL_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025


SL_QWPsc_M1.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

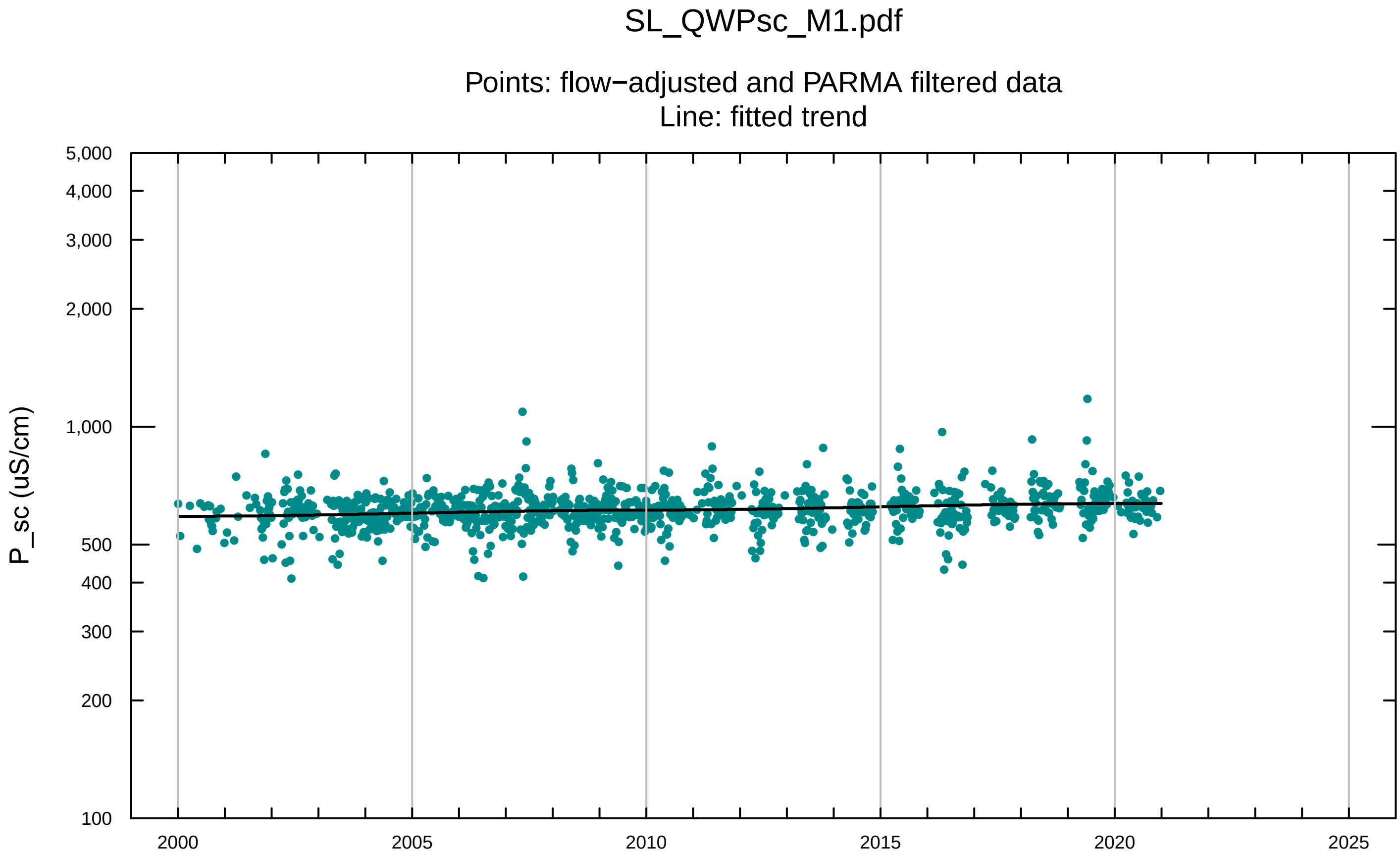
SL_QWPsc_M1.pdf

Standardized PARMA model residuals versus decimal year





SL_QWPsc_M1.pdf
Standardized Parma model residuals versus decimal season
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

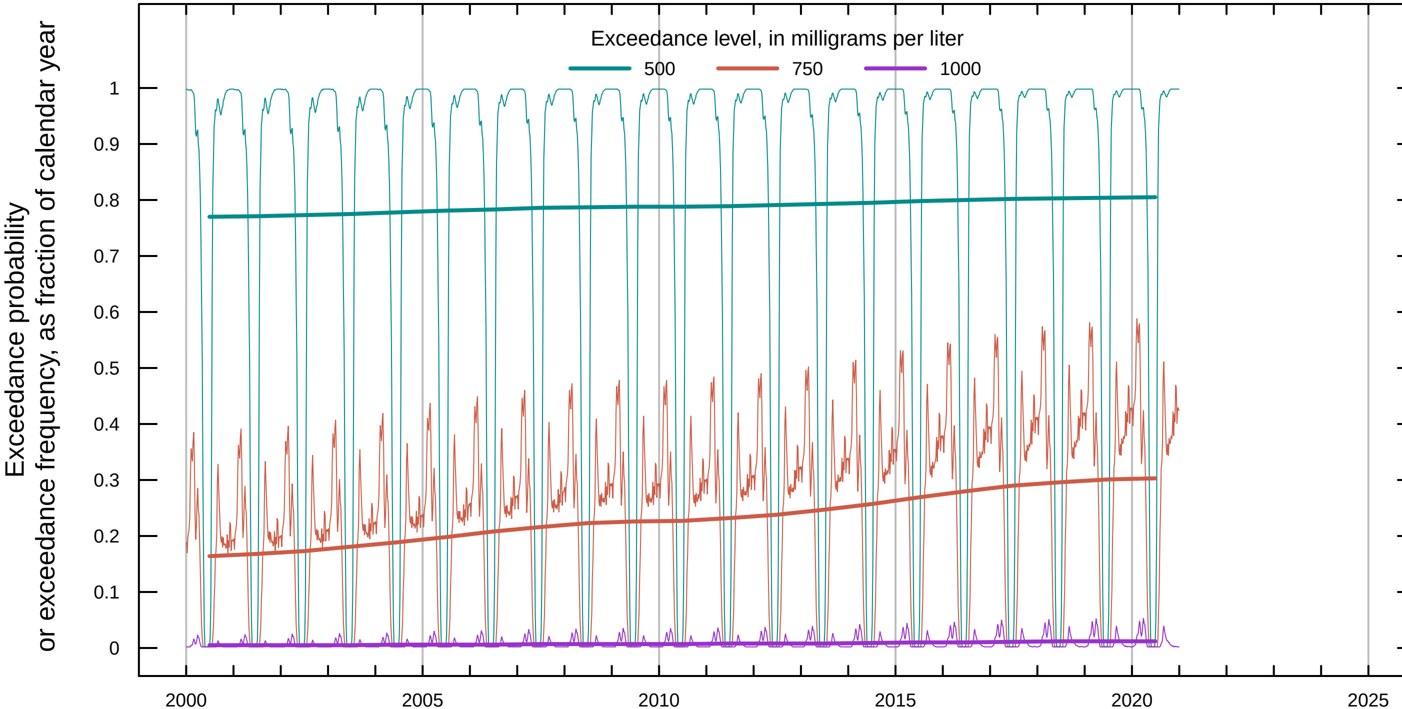

SL_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

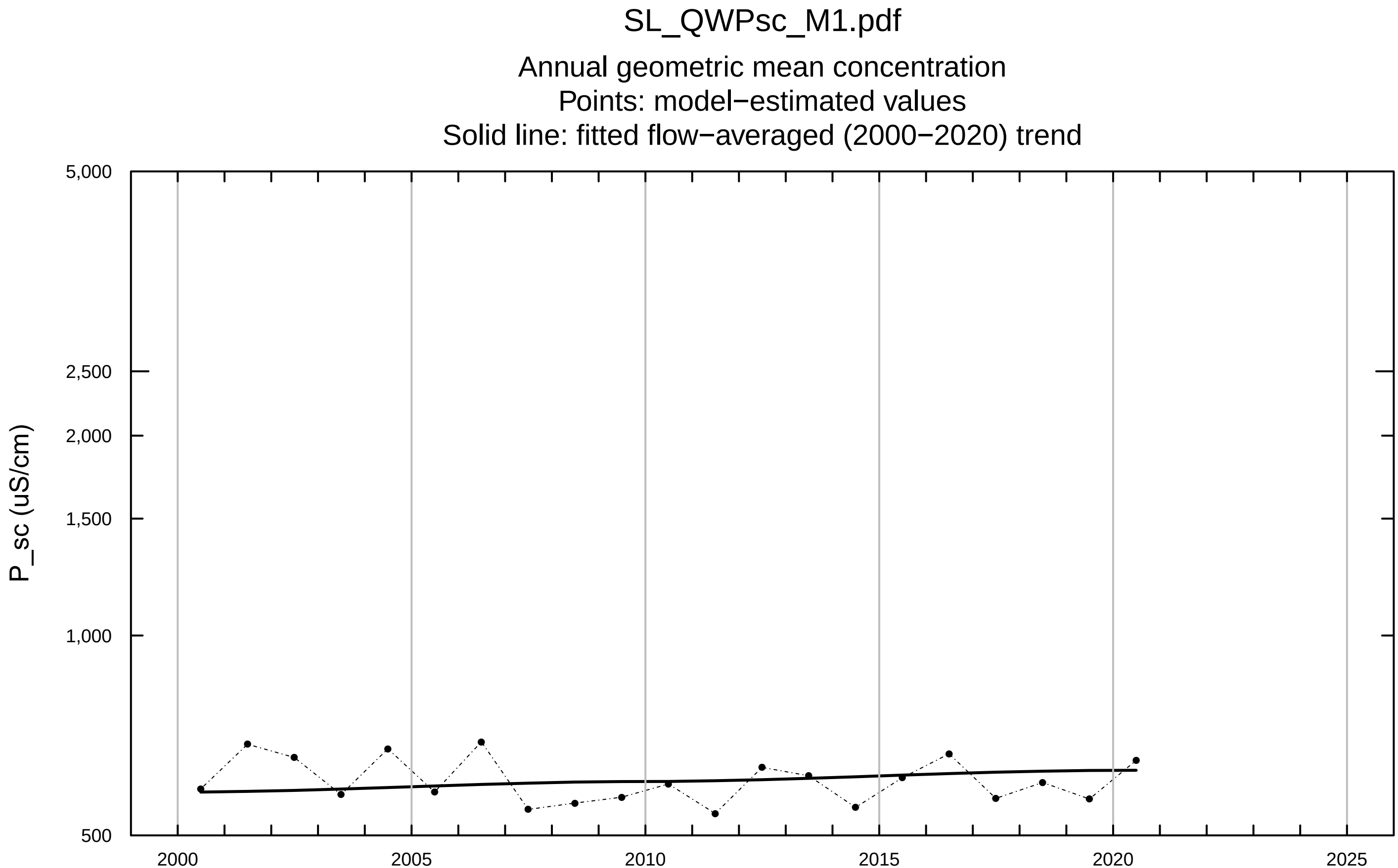
SL_QWPsc_M1.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

Heavy line: Expected annual flow−averaged exceedance frequency

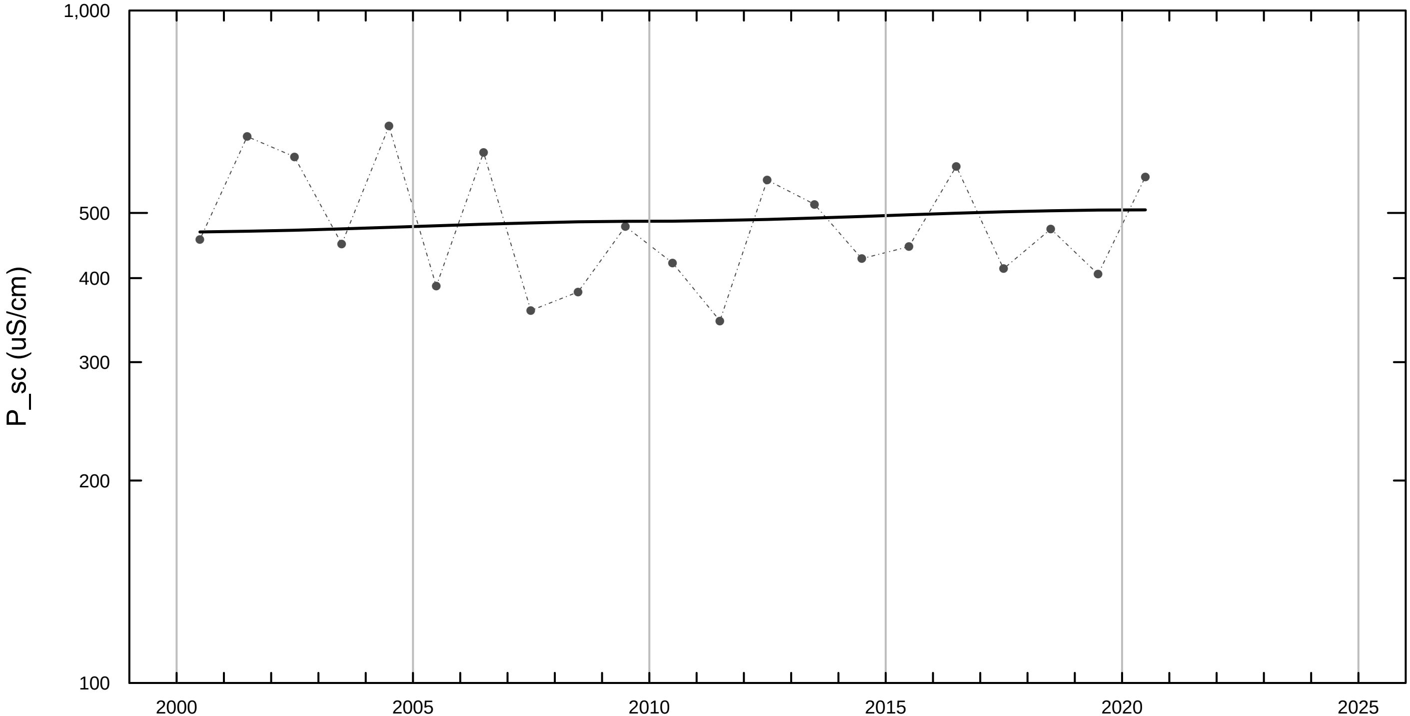


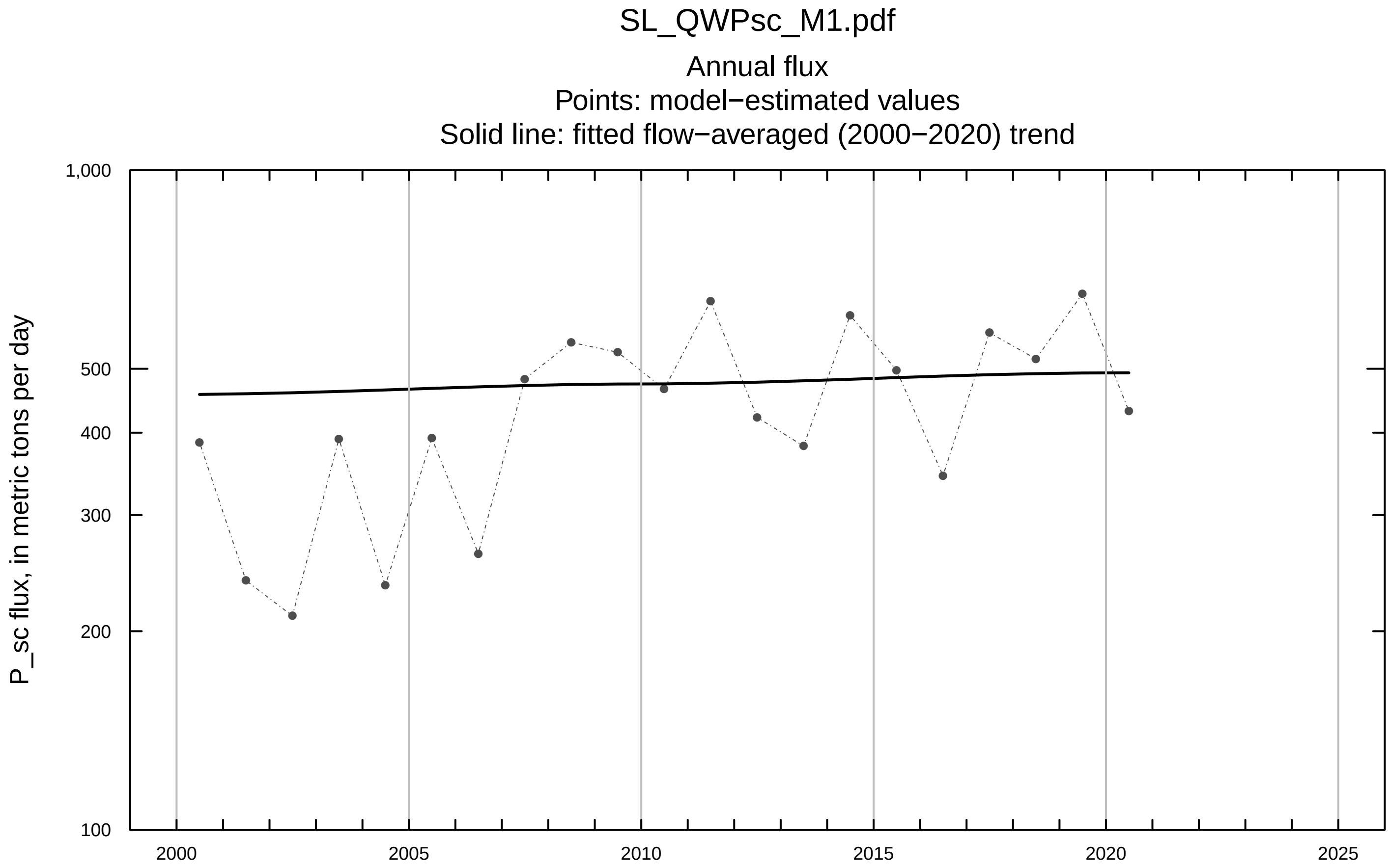


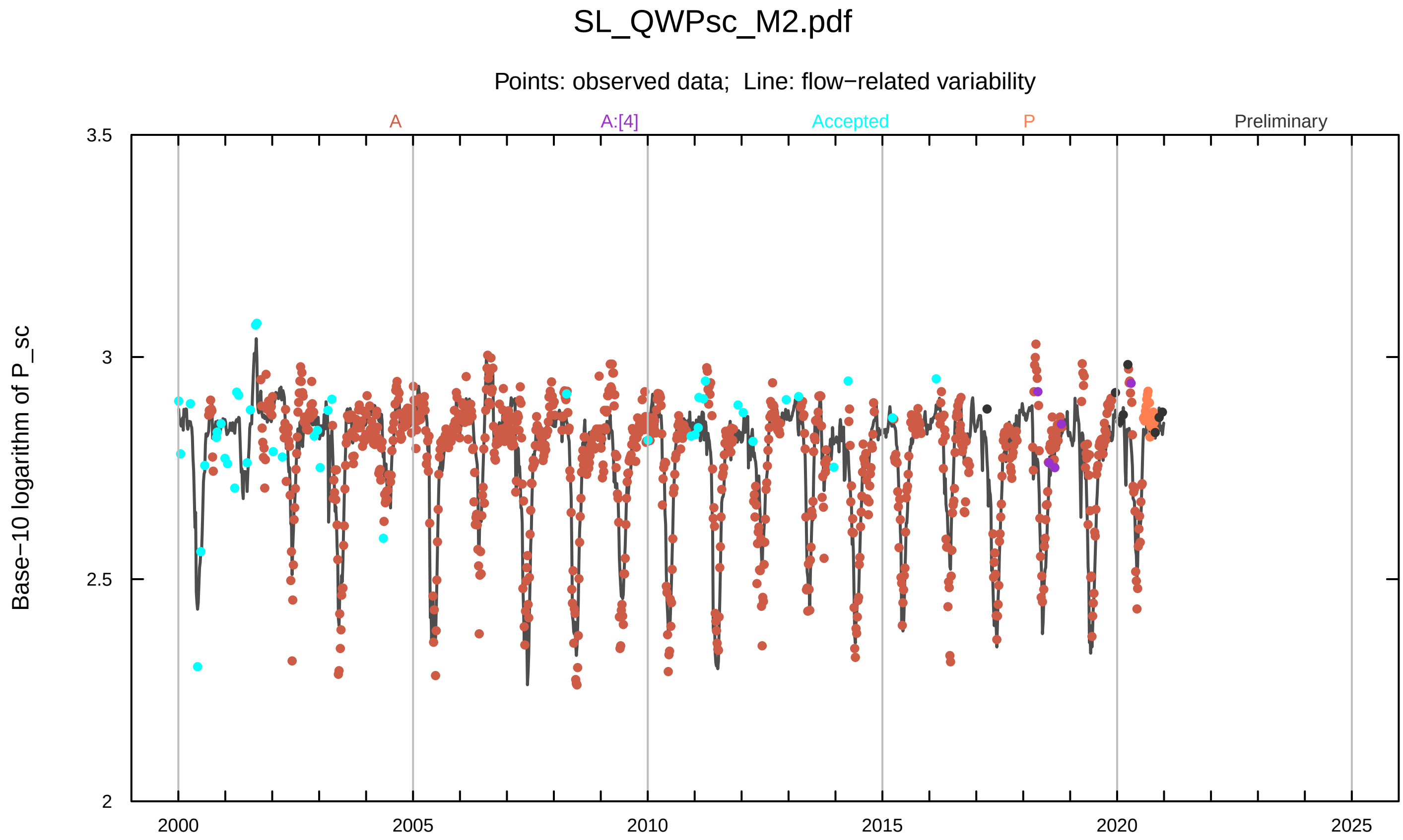
SL_QWPsc_M1.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025

SL_QWPsc_M1.pdf

Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend

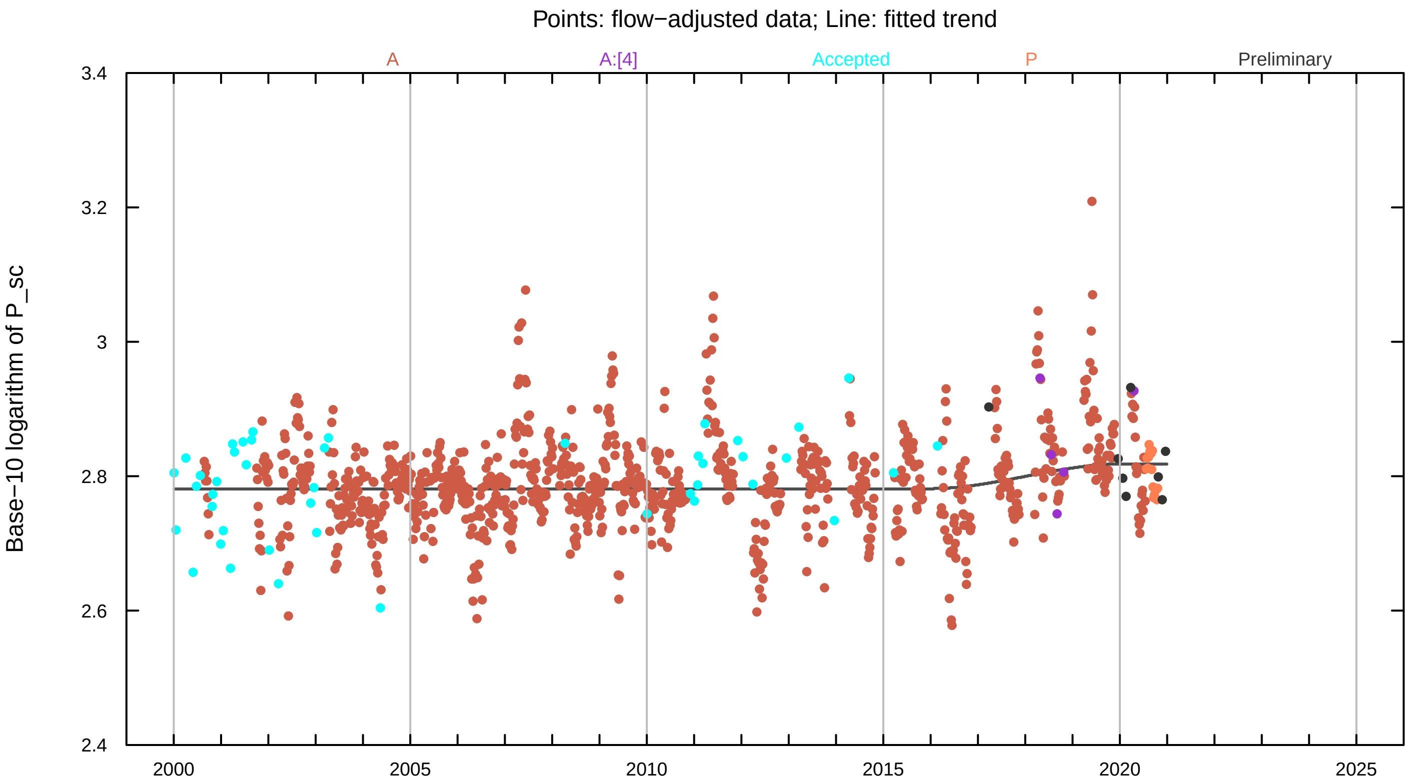


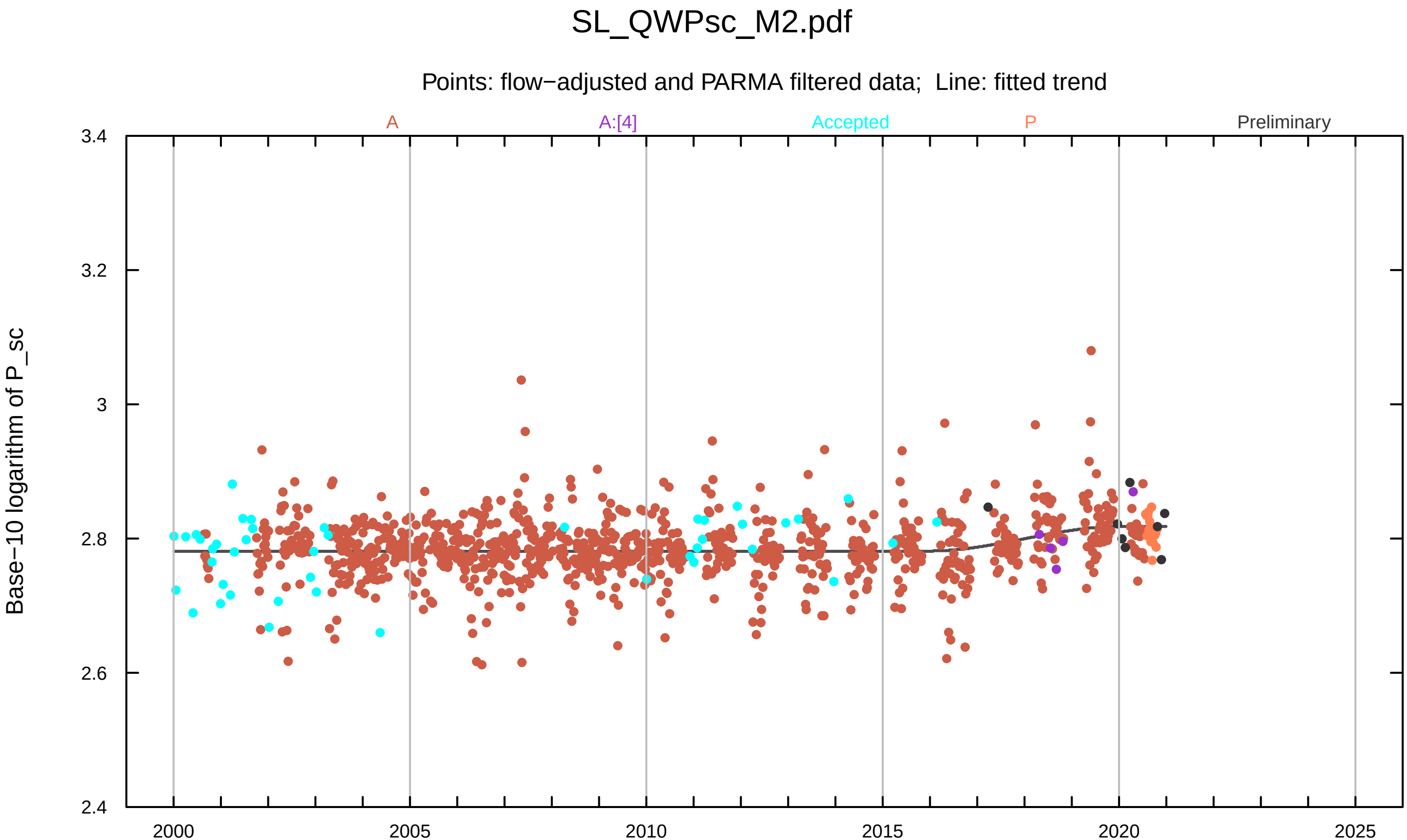

SL_QWPsc_M1.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025



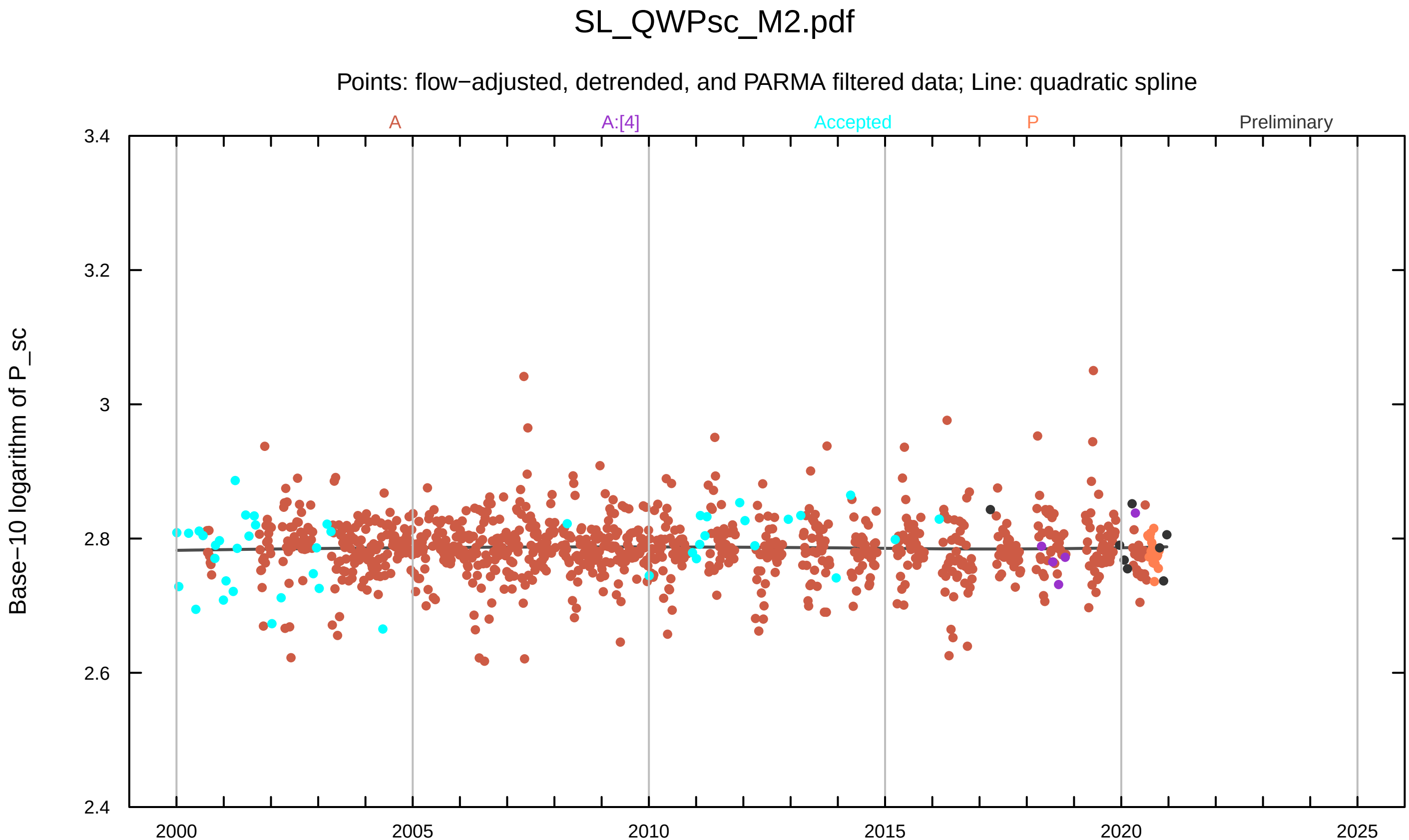
SL_QWPsc_M2.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
Preliminary
3.5
3
2.5
2
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020
2025

SL_QWPsc_M2.pdf





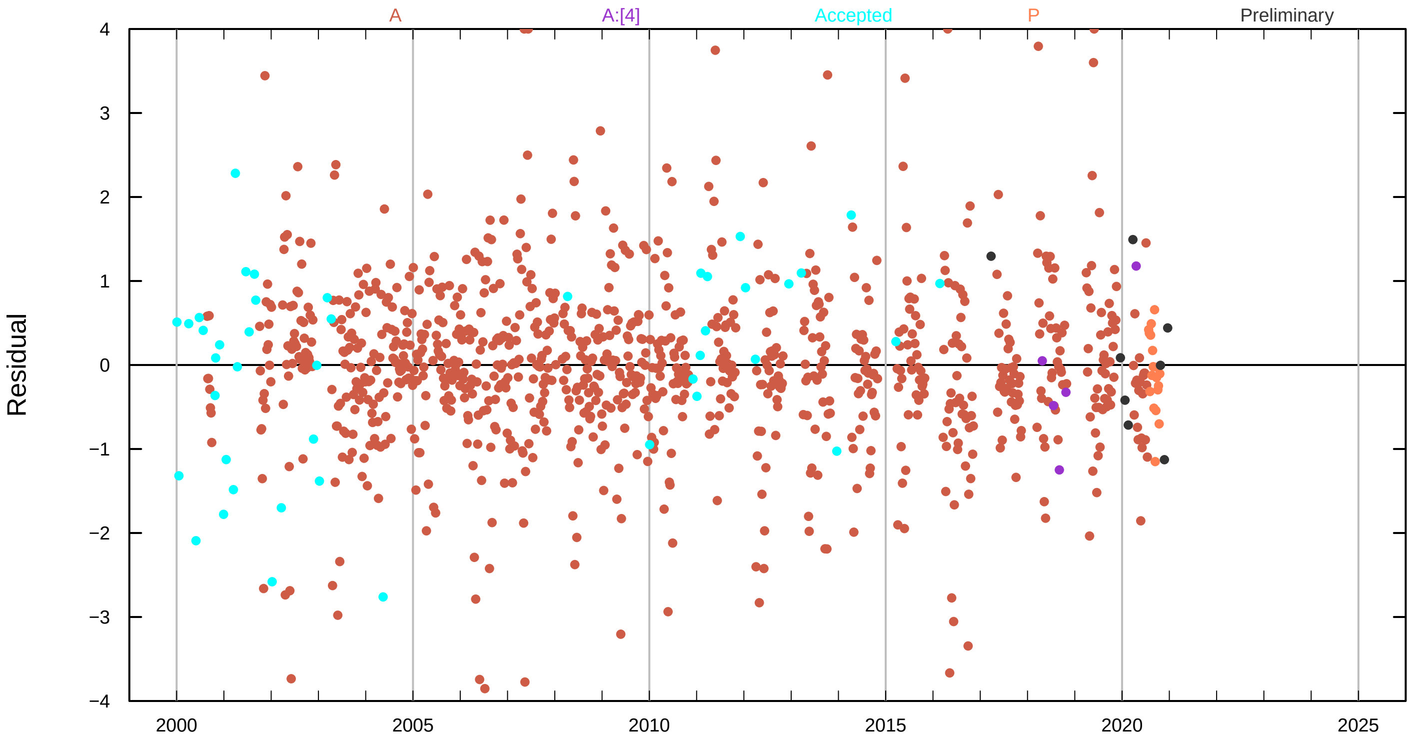
SL_QWPsc_M2.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

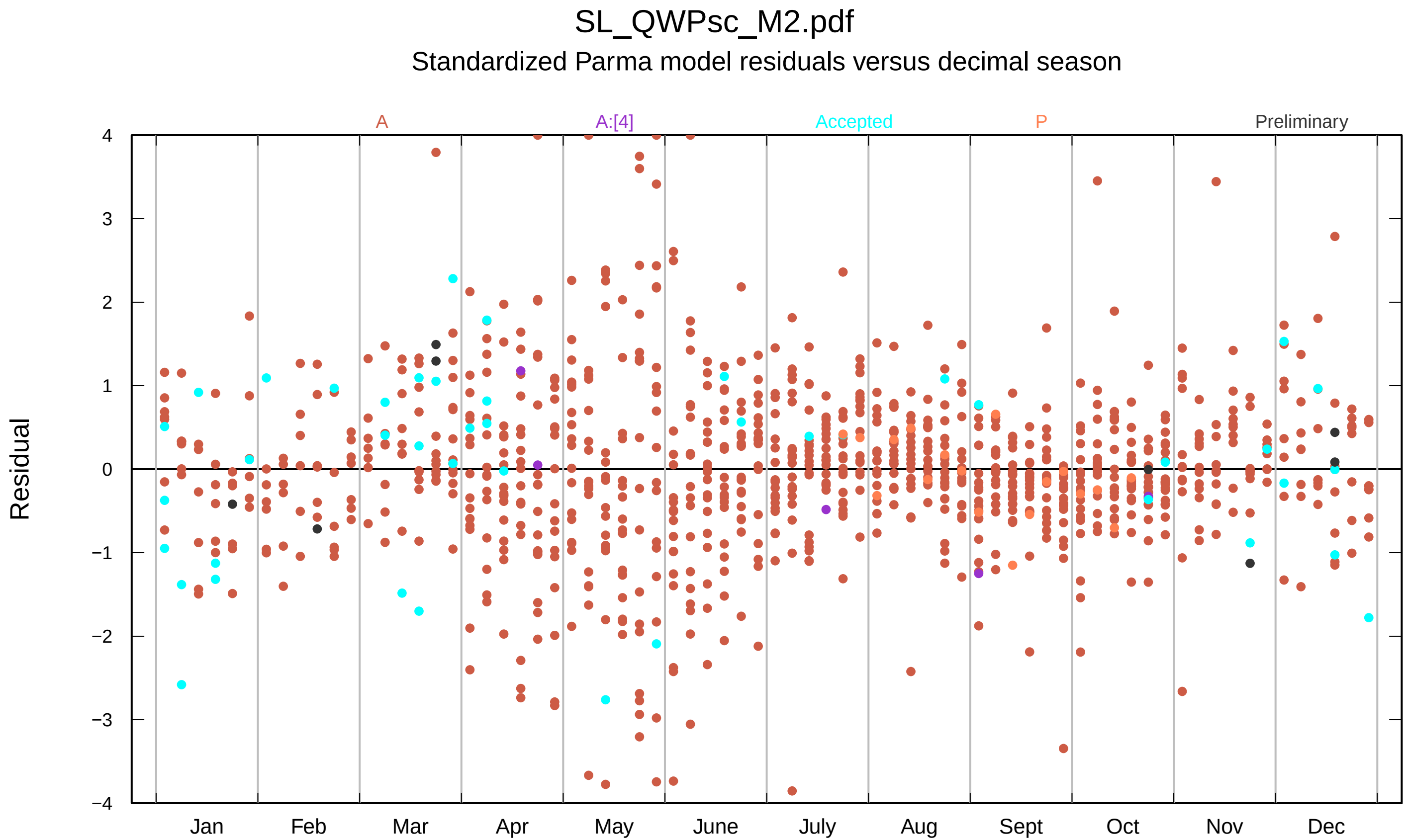


SL_QWPsc_M2.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

SL_QWPsc_M2.pdf

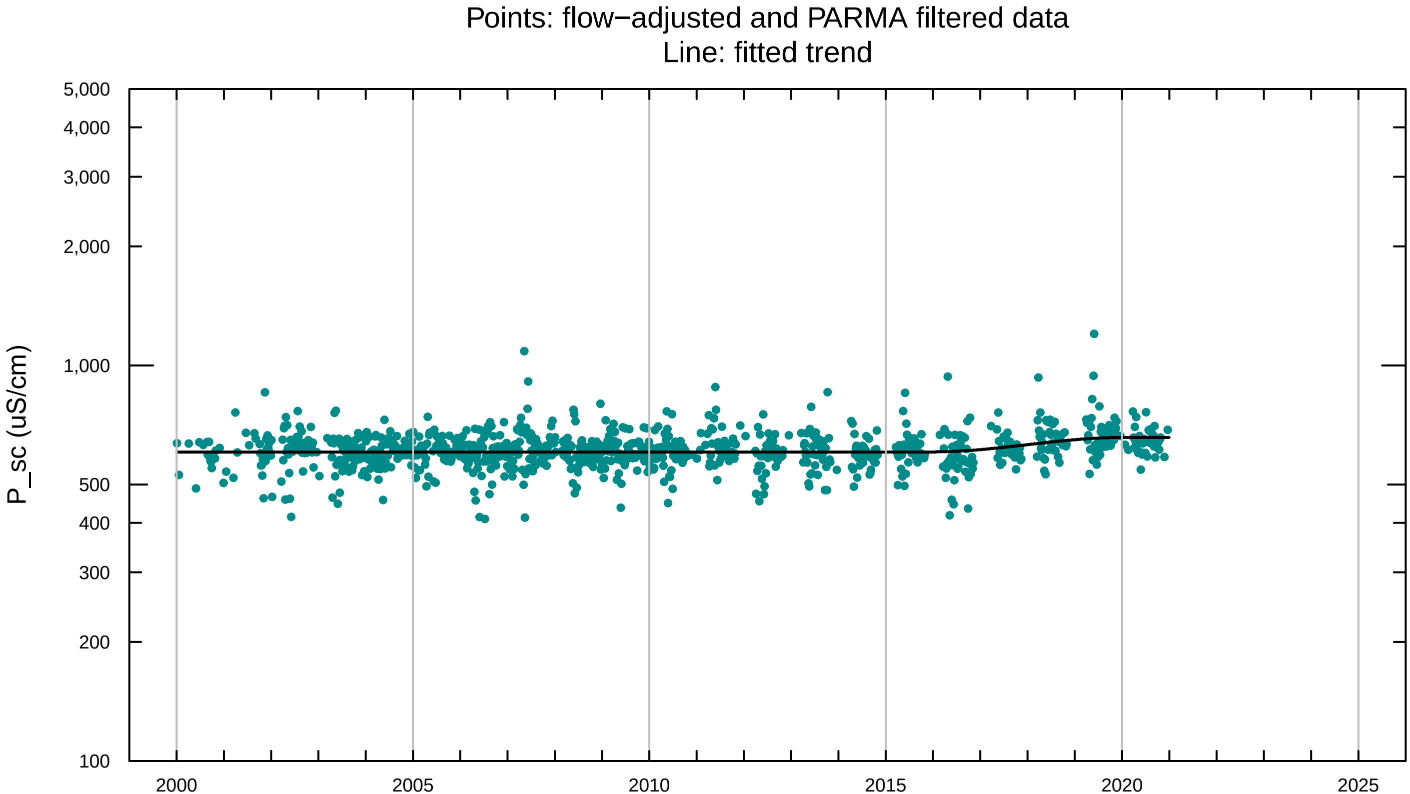
Standardized PARMA model residuals versus decimal year

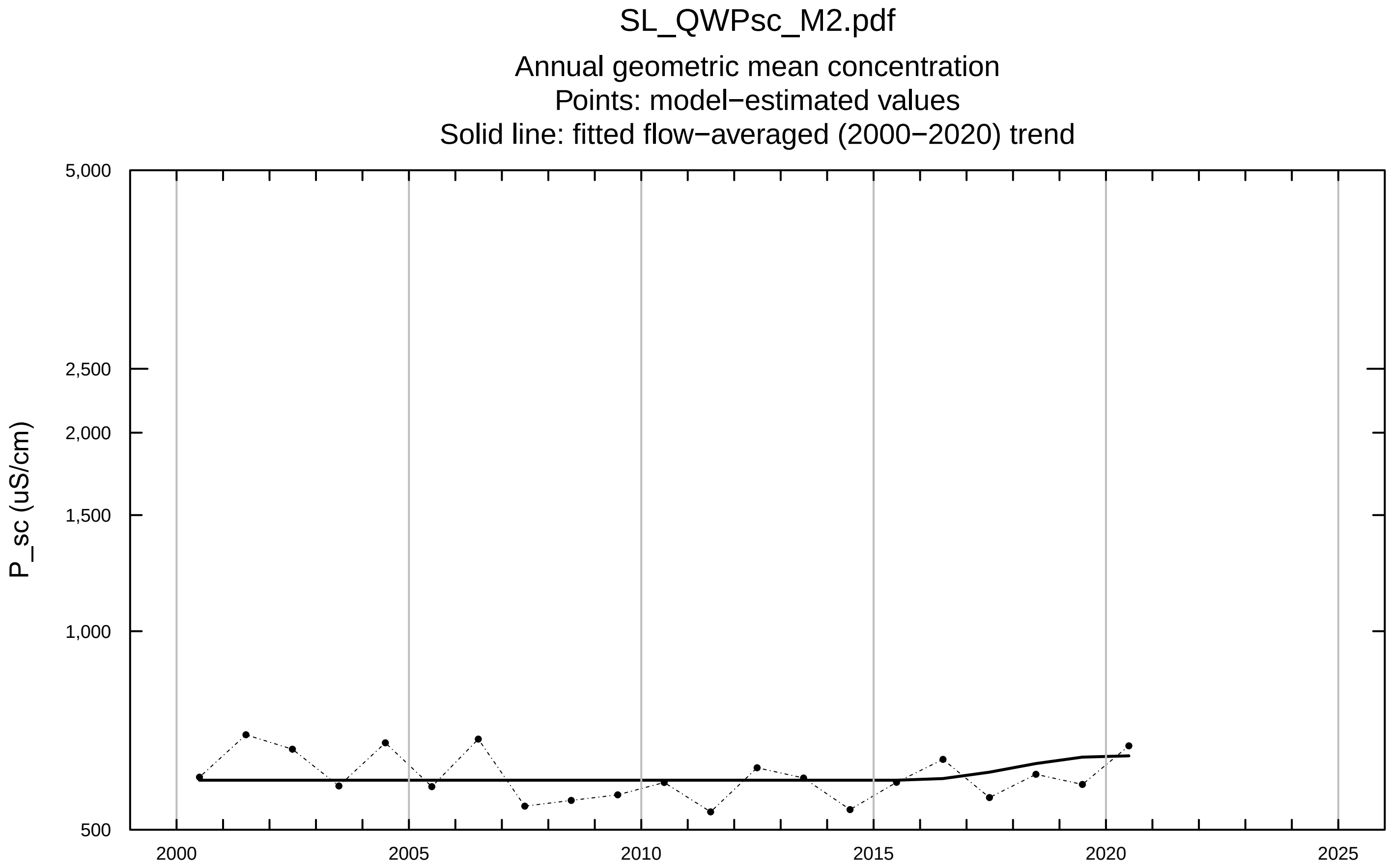




SL_QWPsc_M2.pdf
Standardized Parma model residuals versus decimal season
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

SL_QWPsc_M2.pdf

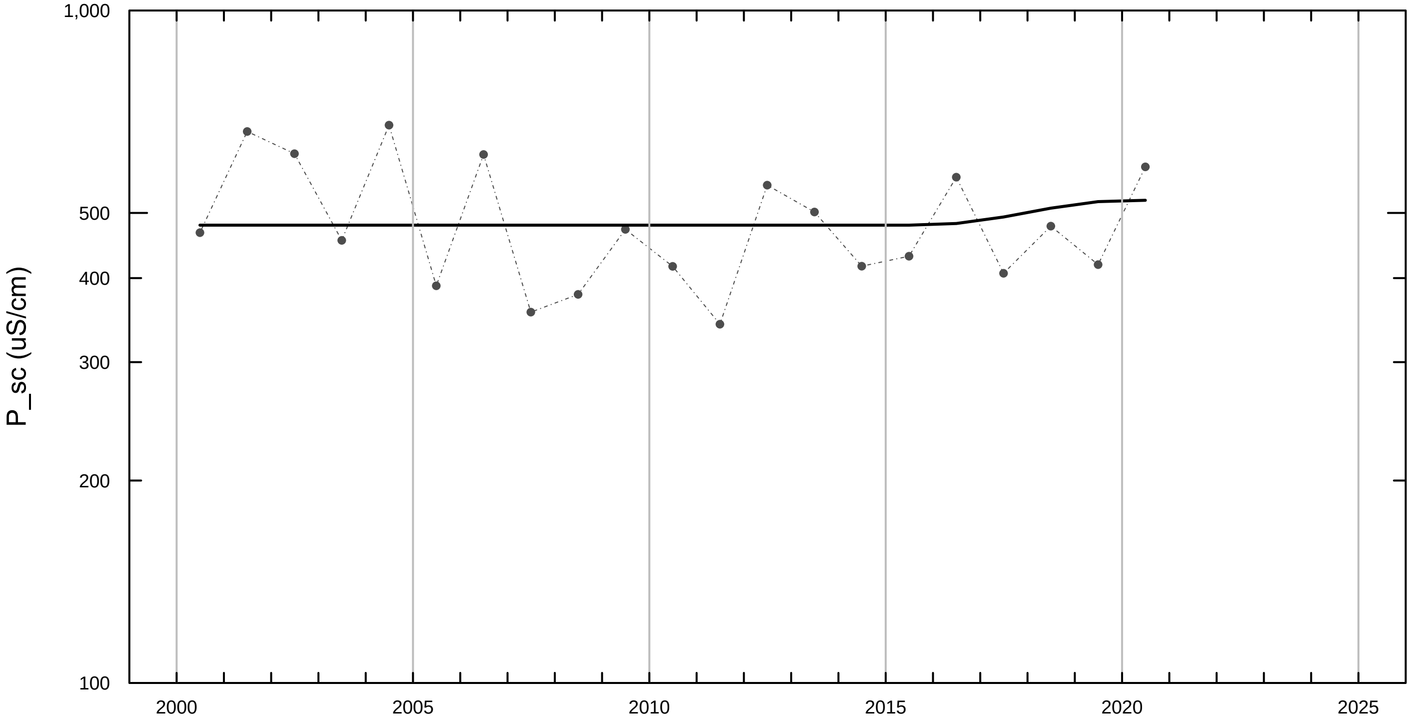


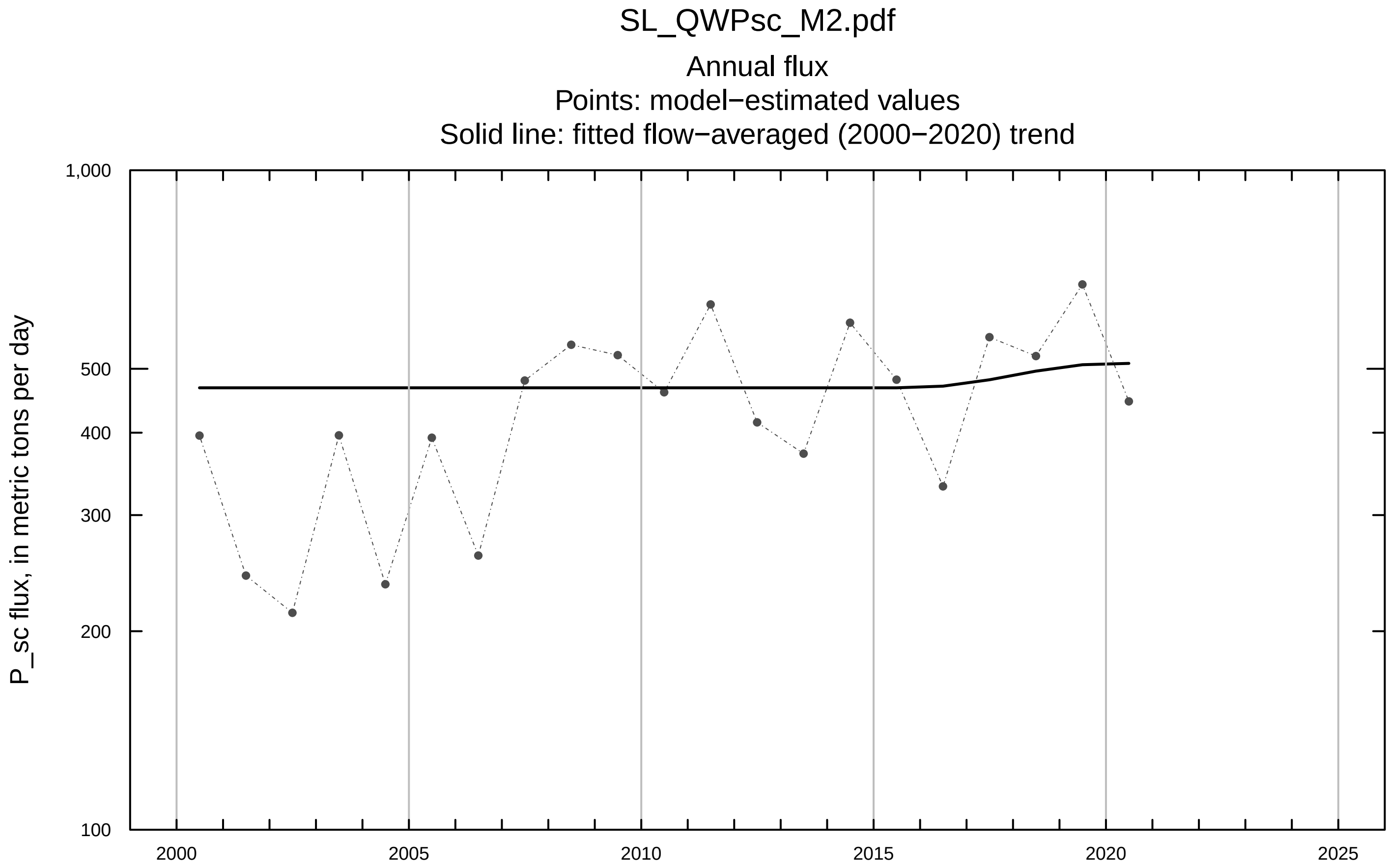


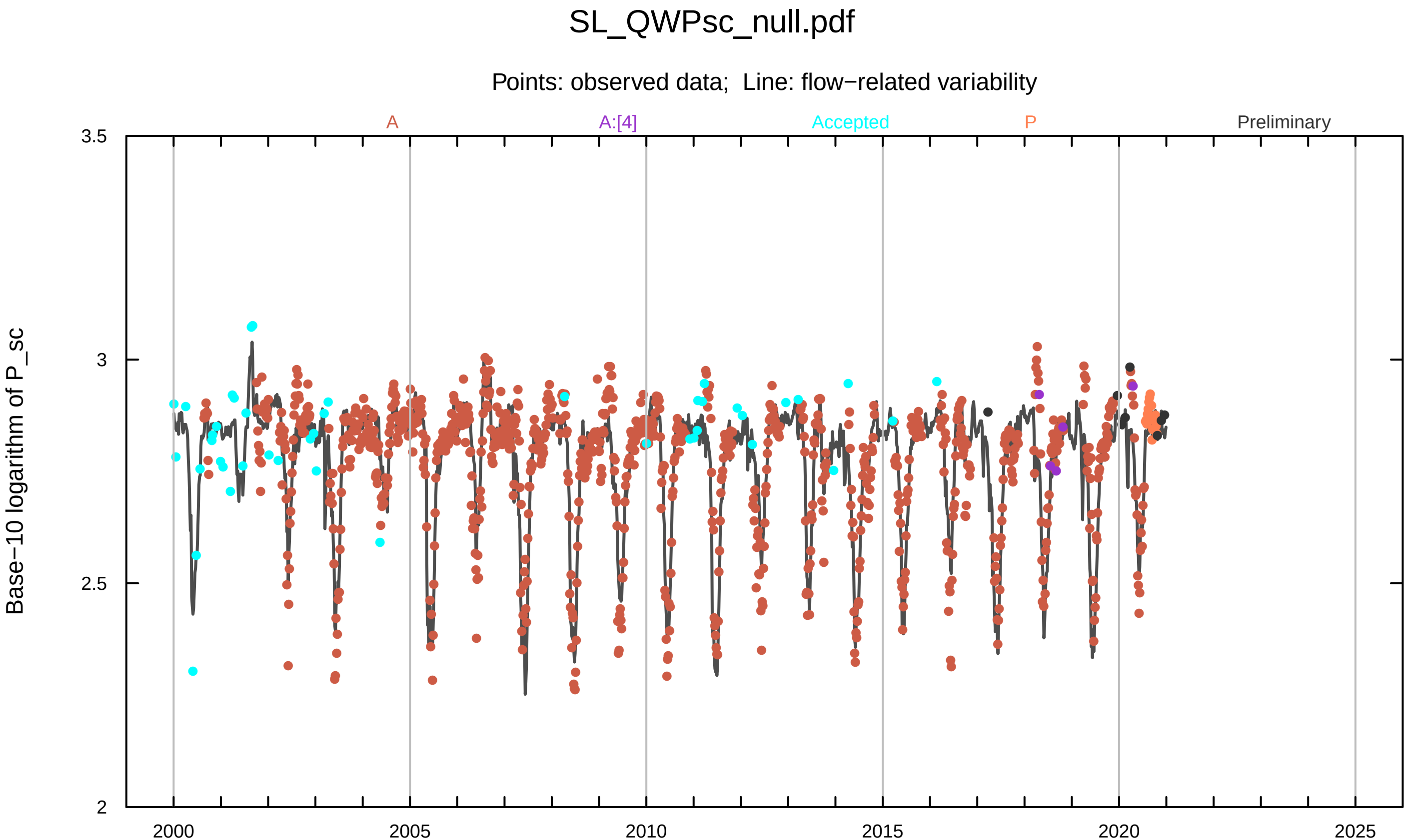
SL_QWPsc_M2.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025

SL_QWPsc_M2.pdf

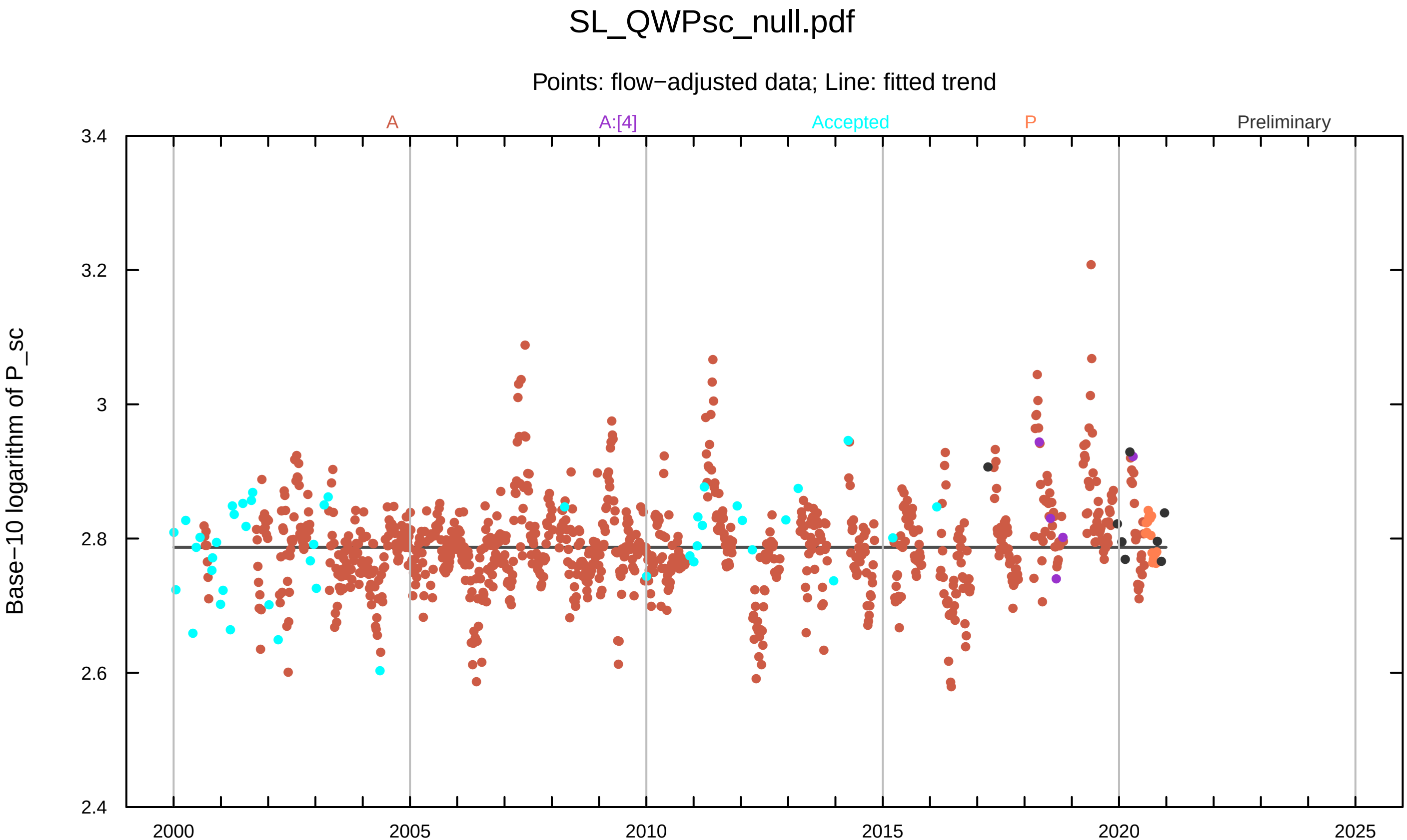
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend

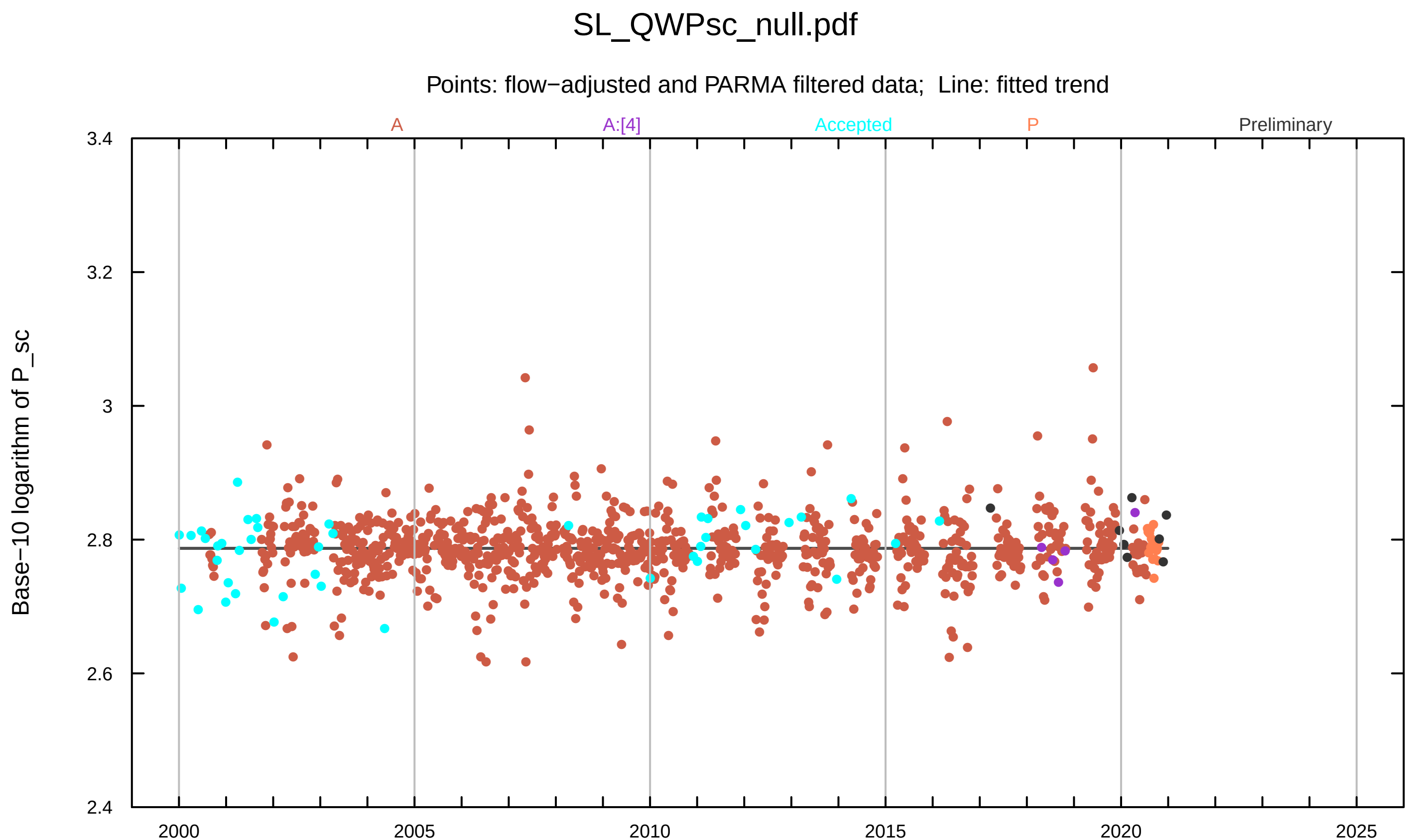



SL_QWPsc_M2.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

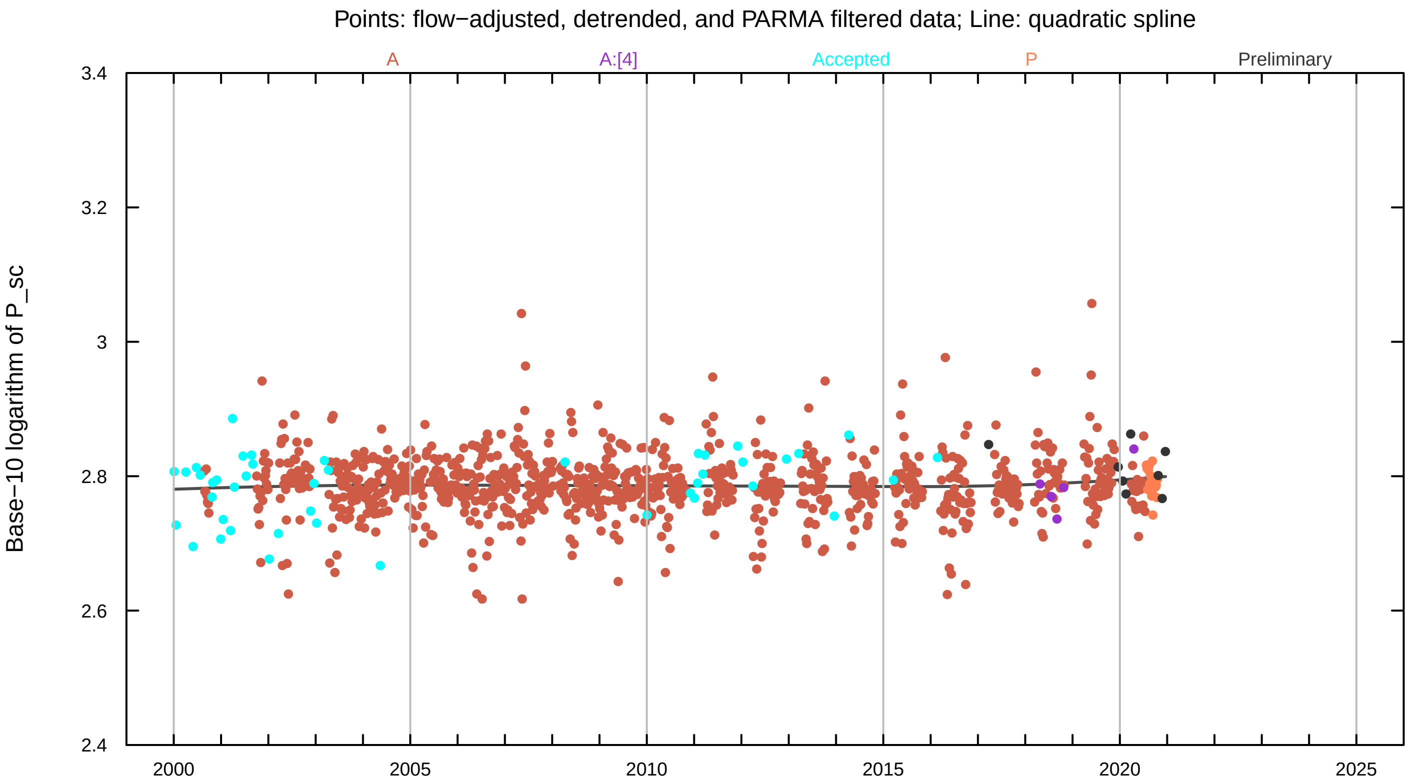


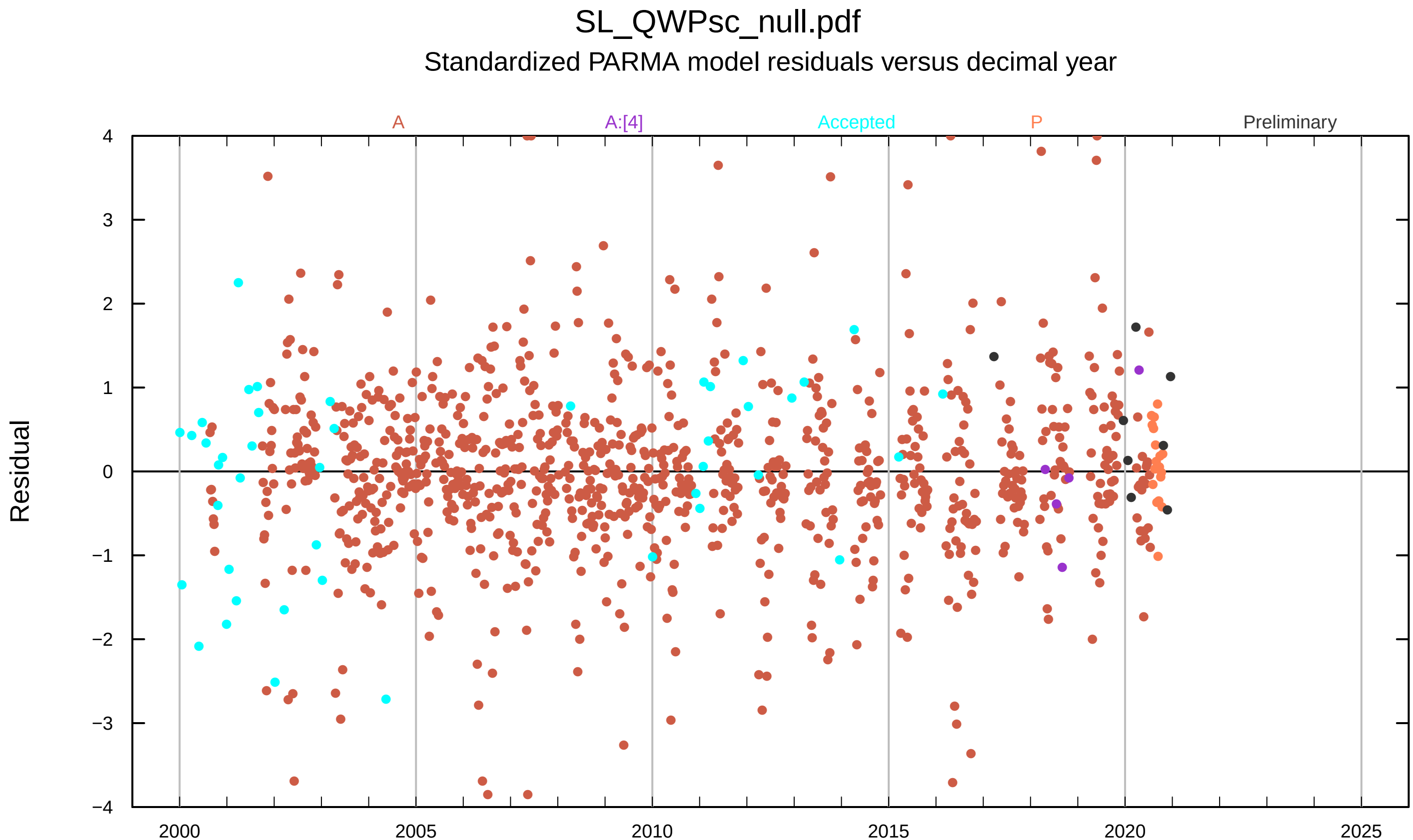
SL_QWPsc_null.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
Preliminary
3.5
3
2.5
2
2000
2005
2010
2015
2020
2025
Base−10 logarithm of P_sc

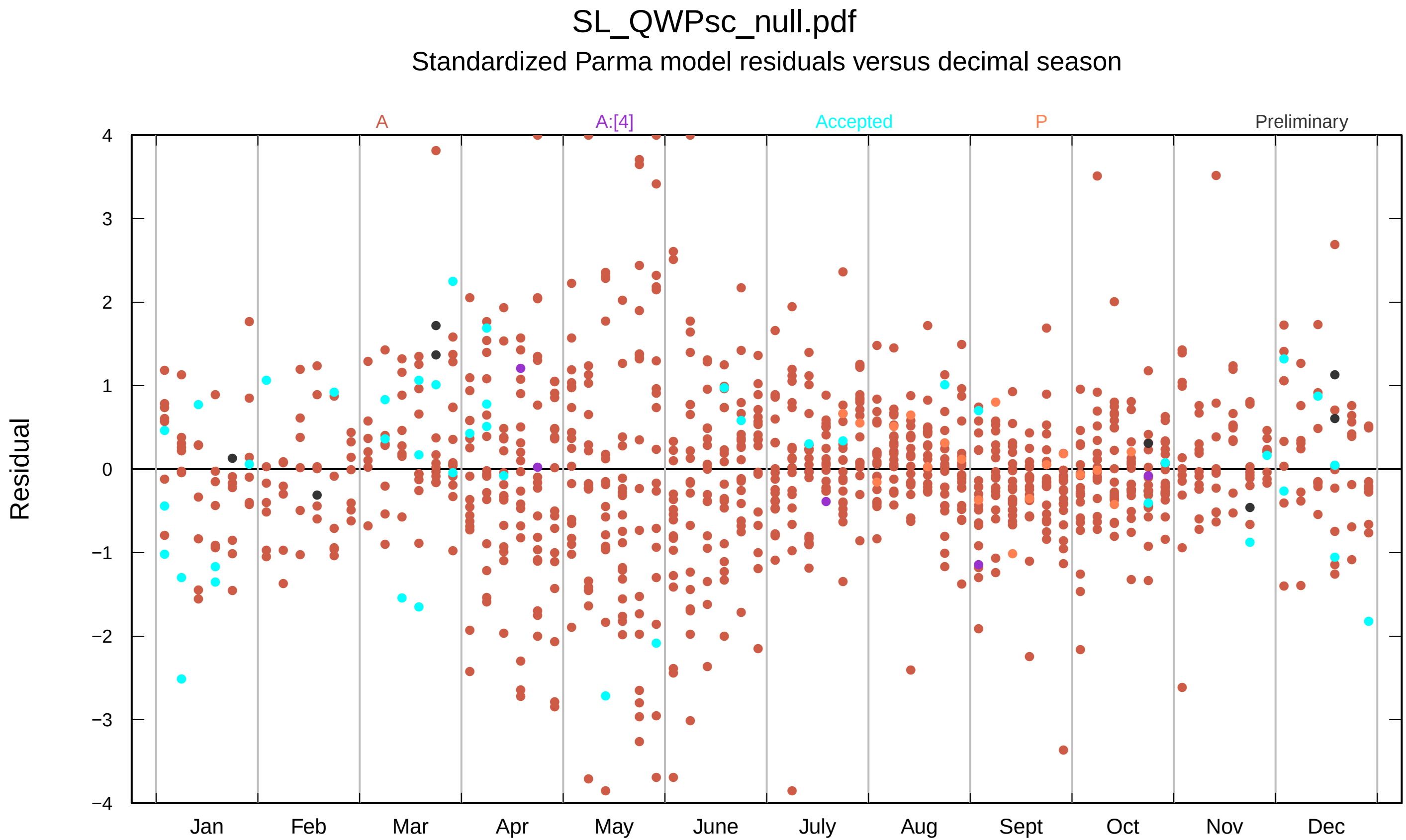

SL_QWPsc_null.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

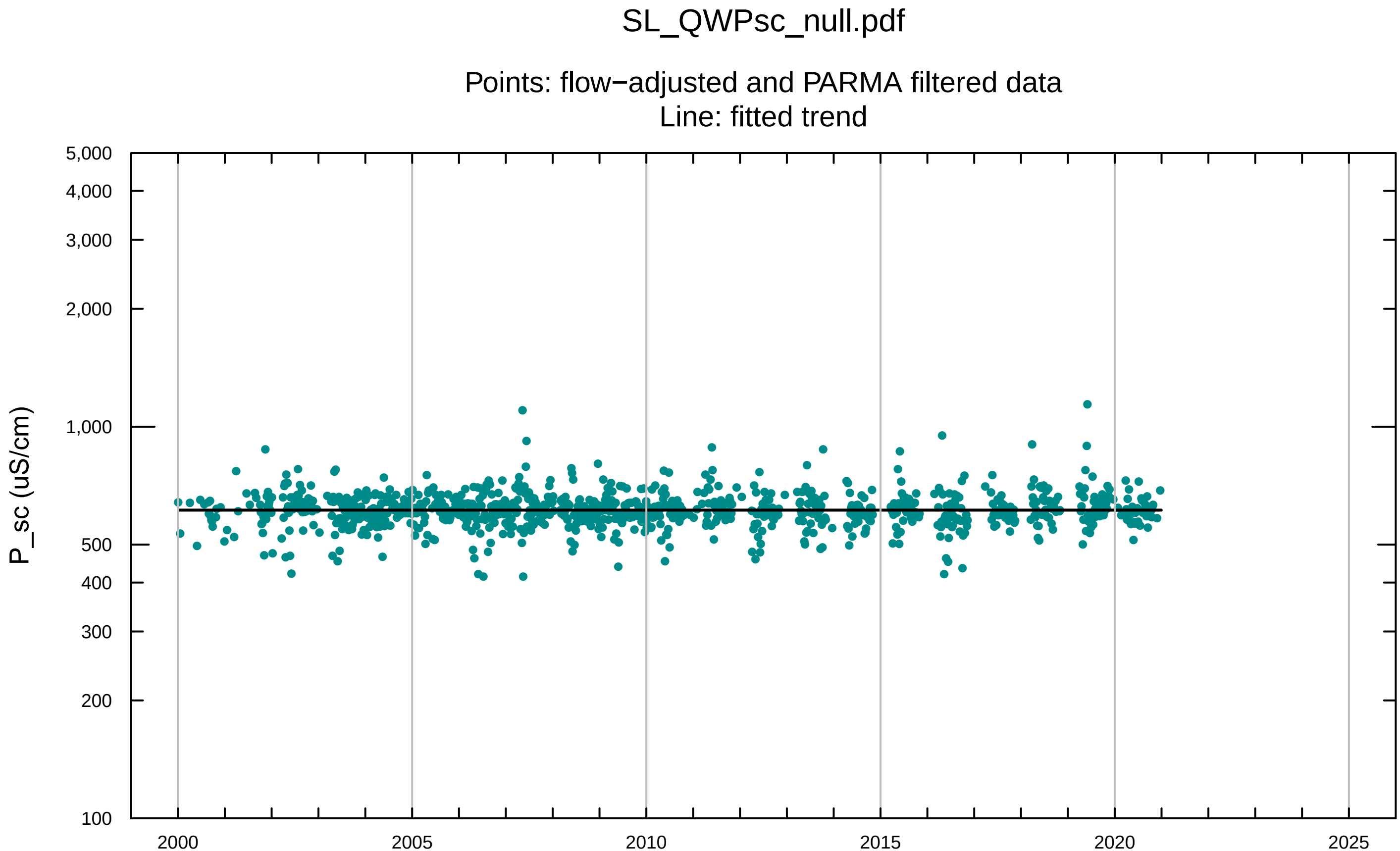

SL_QWPsc_null.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
Preliminary
Base−10 logarithm of P_sc
3.4
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

SL_QWPsc_null.pdf




SL_QWPsc_null.pdf
Standardized PARMA model residuals versus decimal year
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025


SL_QWPsc_null.pdf
Standardized Parma model residuals versus decimal season
A
A:[4]
Accepted
P
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec



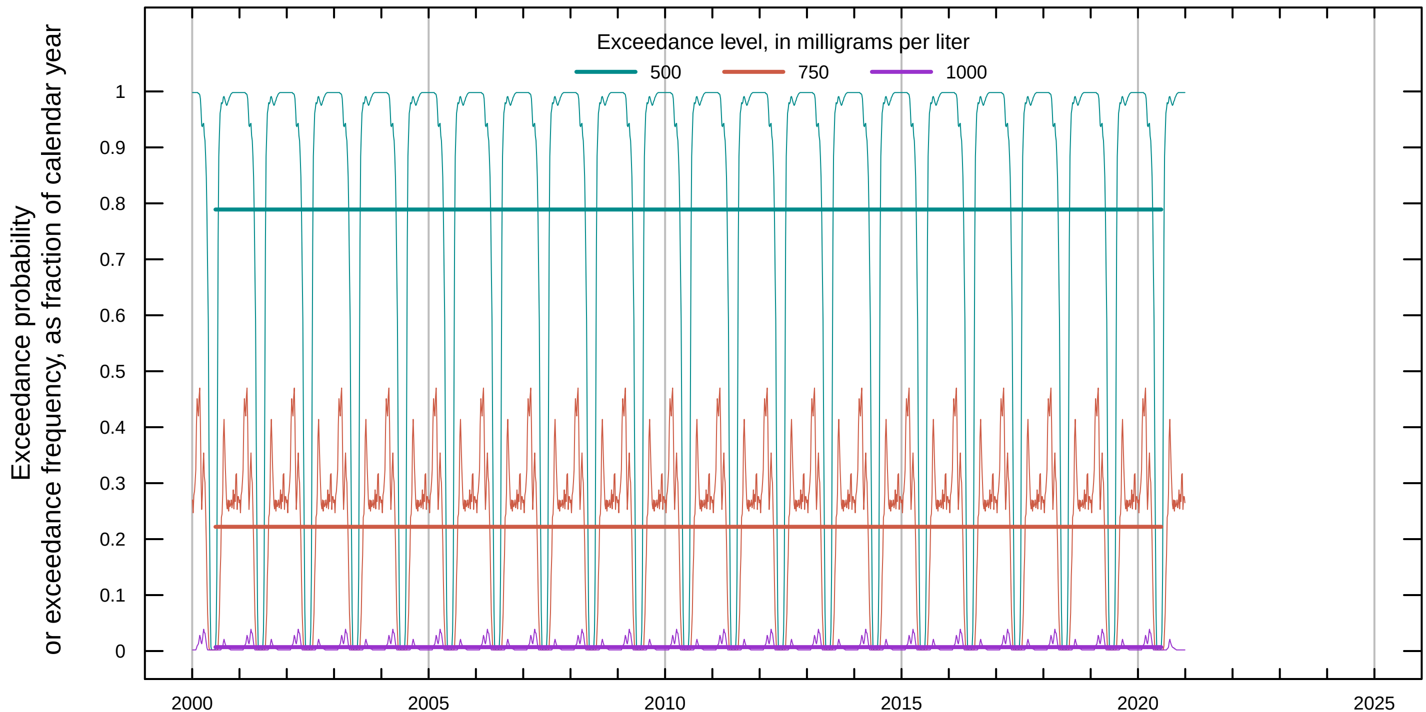
SL_QWPsc_null.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

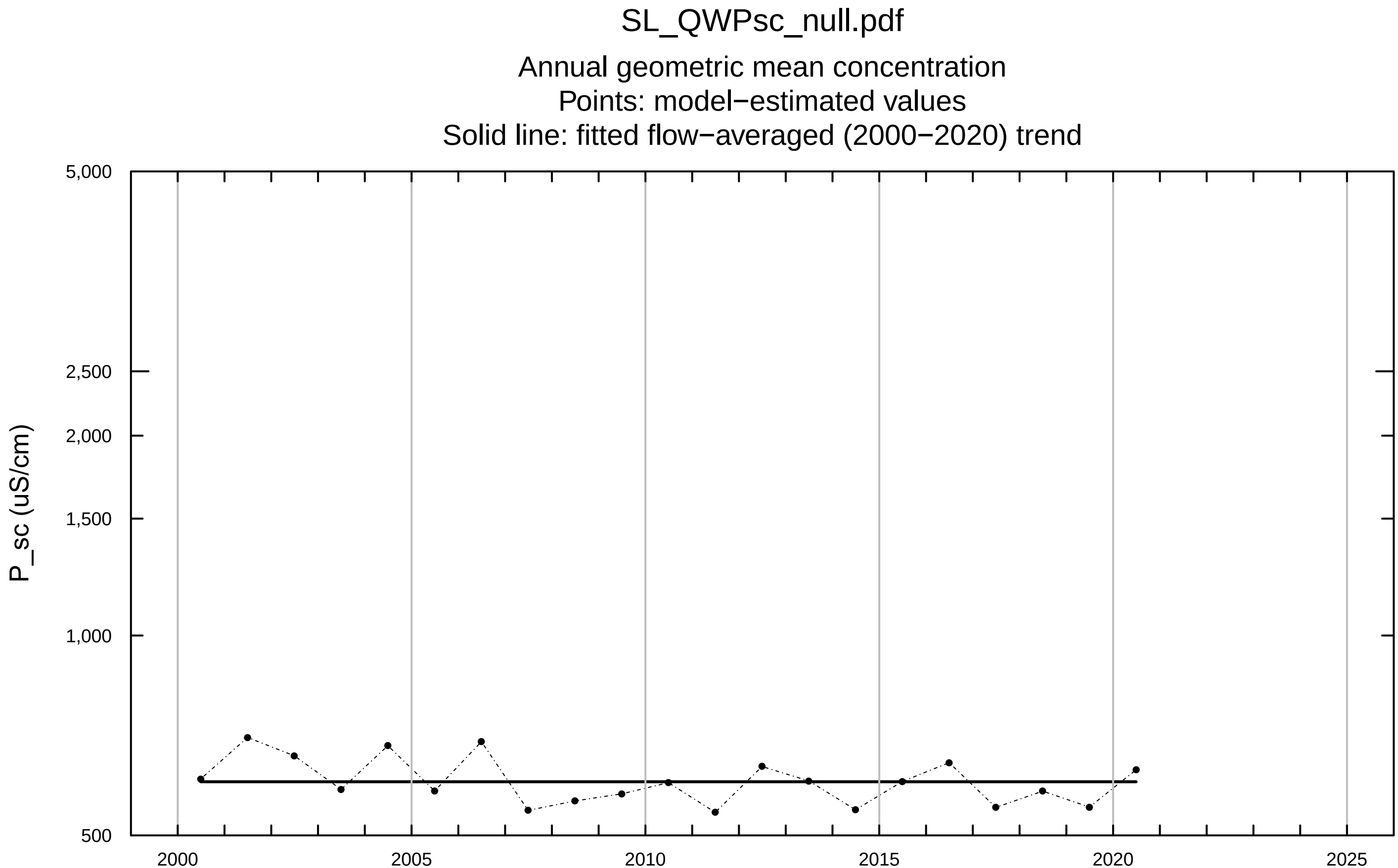
SL_QWPsc_null.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

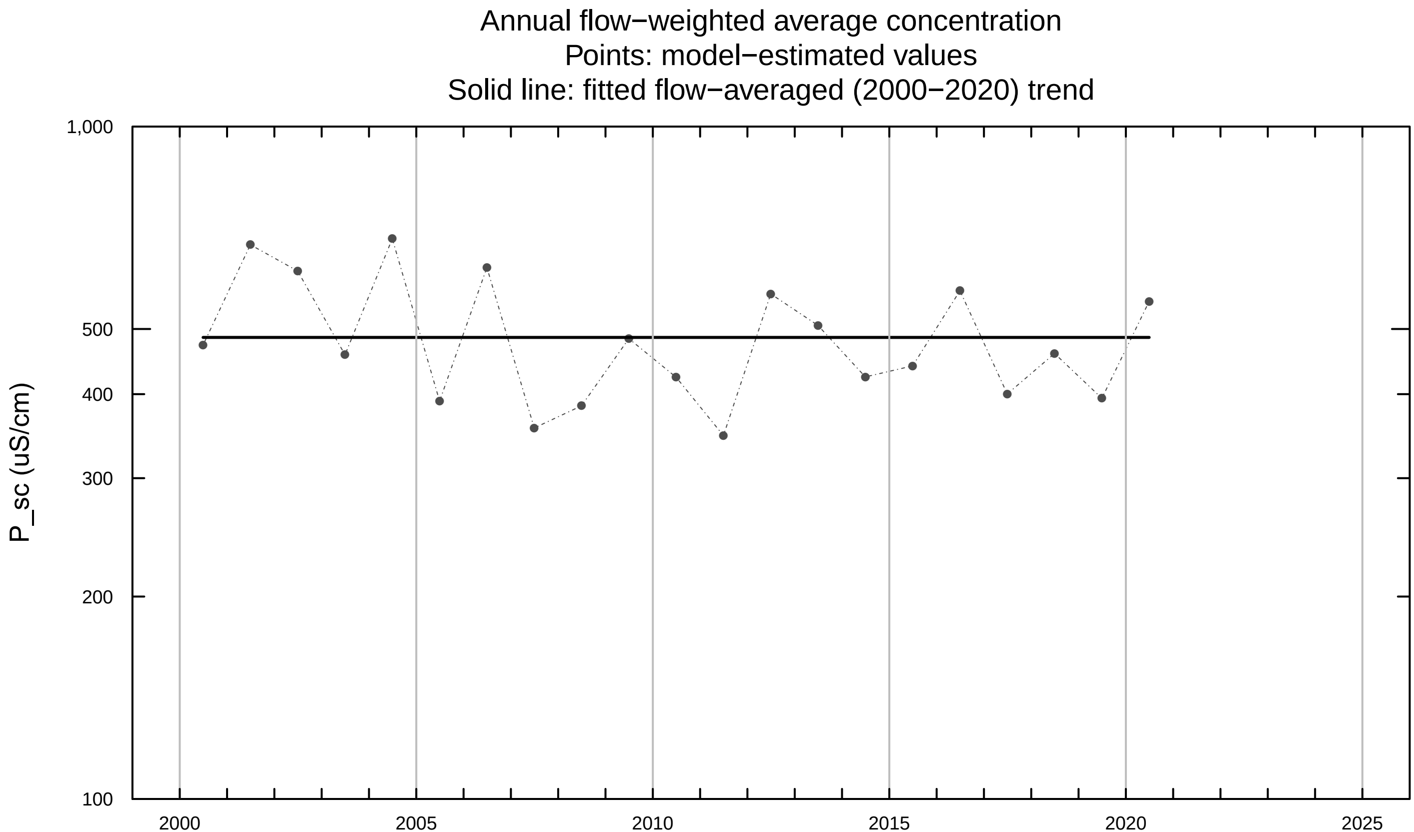
Thin line: Flow−averaged exceedance probability

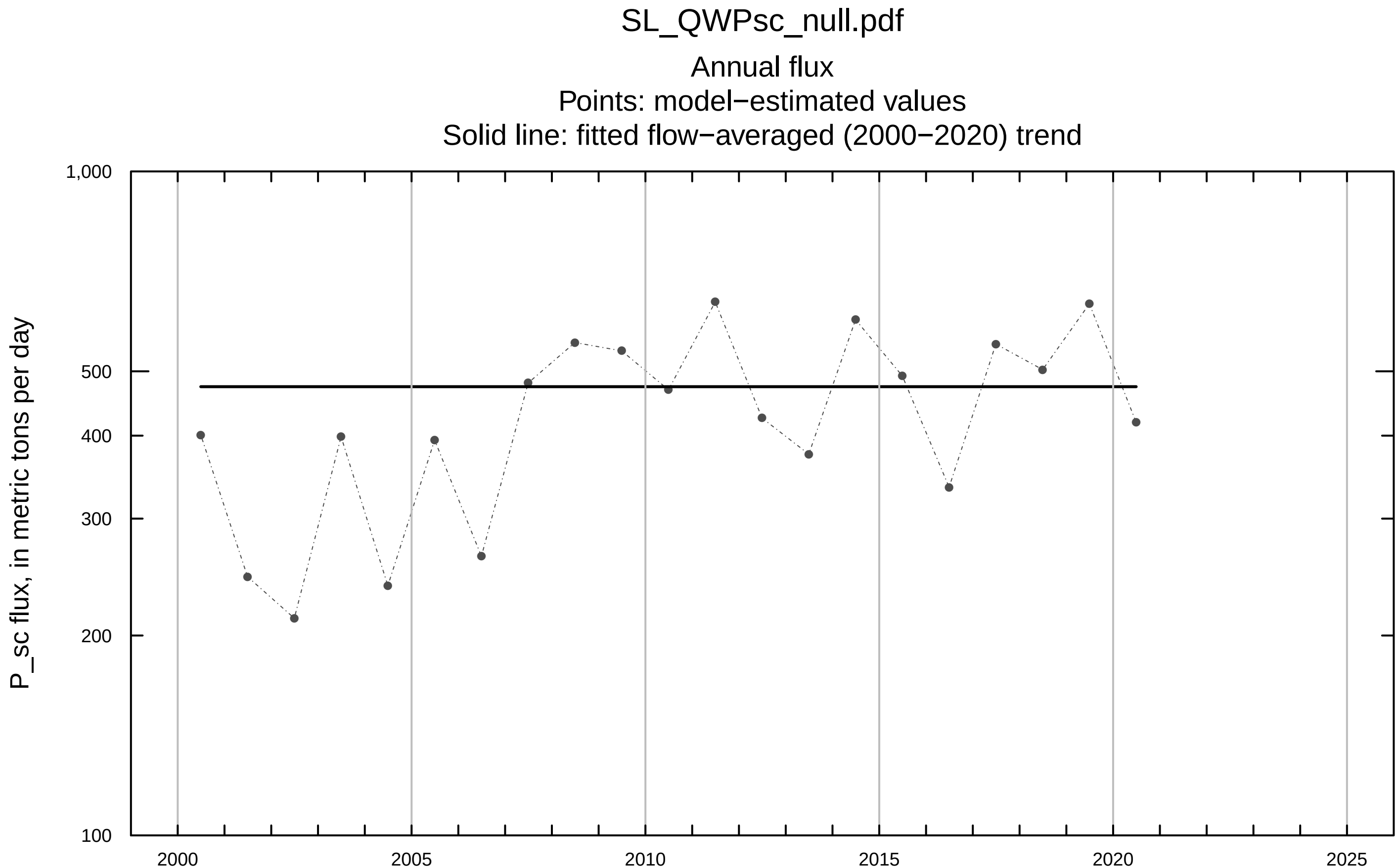
Heavy line: Expected annual flow−averaged exceedance frequency



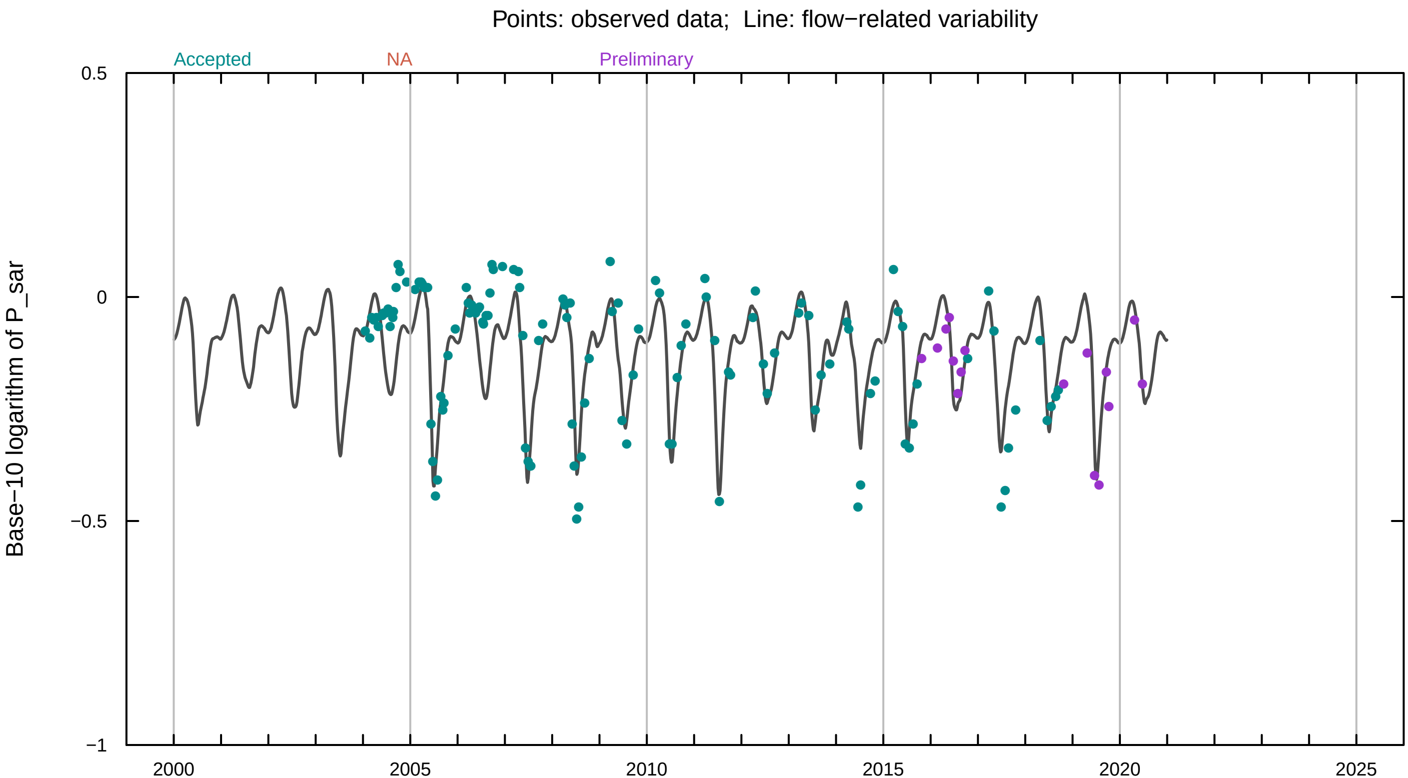

SL_QWPsc_null.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025

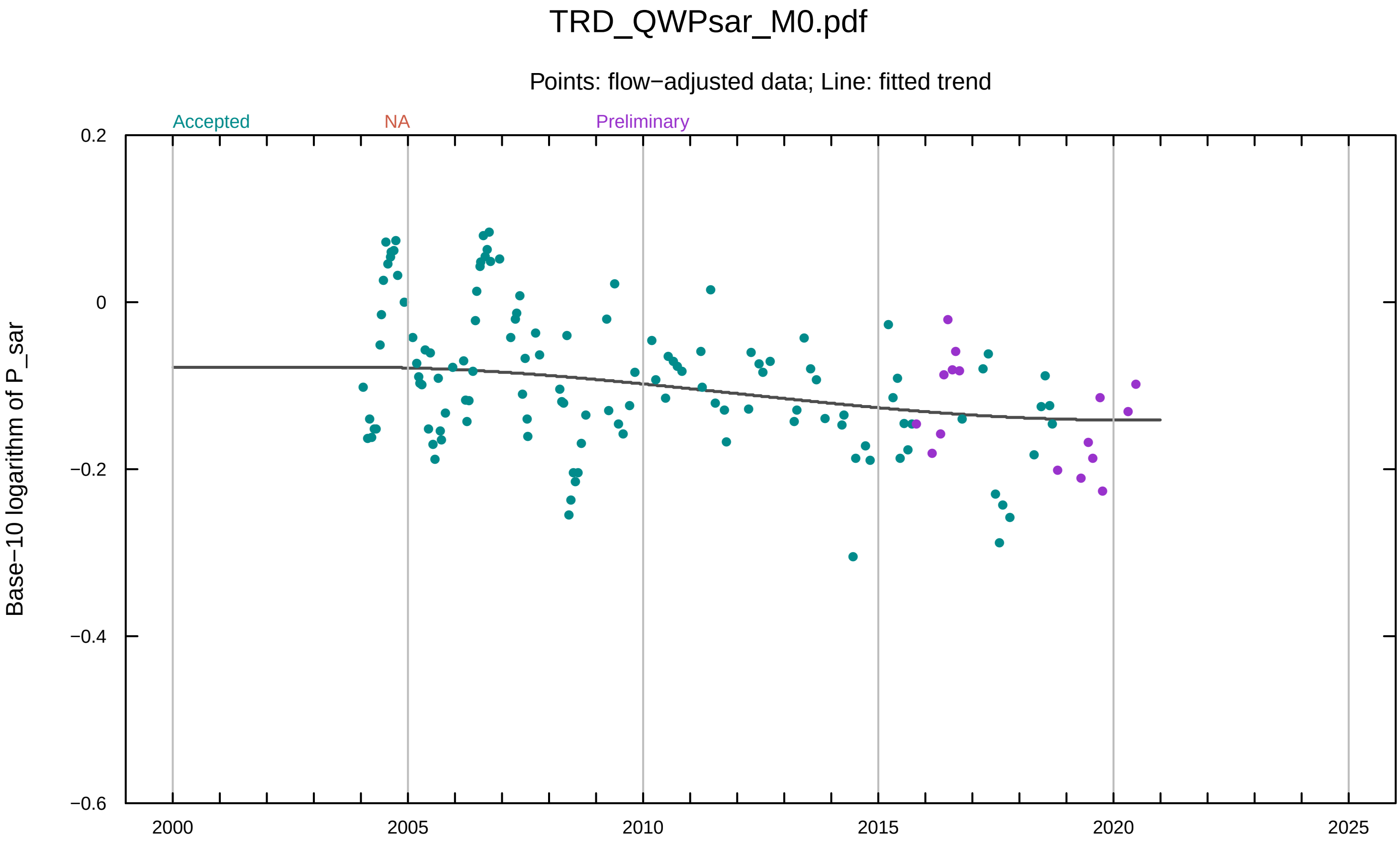
SL_QWPsc_null.pdf




SL_QWPsc_null.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

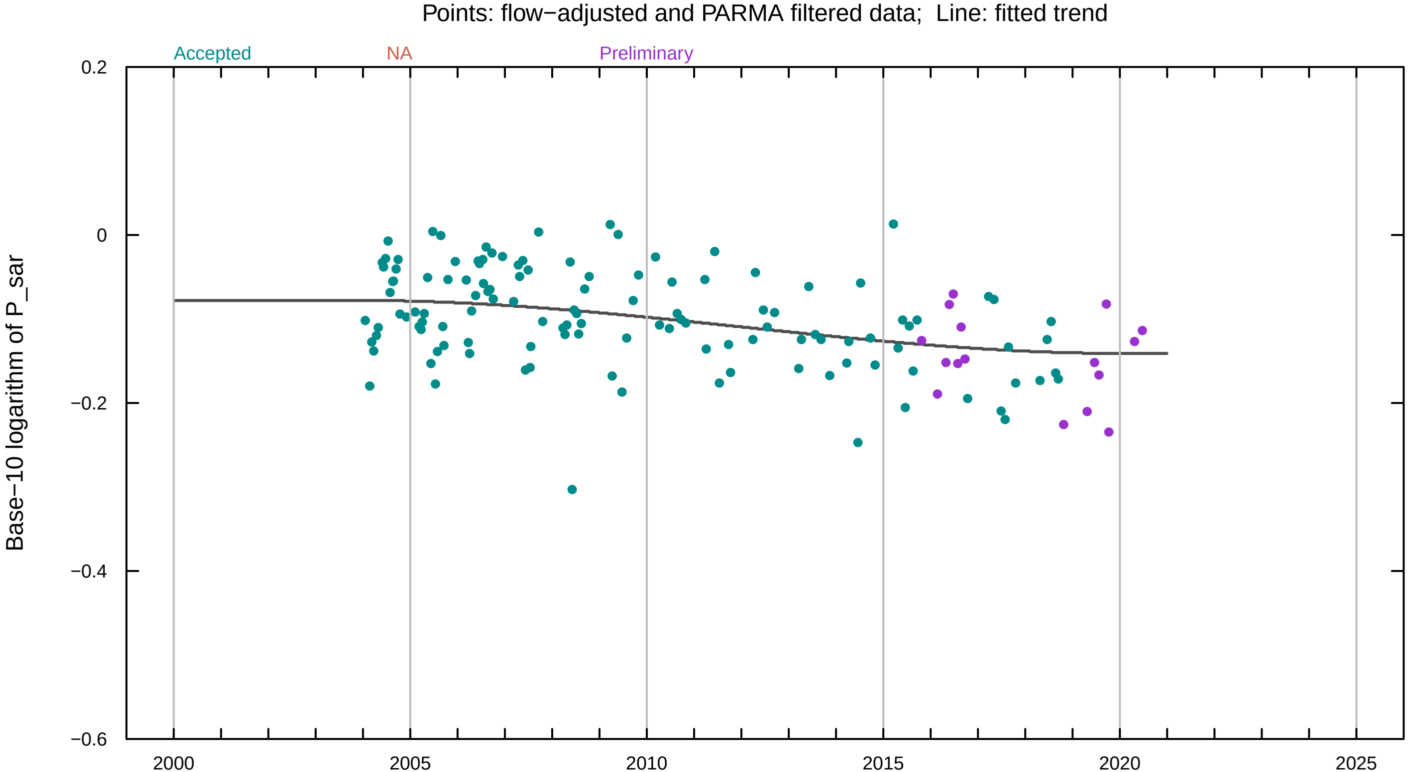
TRD_QWPsar_M0.pdf

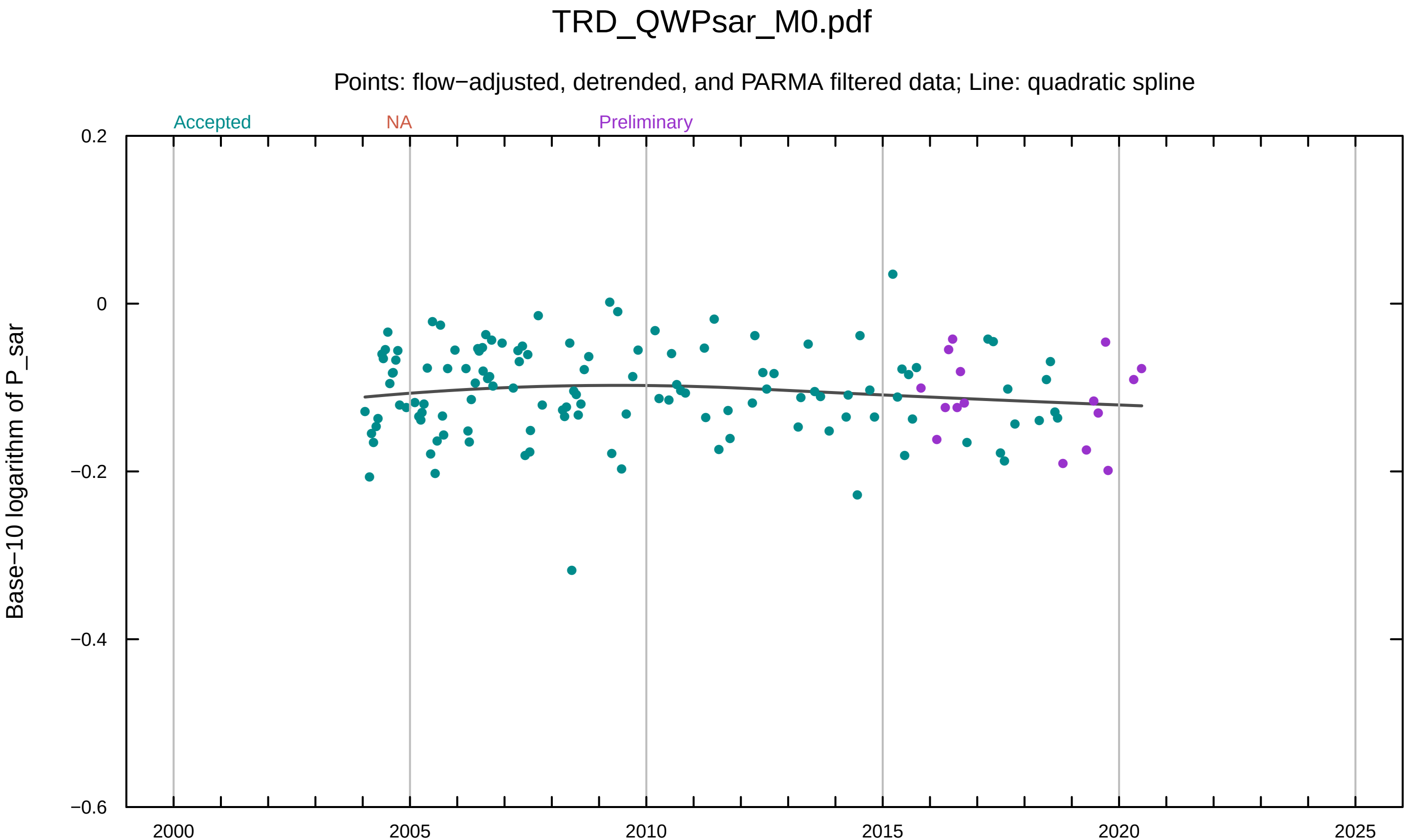




TRD_QWPsar_M0.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.2
0
−0.2
−0.4
−0.6
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

TRD_QWPsar_M0.pdf

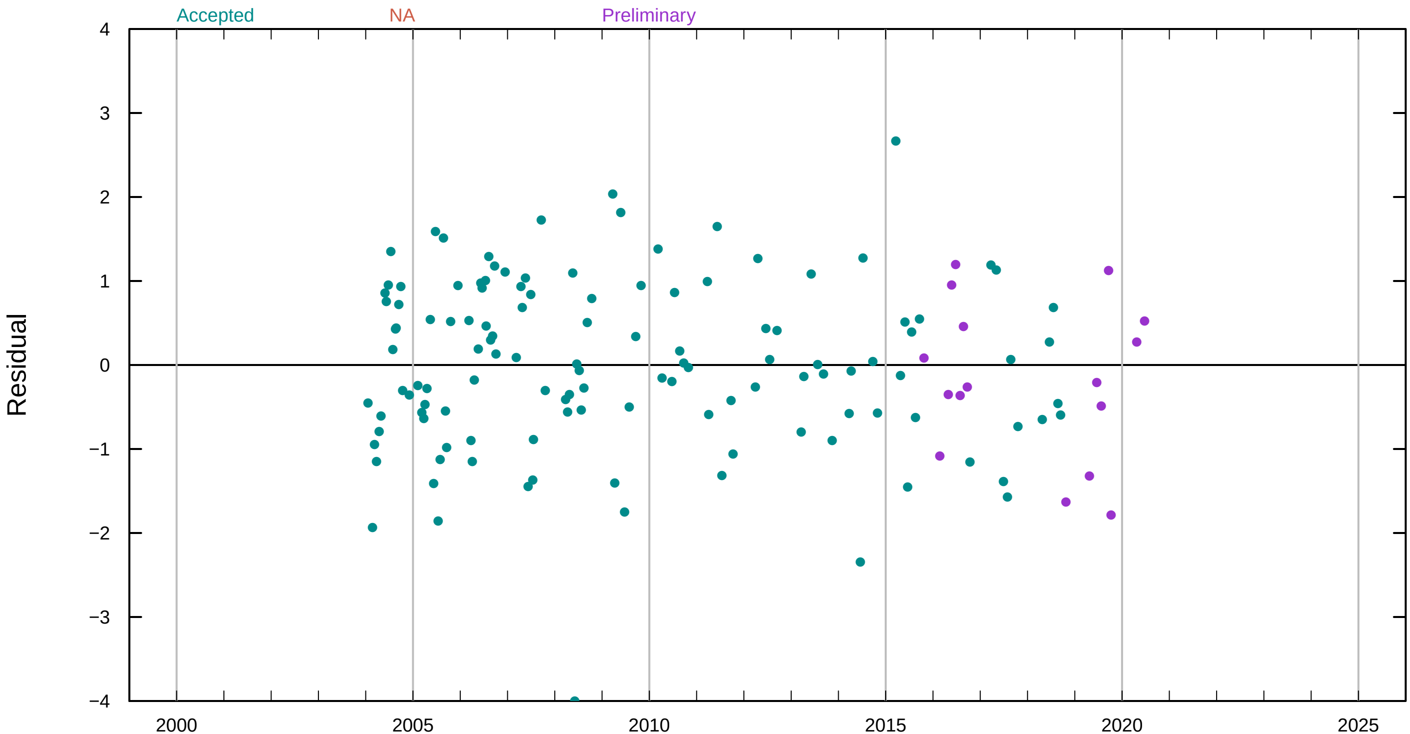


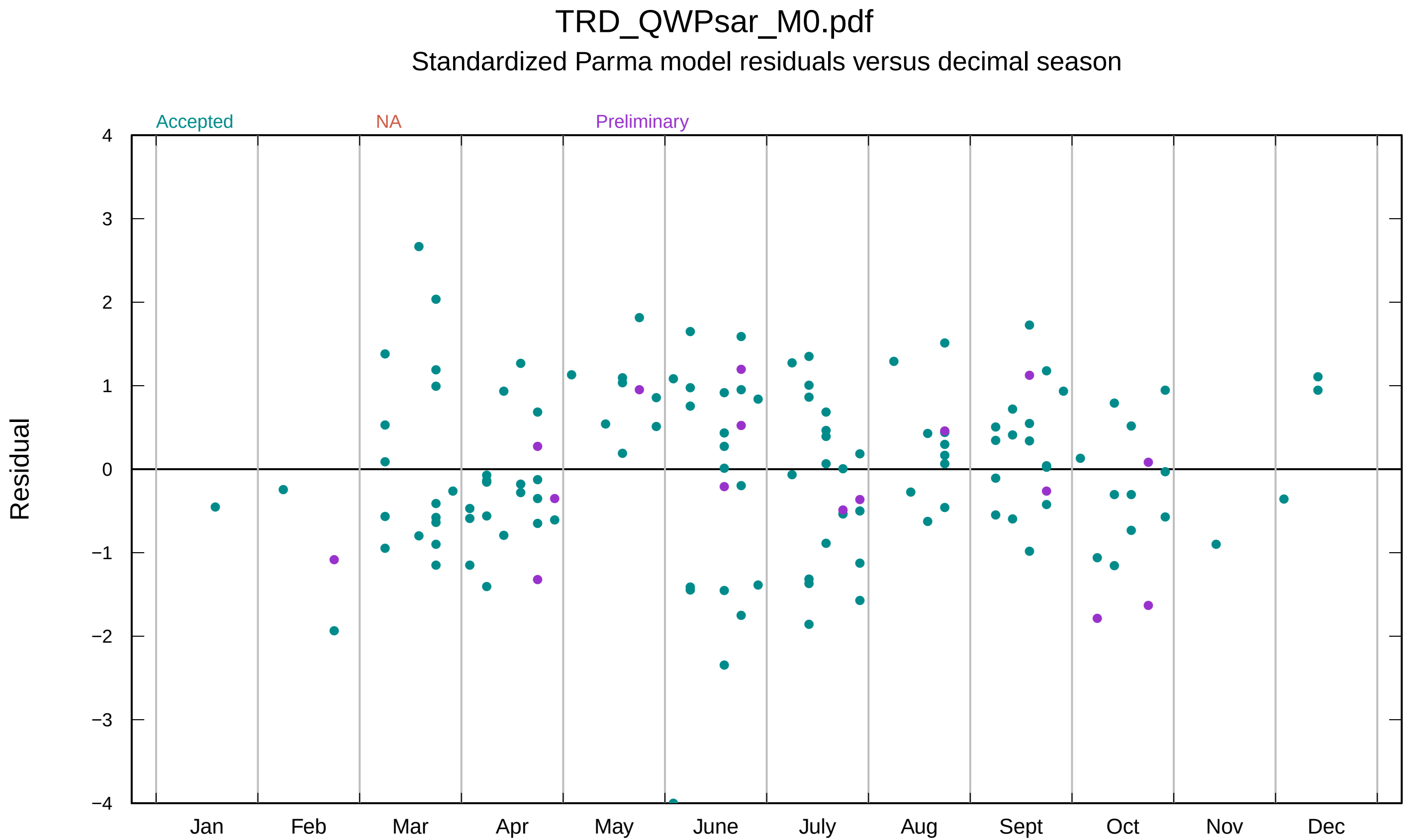


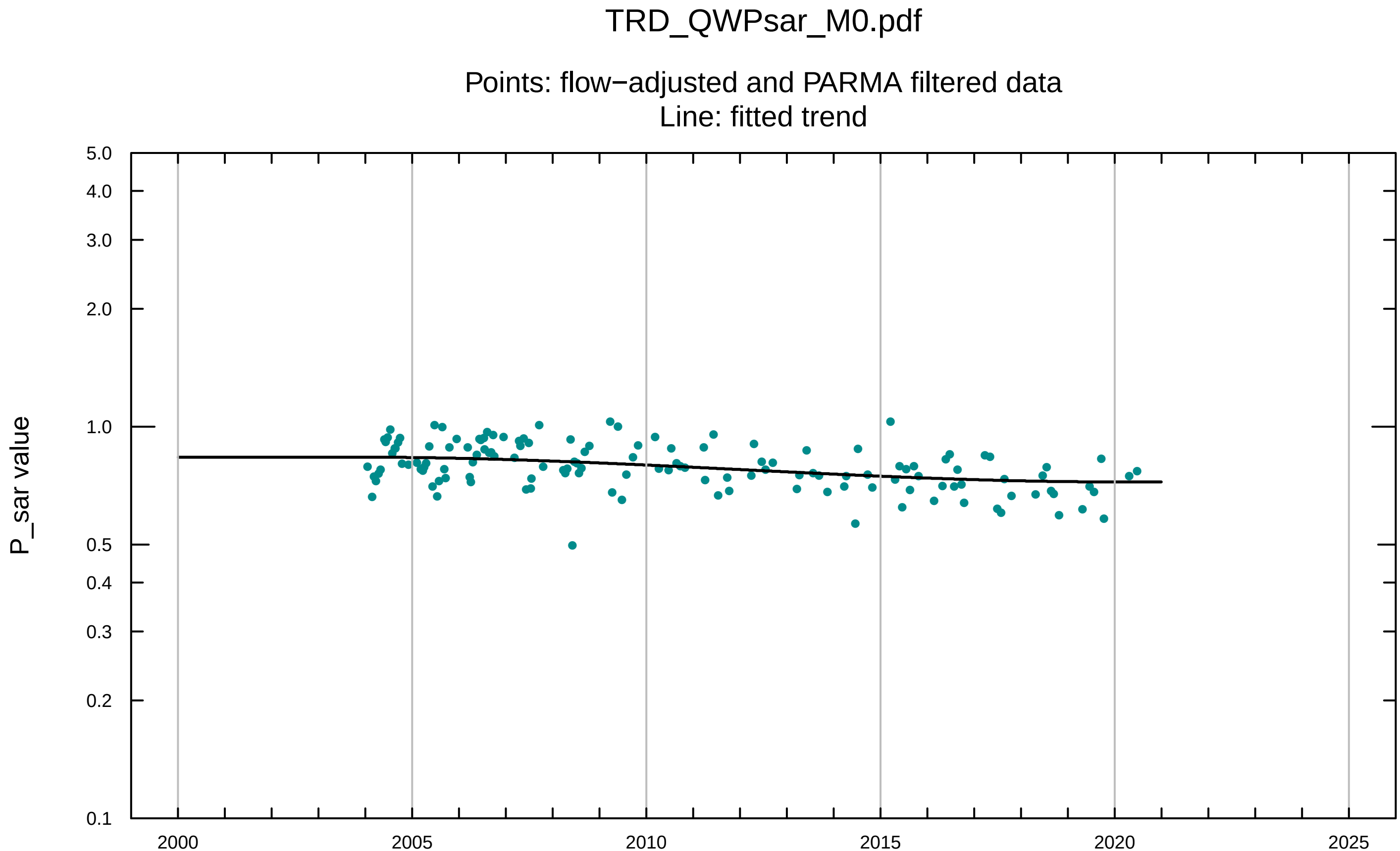
TRD_QWPsar_M0.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
0.2
0
−0.2
−0.4
−0.6
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

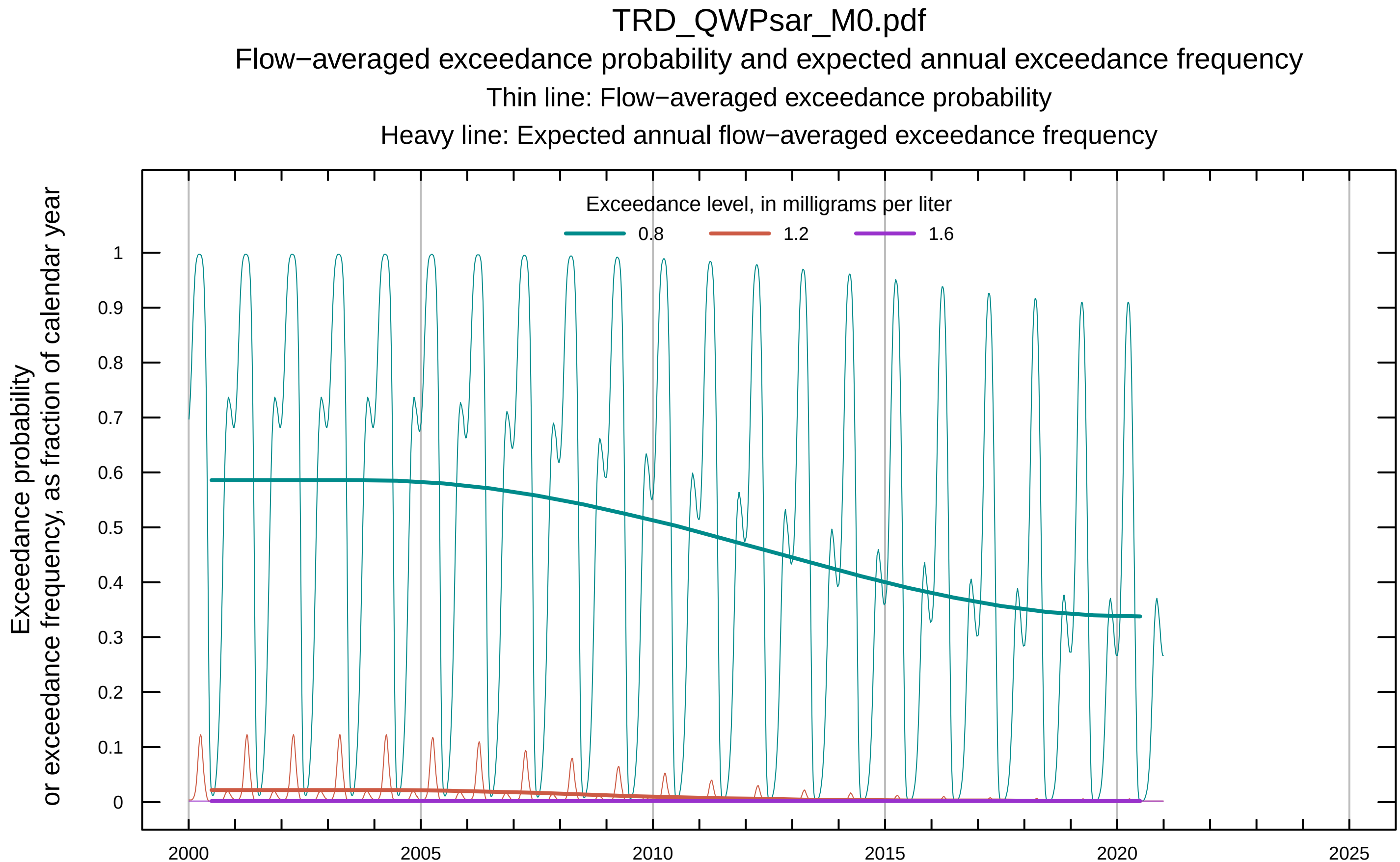
TRD_QWPsar_M0.pdf

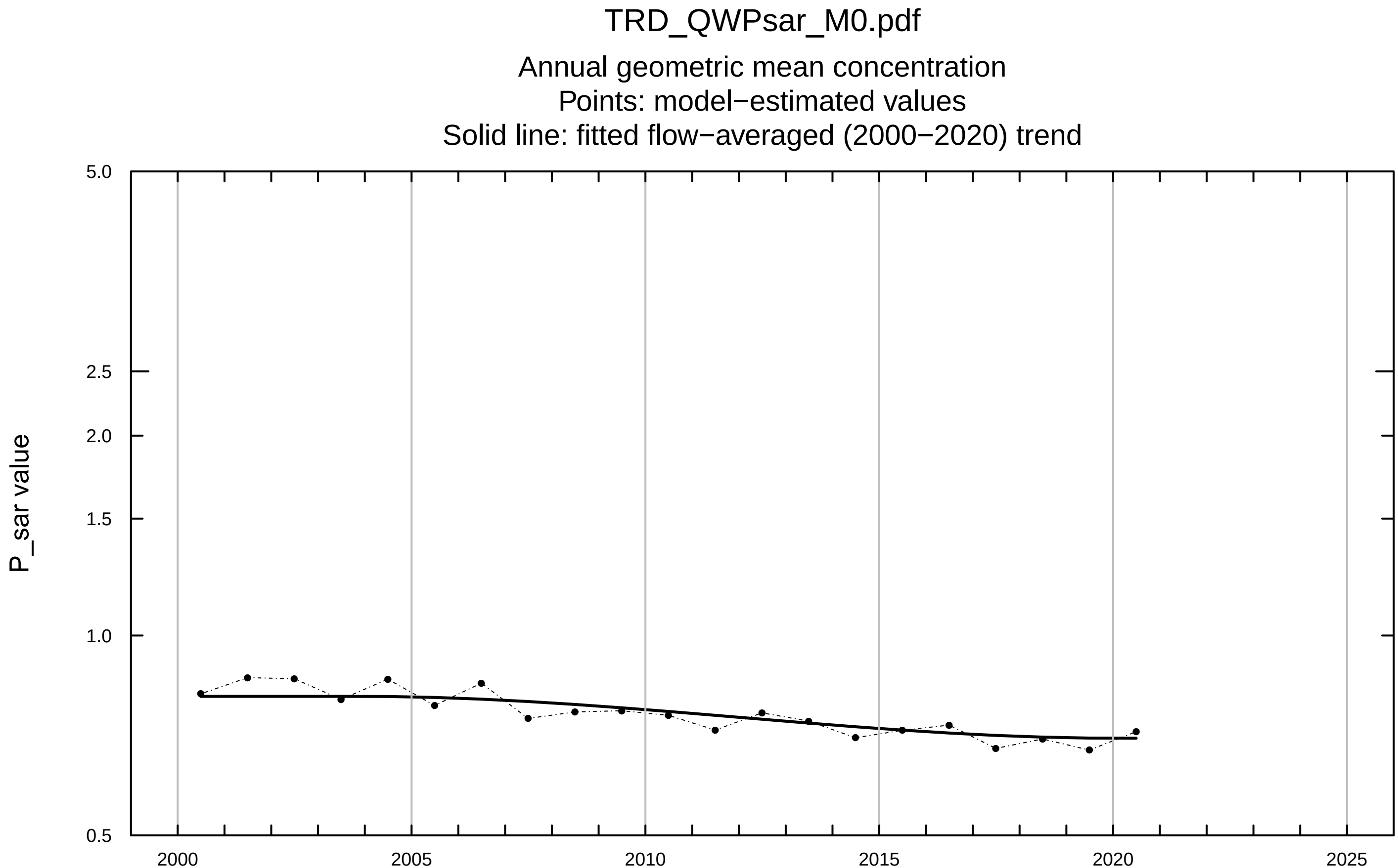
Standardized PARMA model residuals versus decimal year

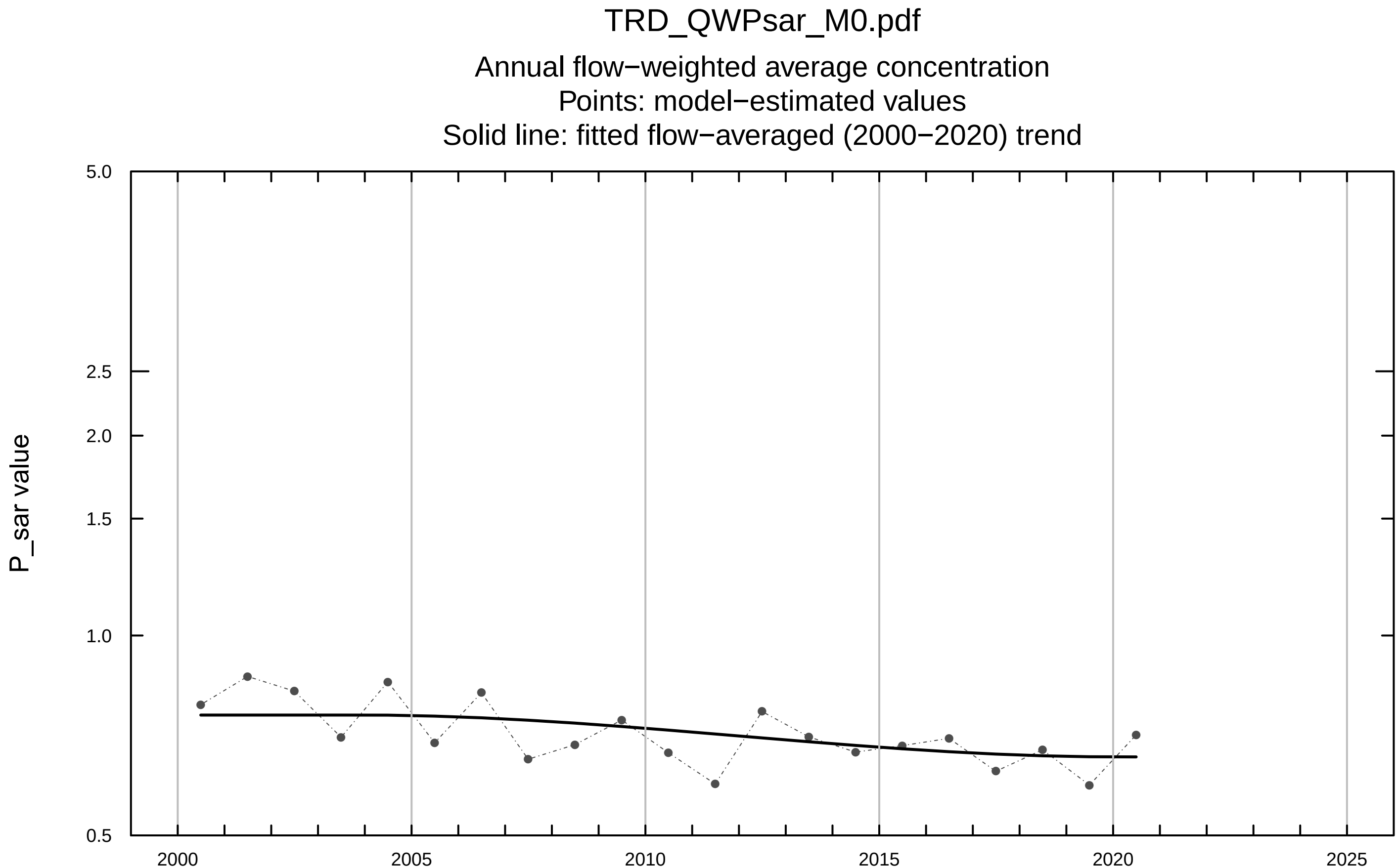



TRD_QWPsar_M0.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

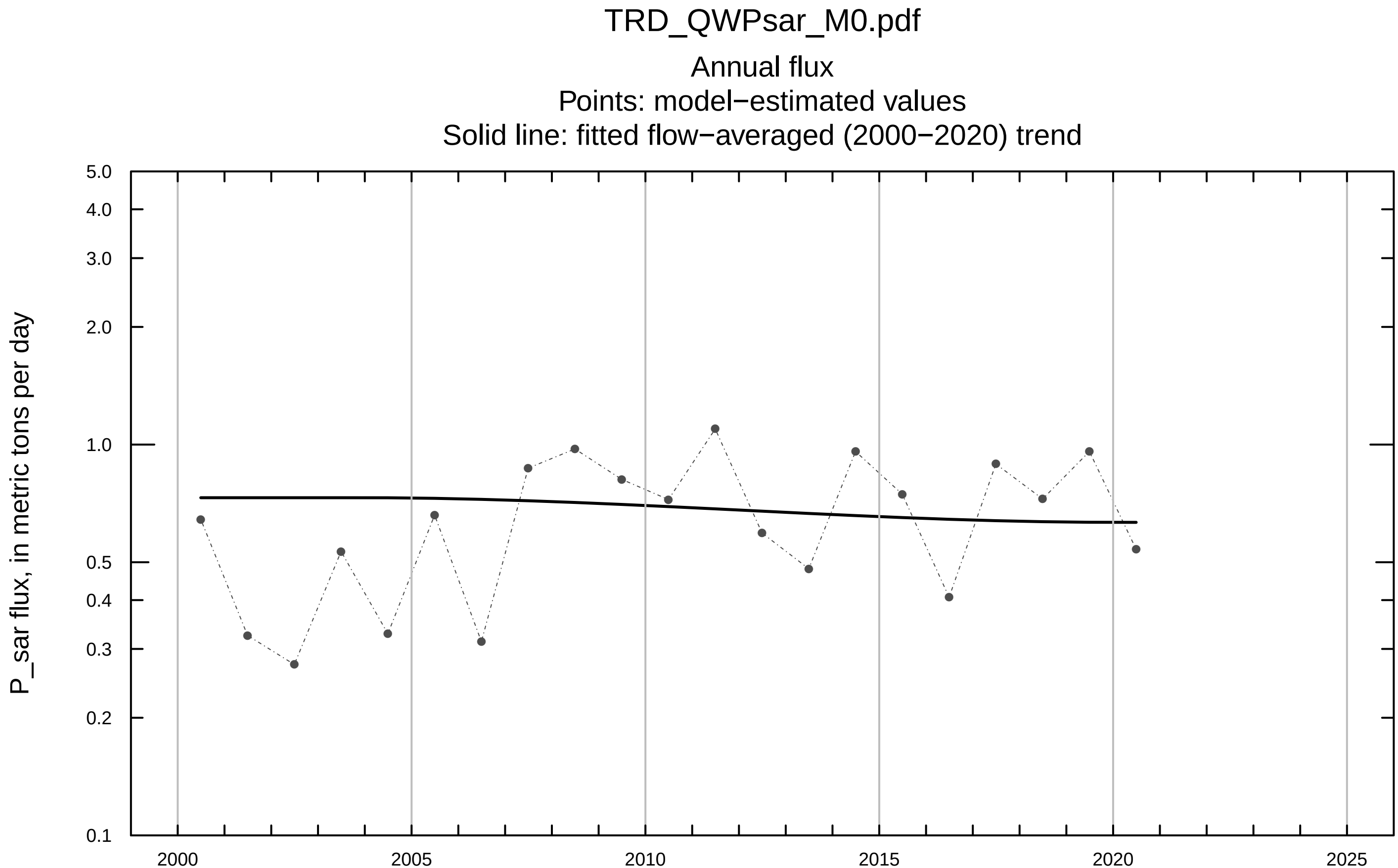

TRD_QWPsar_M0.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025


TRD_QWPsar_M0.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025

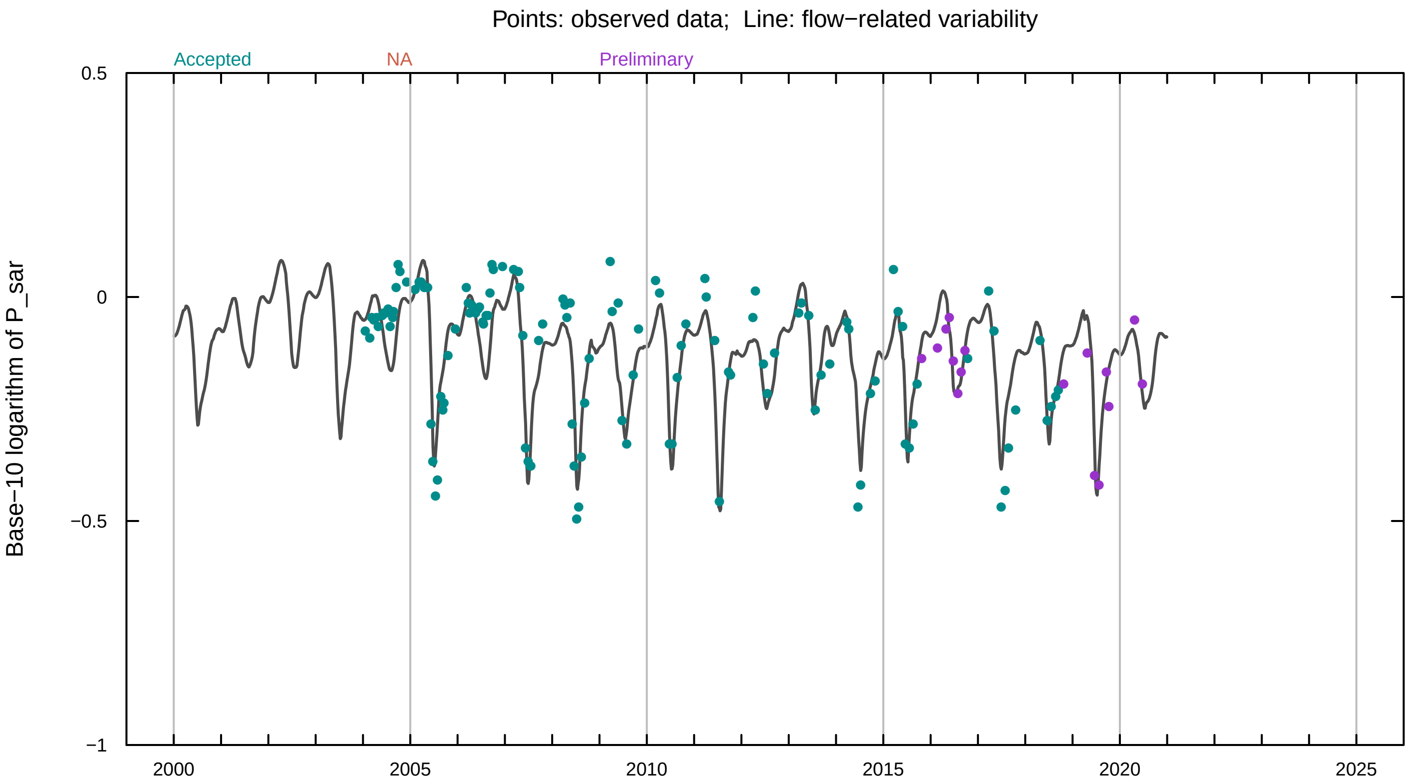

TRD_QWPsar_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025



TRD_QWPsar_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

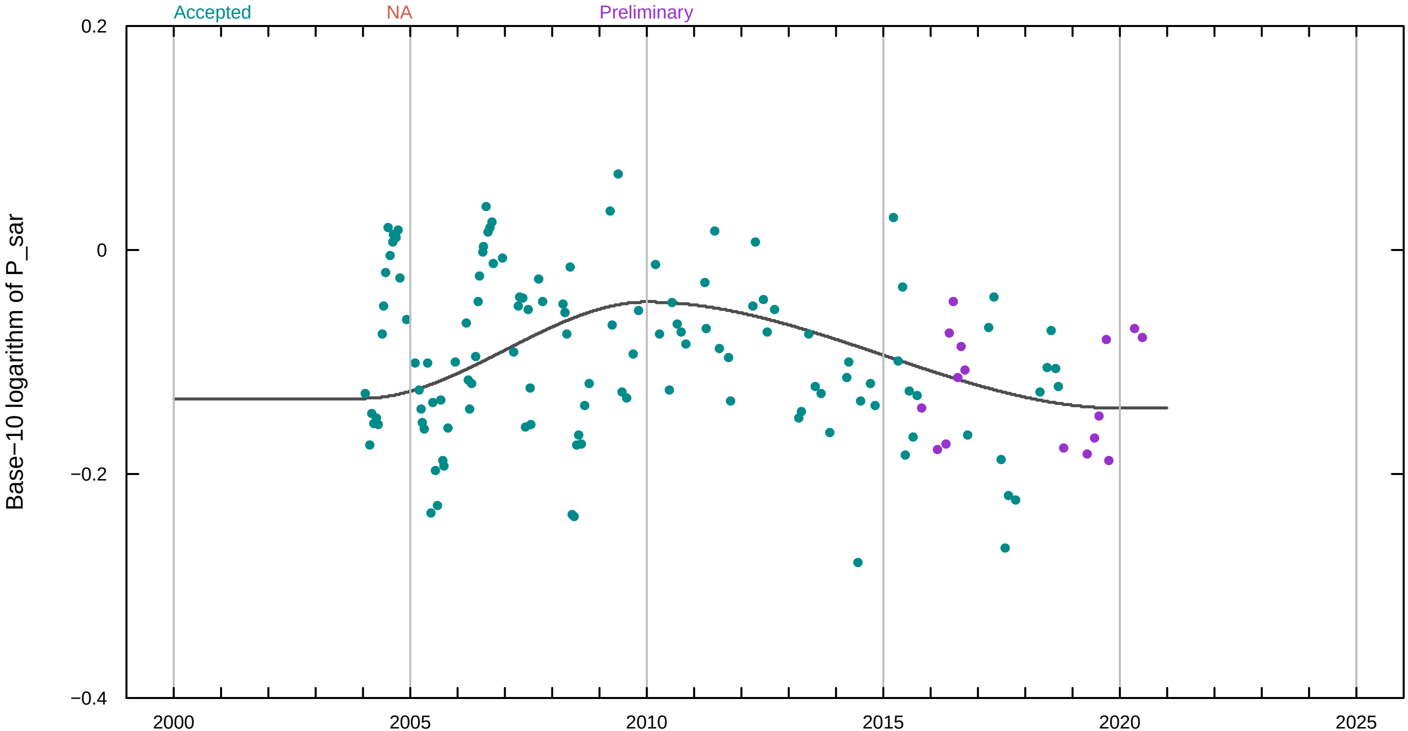

TRD_QWPsar_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

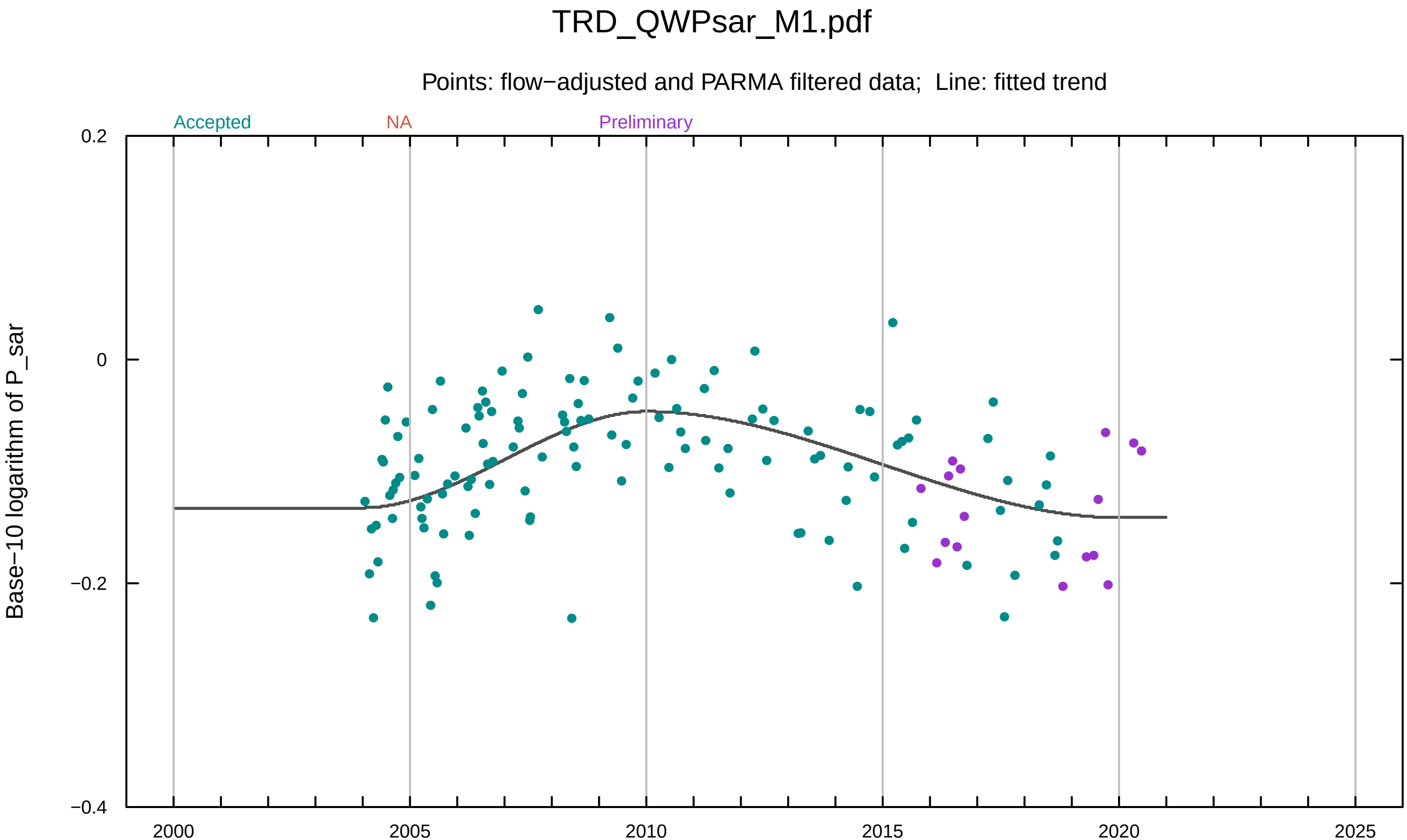
TRD_QWPsar_M1.pdf

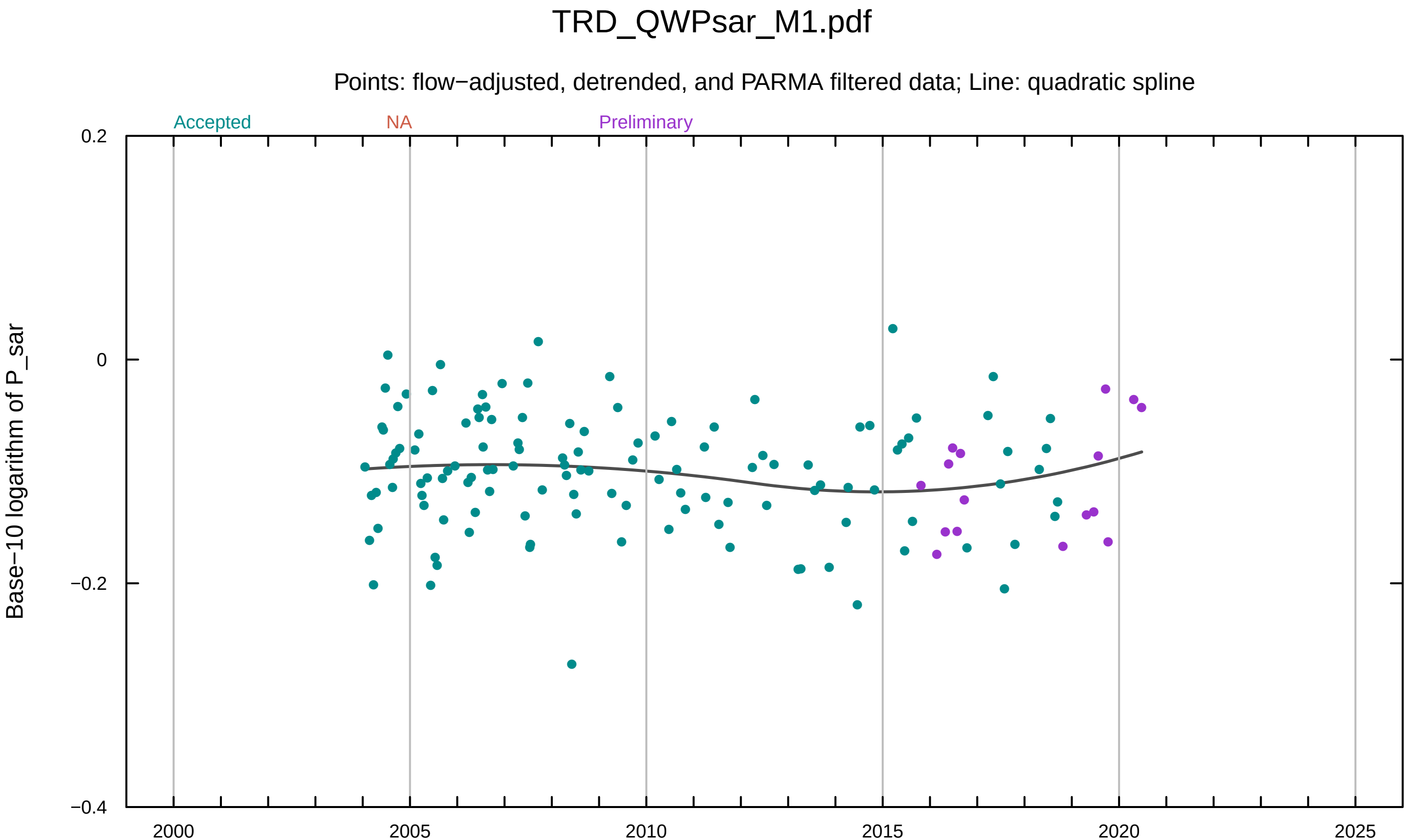


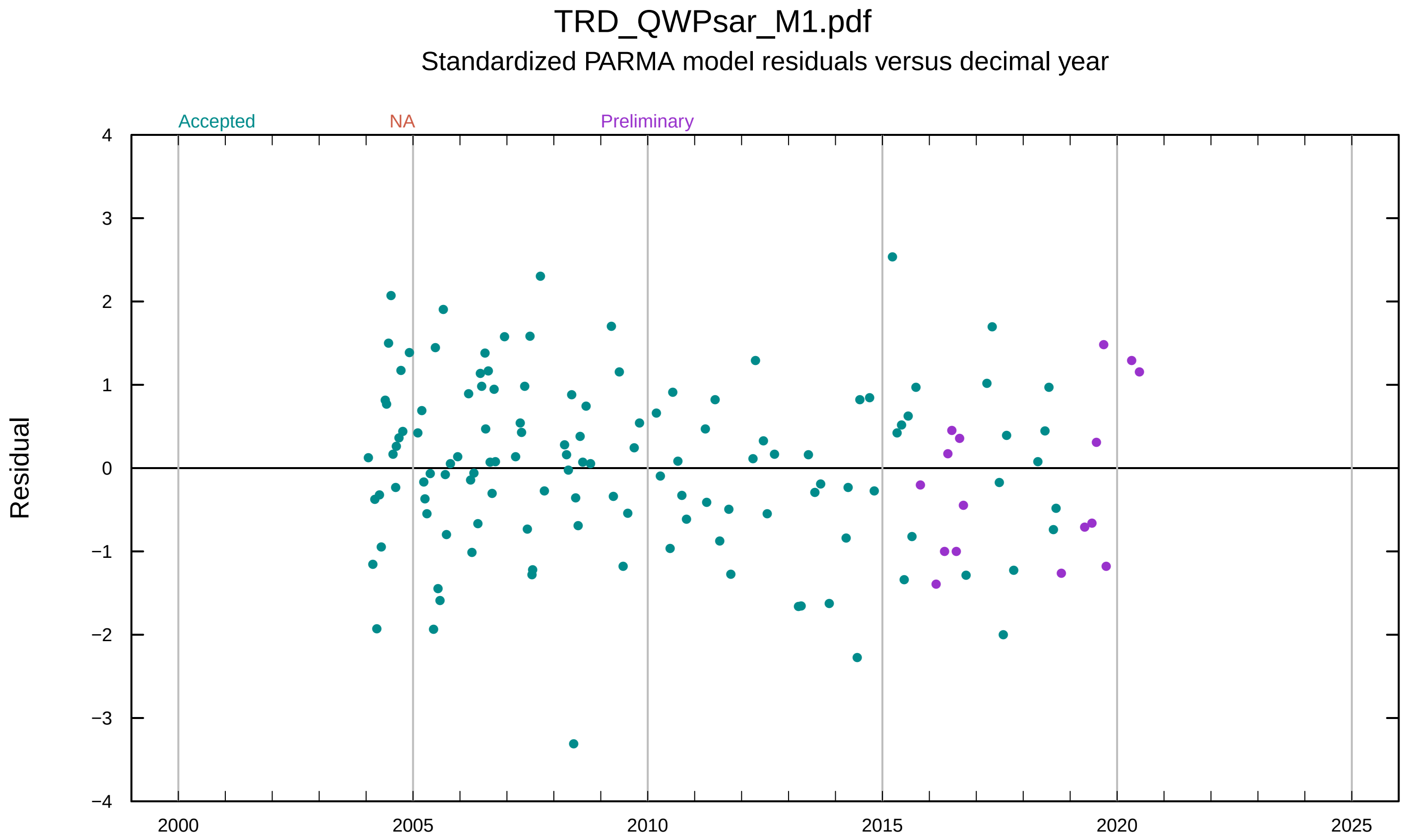
TRD_QWPsar_M1.pdf

Points: flow−adjusted data; Line: fitted trend

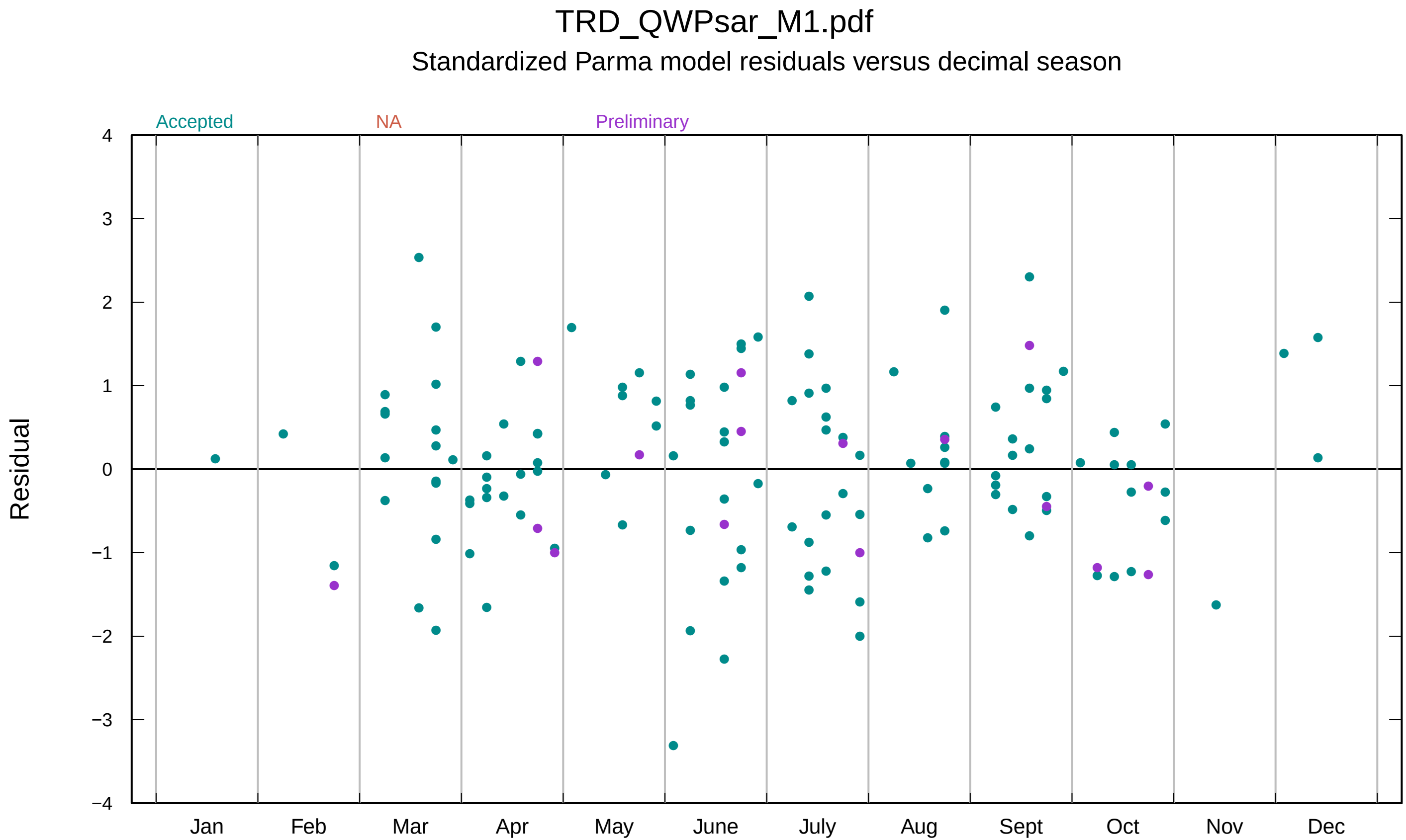


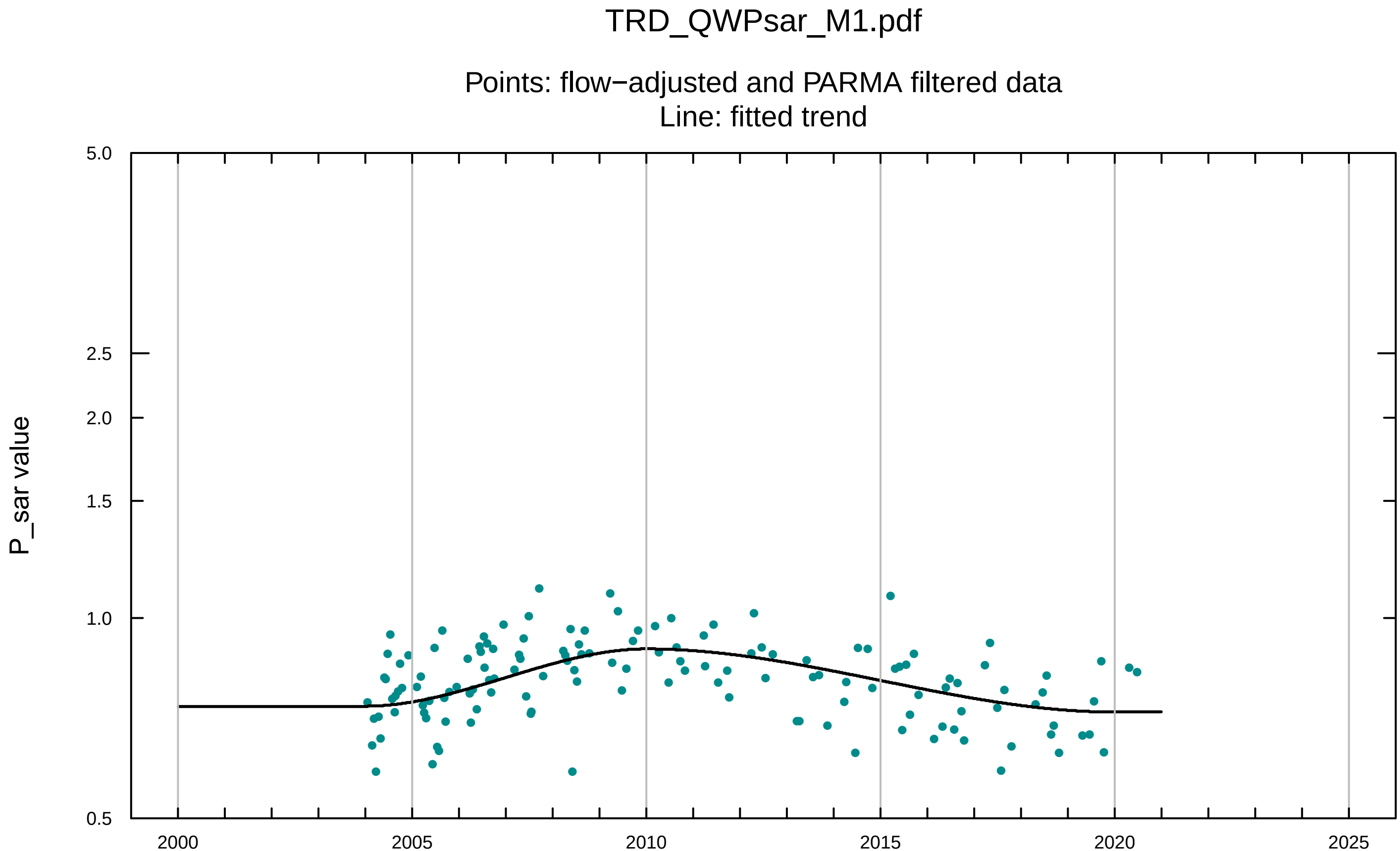

TRD_QWPsar_M1.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

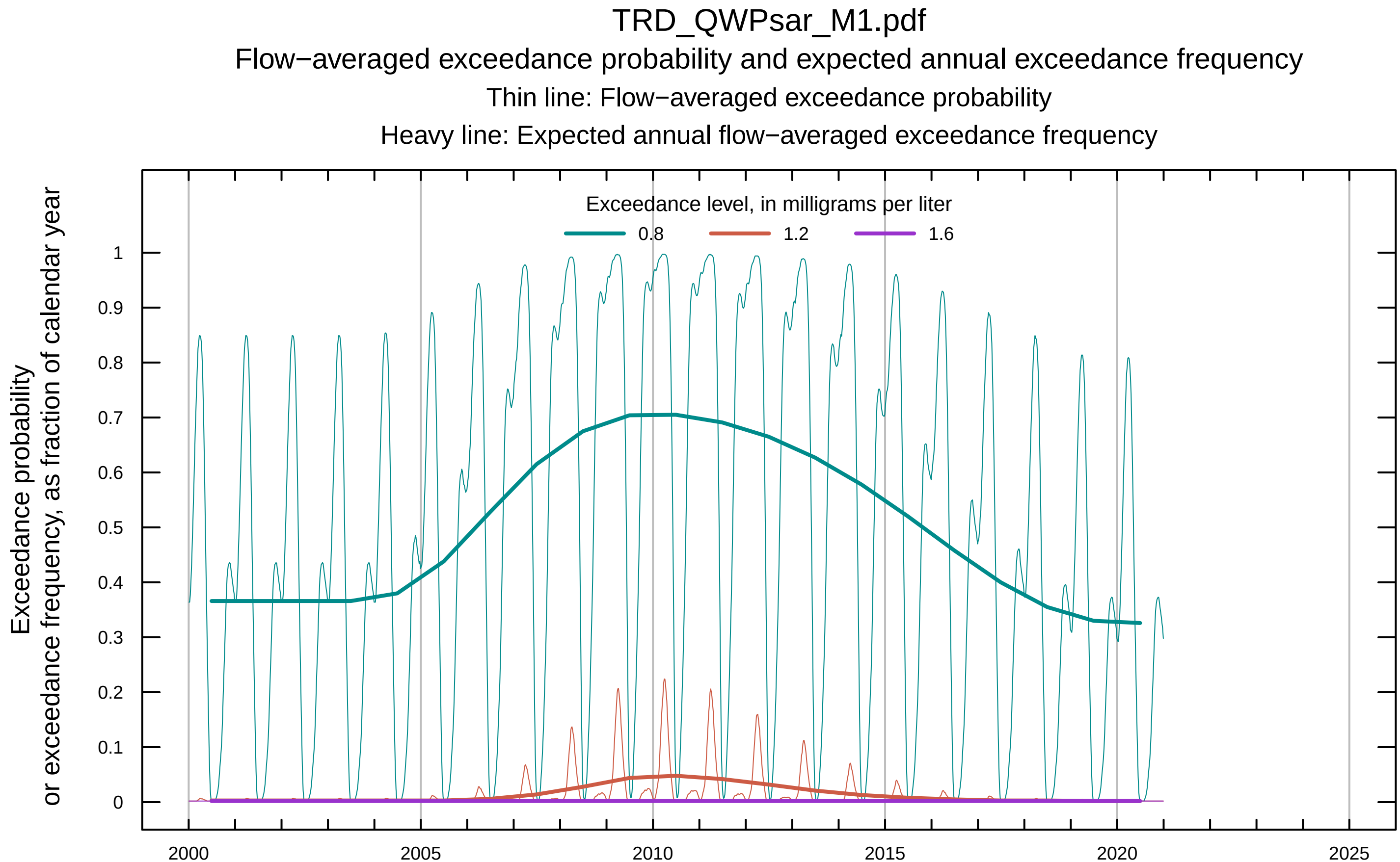

TRD_QWPsar_M1.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025



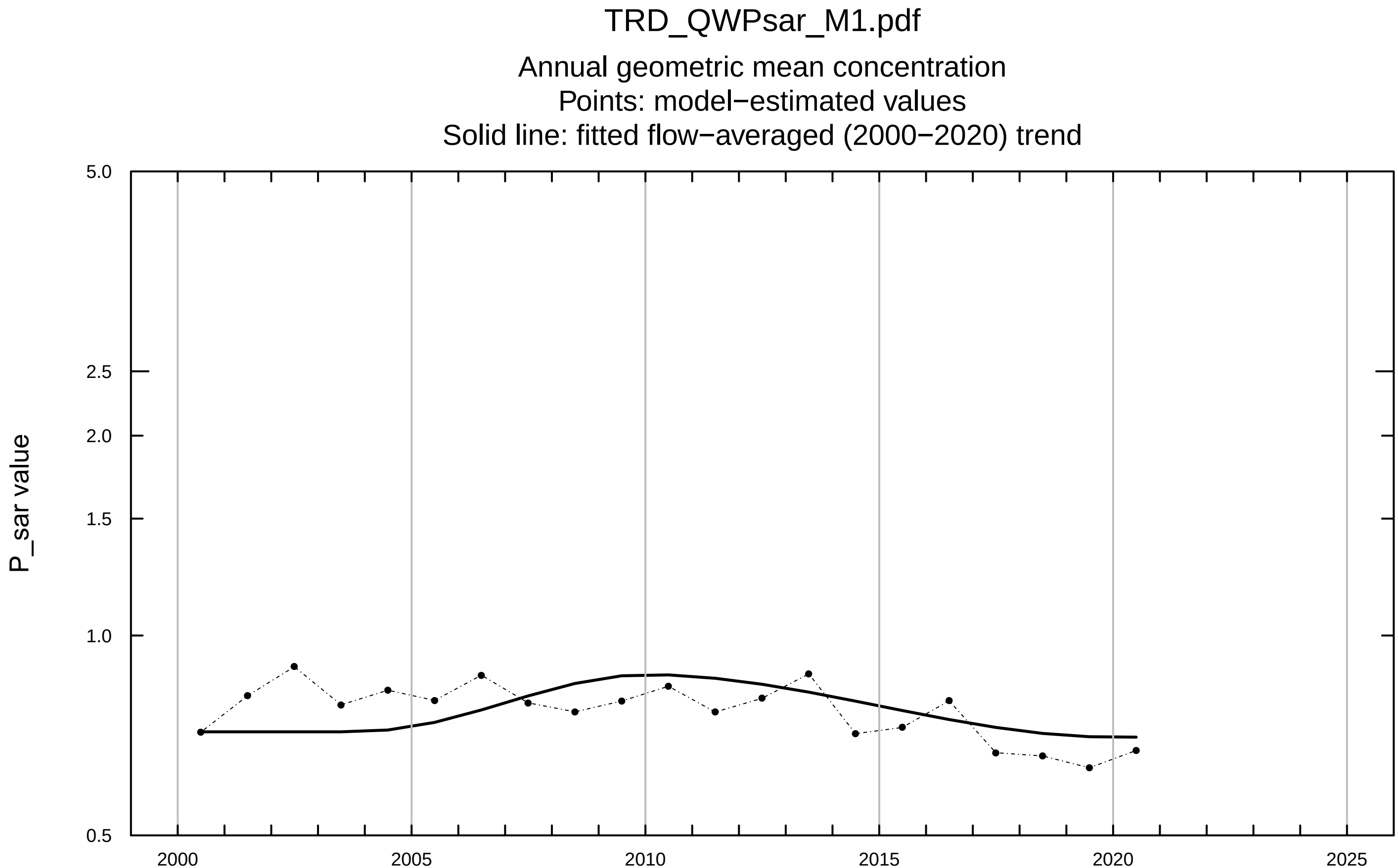
TRD_QWPsar_M1.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025

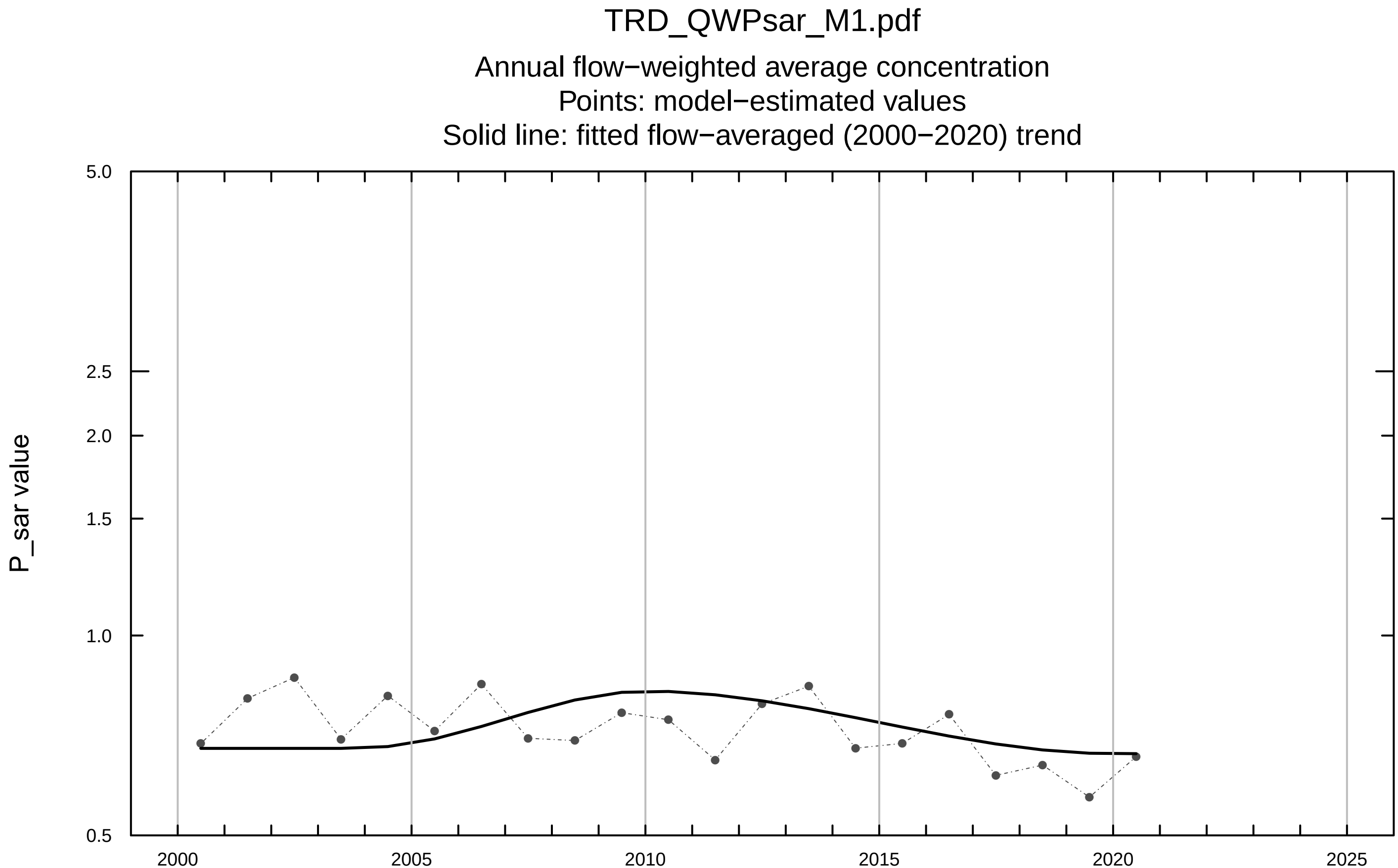

TRD_QWPsar_M1.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec


TRD_QWPsar_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

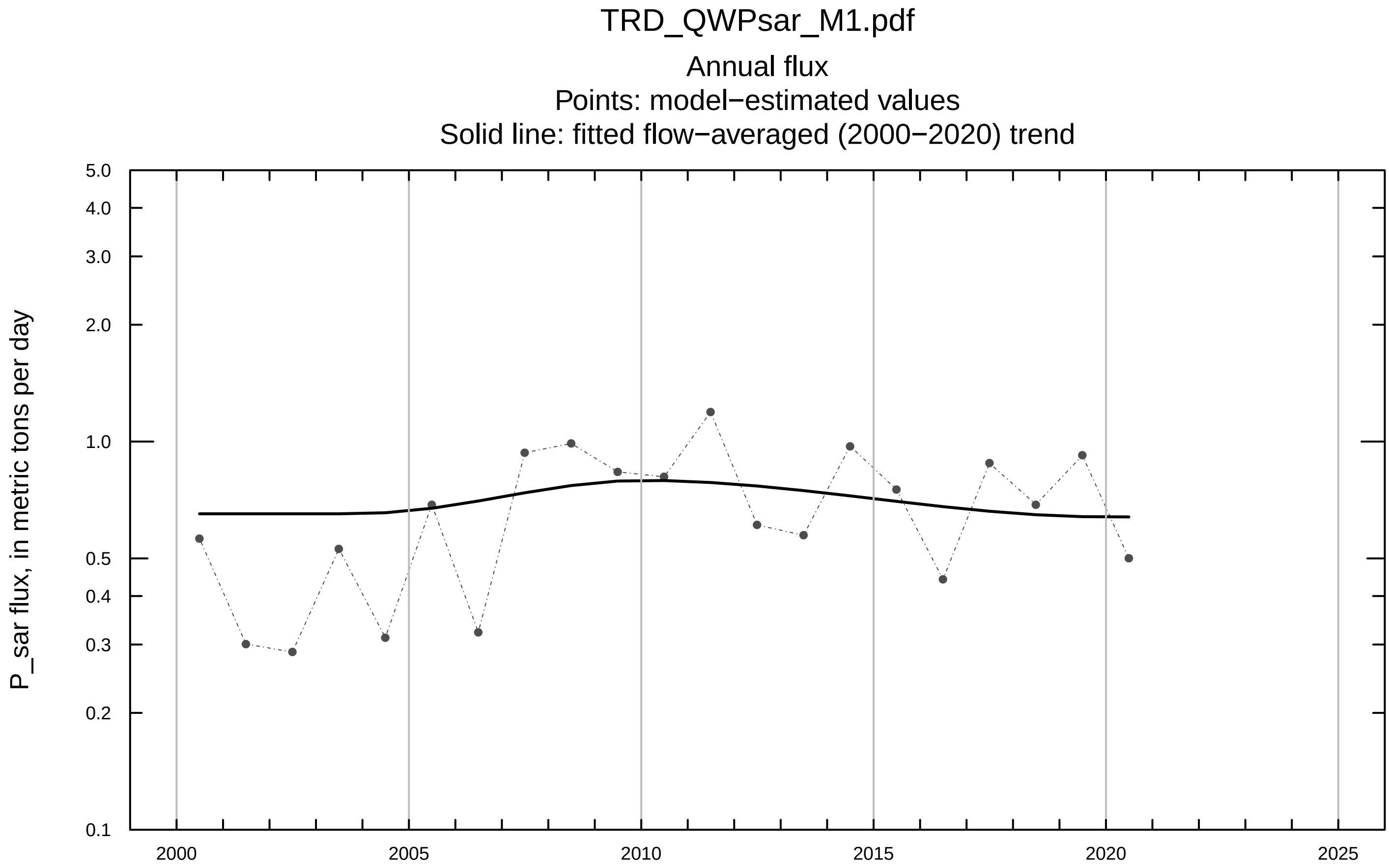


TRD_QWPsar_M1.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
0.8
1.2
1.6
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025

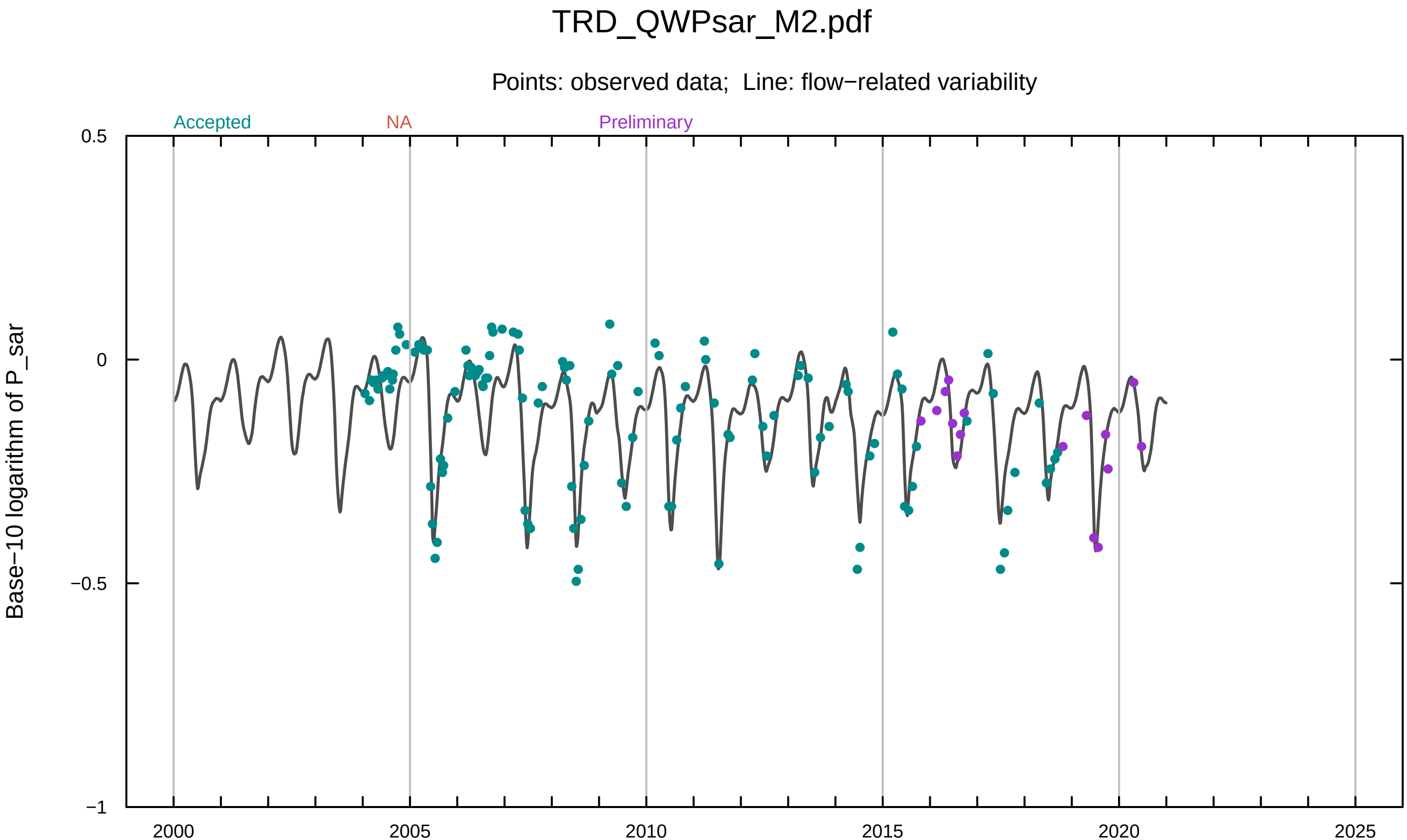

TRD_QWPsar_M1.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025



TRD_QWPsar_M1.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025



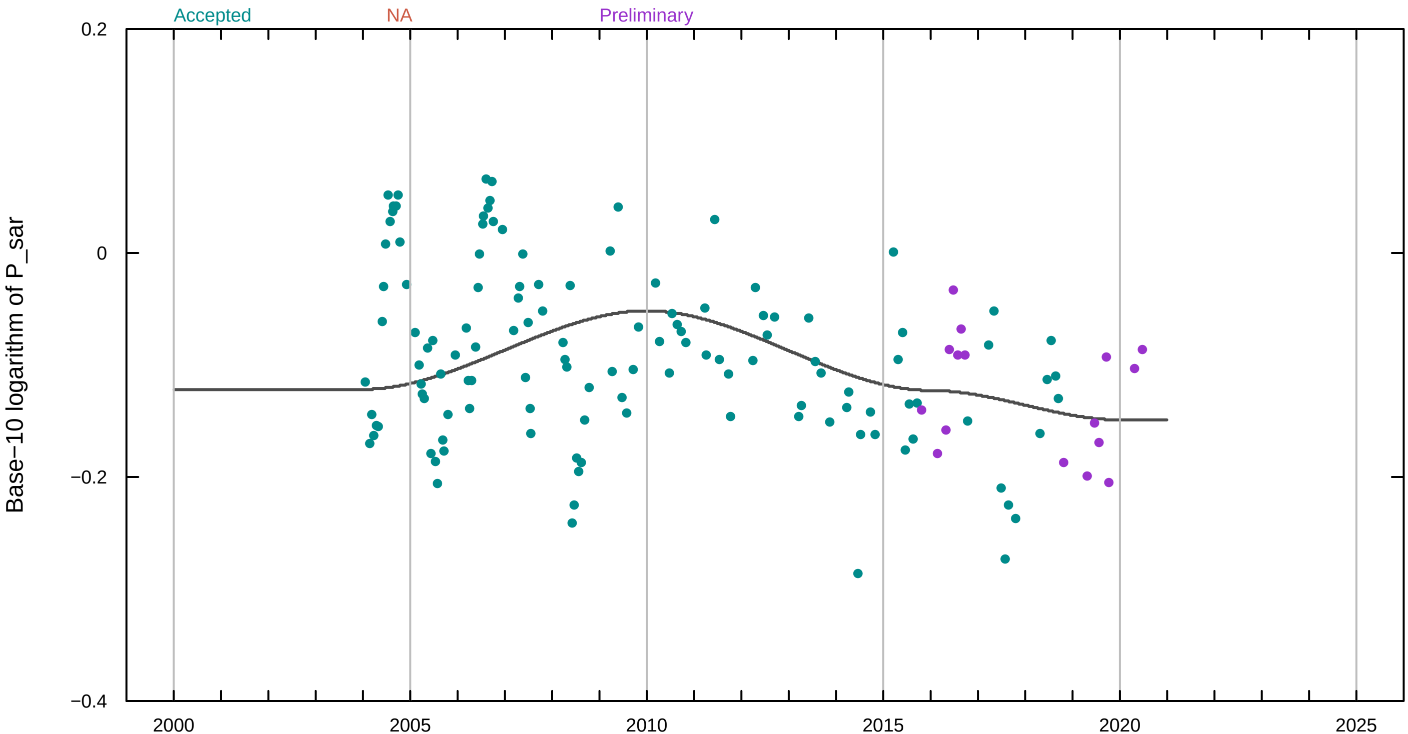
TRD_QWPsar_M1.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

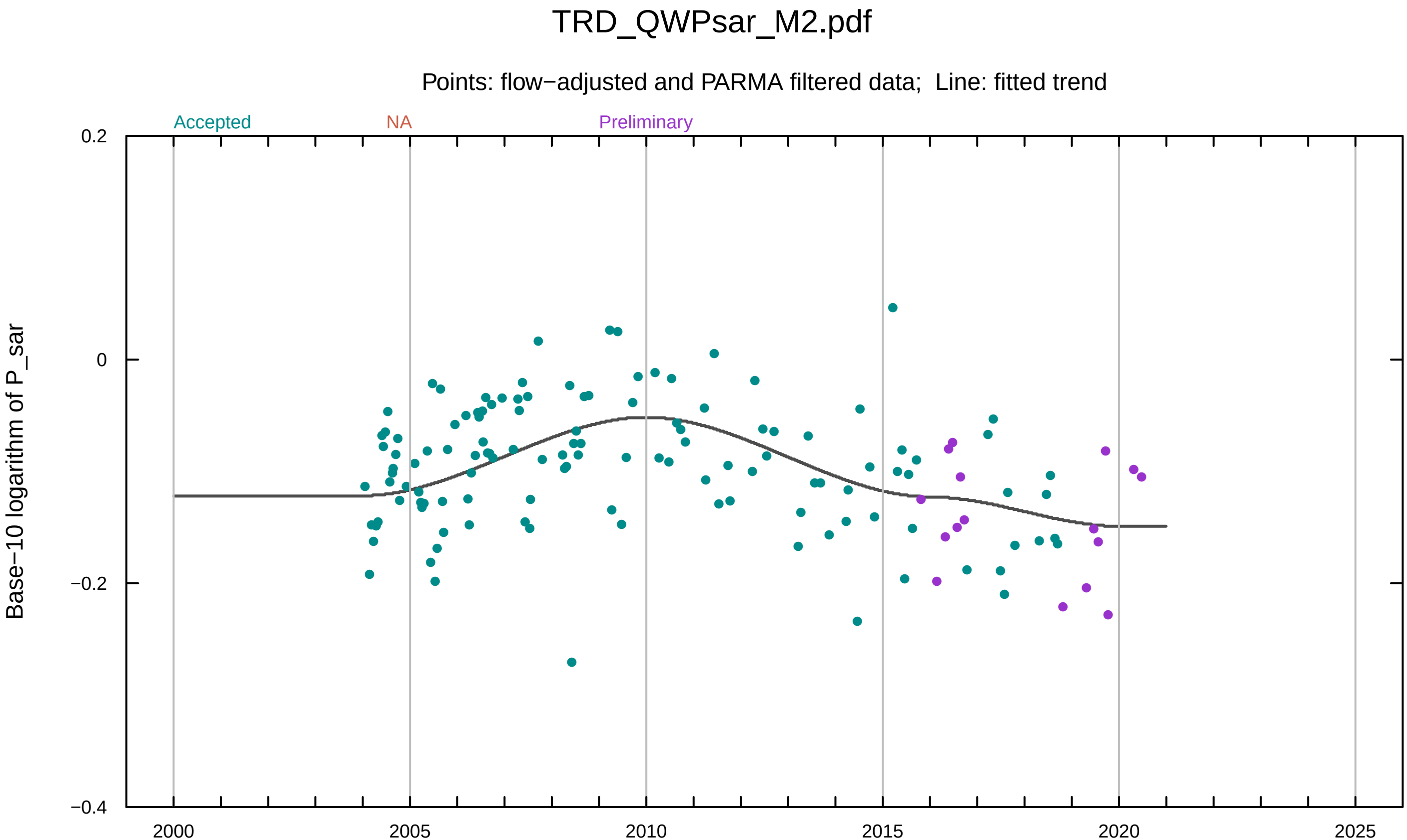


TRD_QWPsar_M2.pdf
Points: observed data; Line: flow−related variability
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.5
0
−0.5
−1
2000
2005
2010
2015
2020
2025

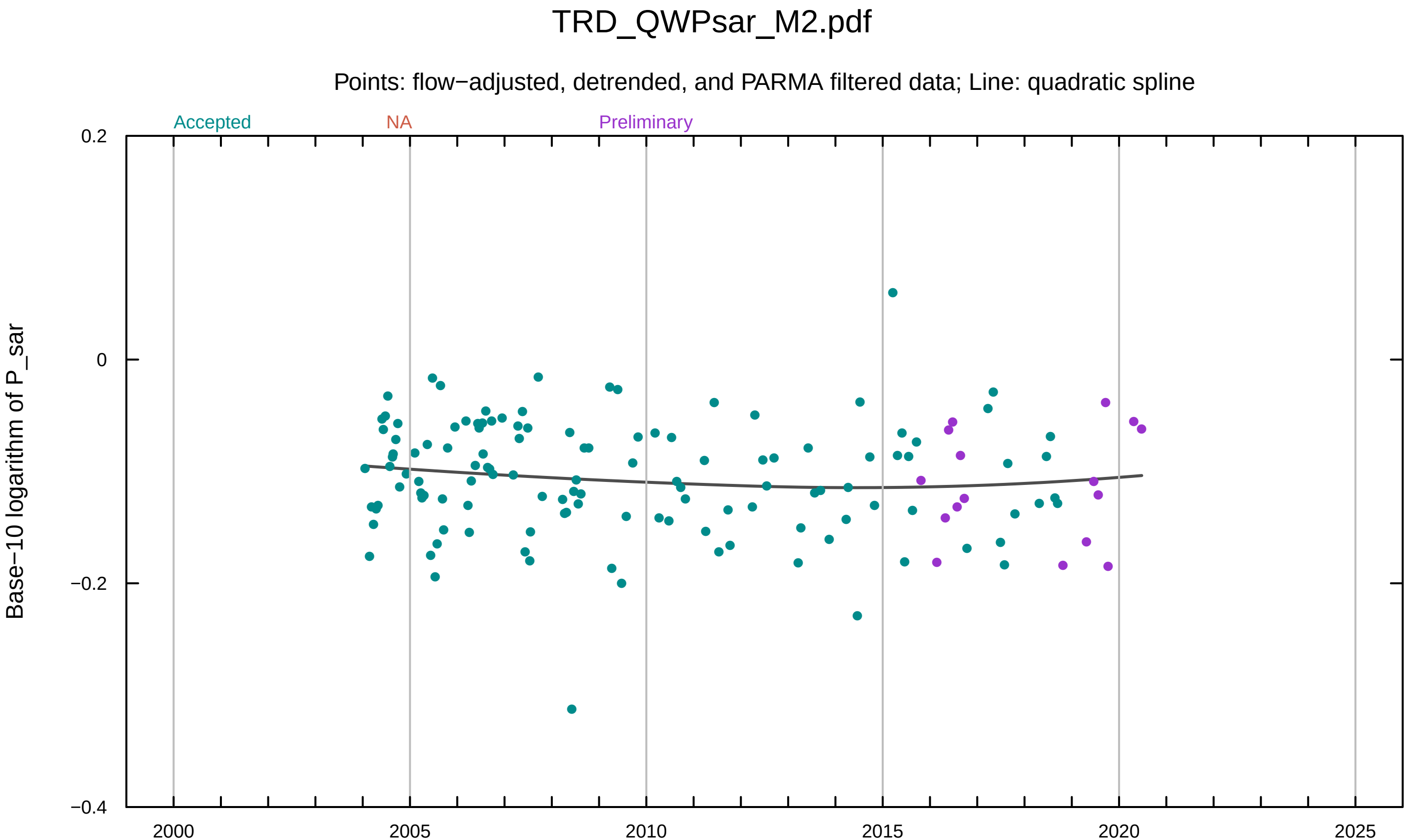
TRD_QWPsar_M2.pdf

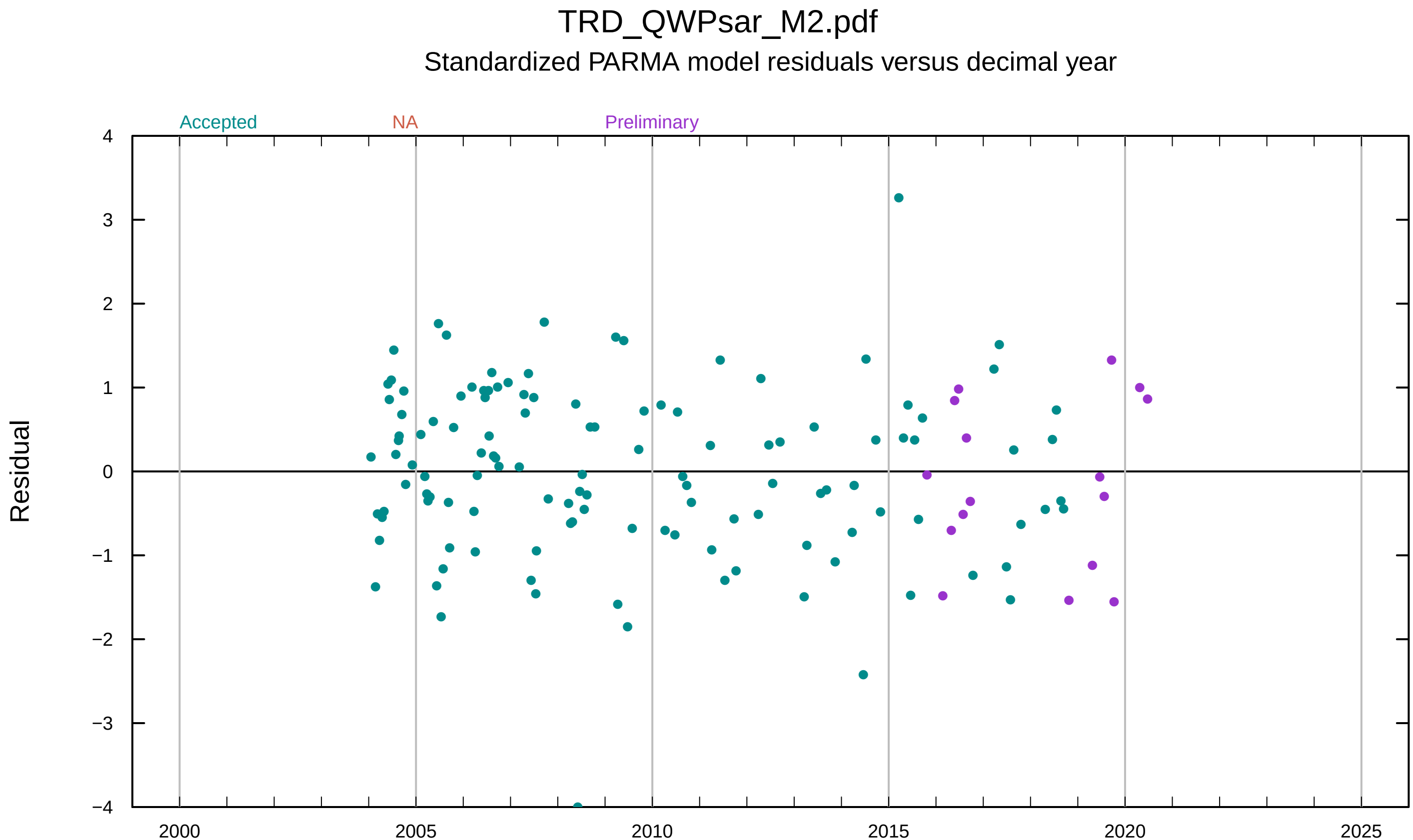
Points: flow−adjusted data; Line: fitted trend

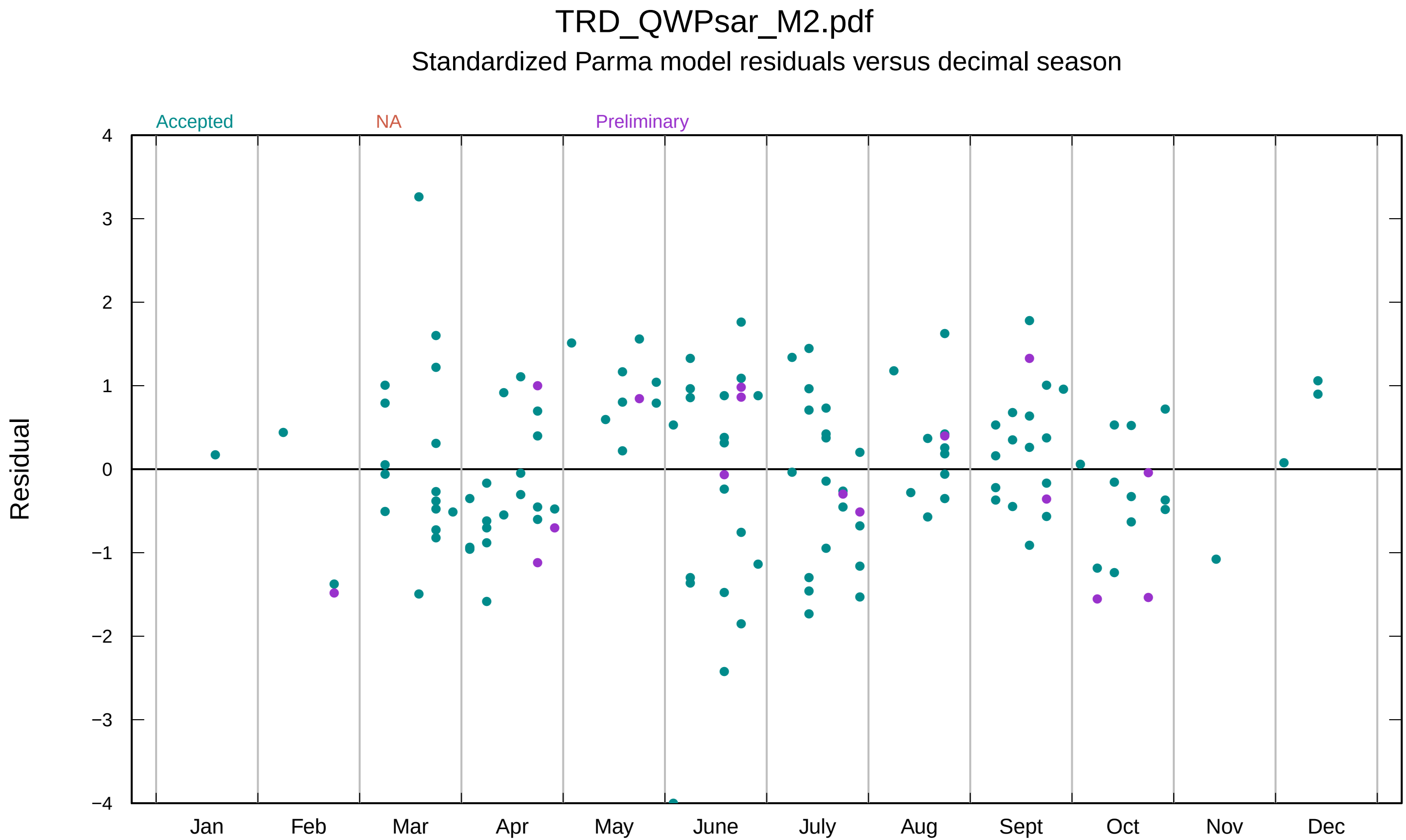




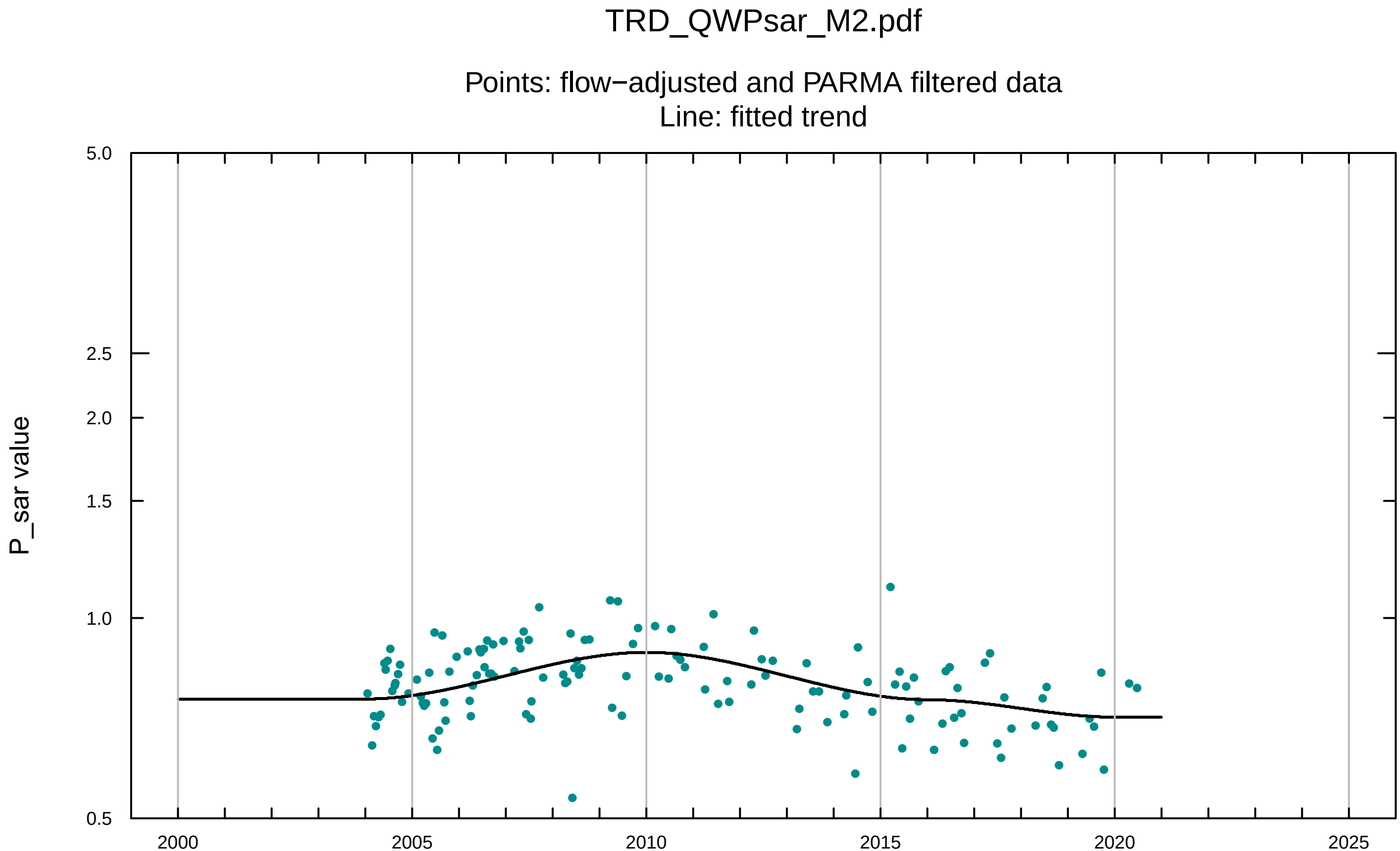
TRD_QWPsar_M2.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020
2025


TRD_QWPsar_M2.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020
2025


TRD_QWPsar_M2.pdf
Standardized PARMA model residuals versus decimal year
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025



TRD_QWPsar_M2.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
4
3
2
1
0
−1
−2
−3
−4
Residual
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

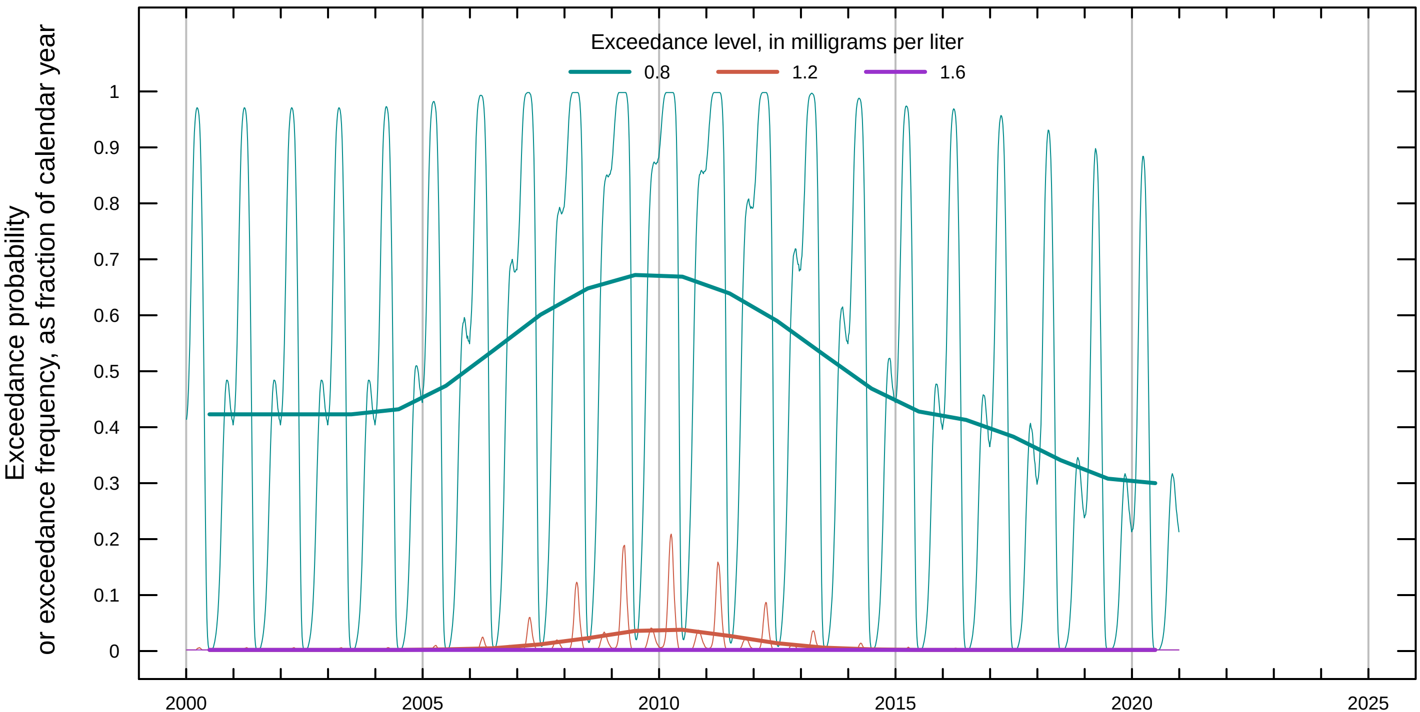

TRD_QWPsar_M2.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

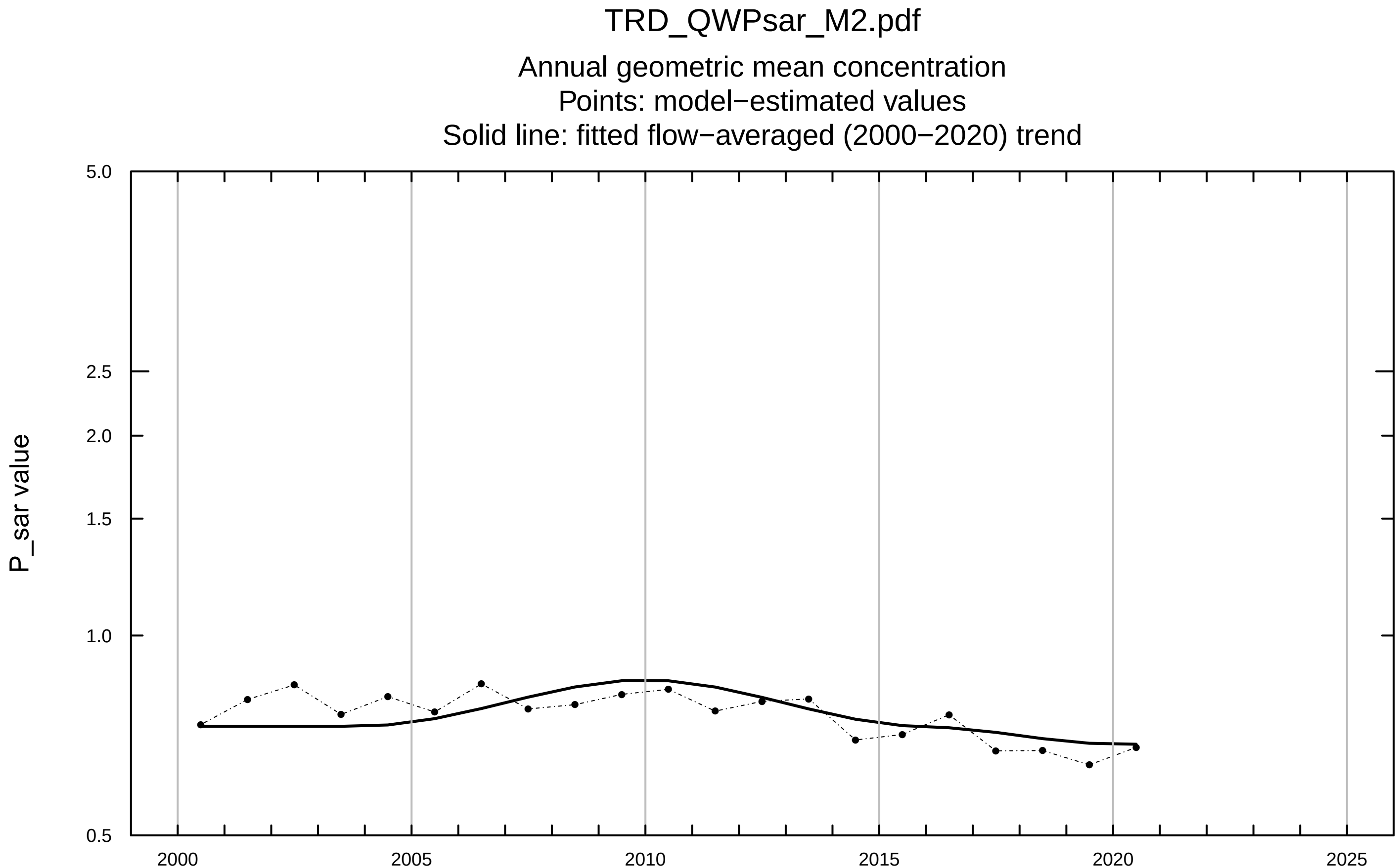
TRD_QWPsar_M2.pdf

Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

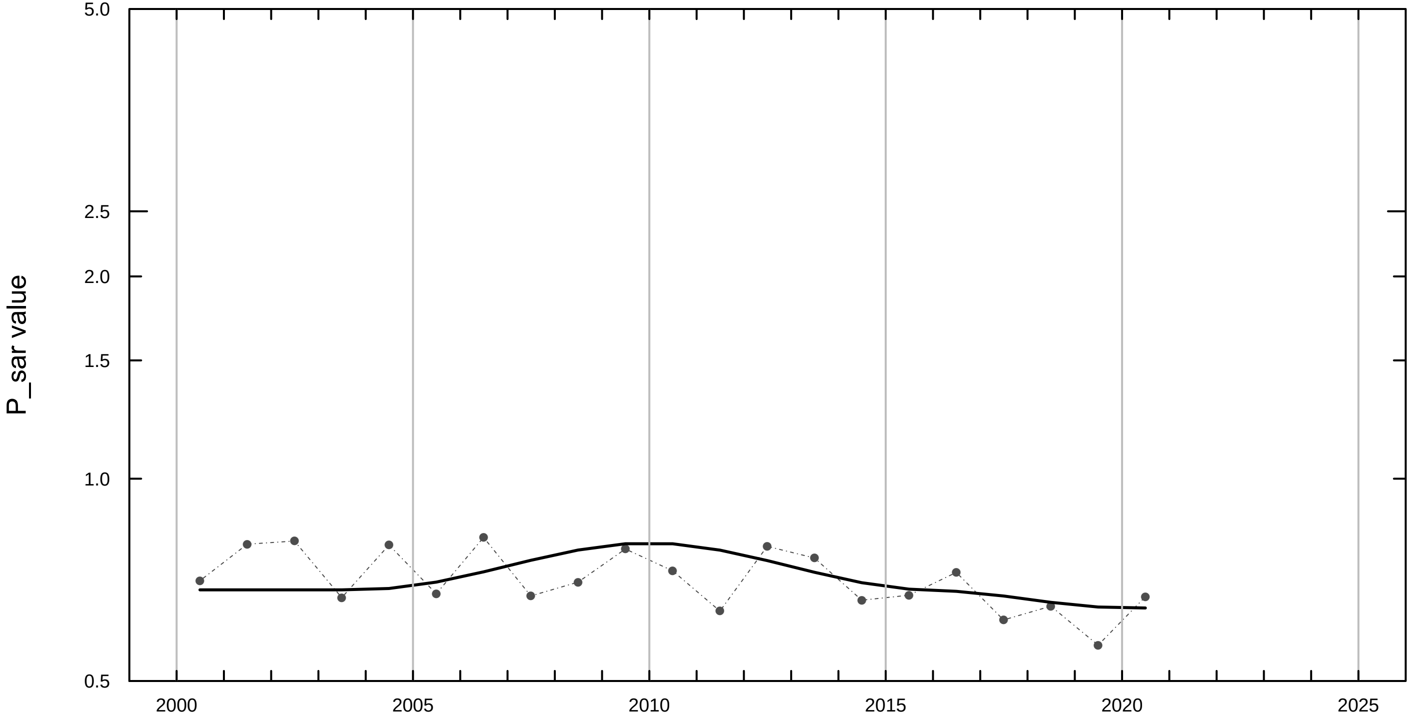
Heavy line: Expected annual flow−averaged exceedance frequency

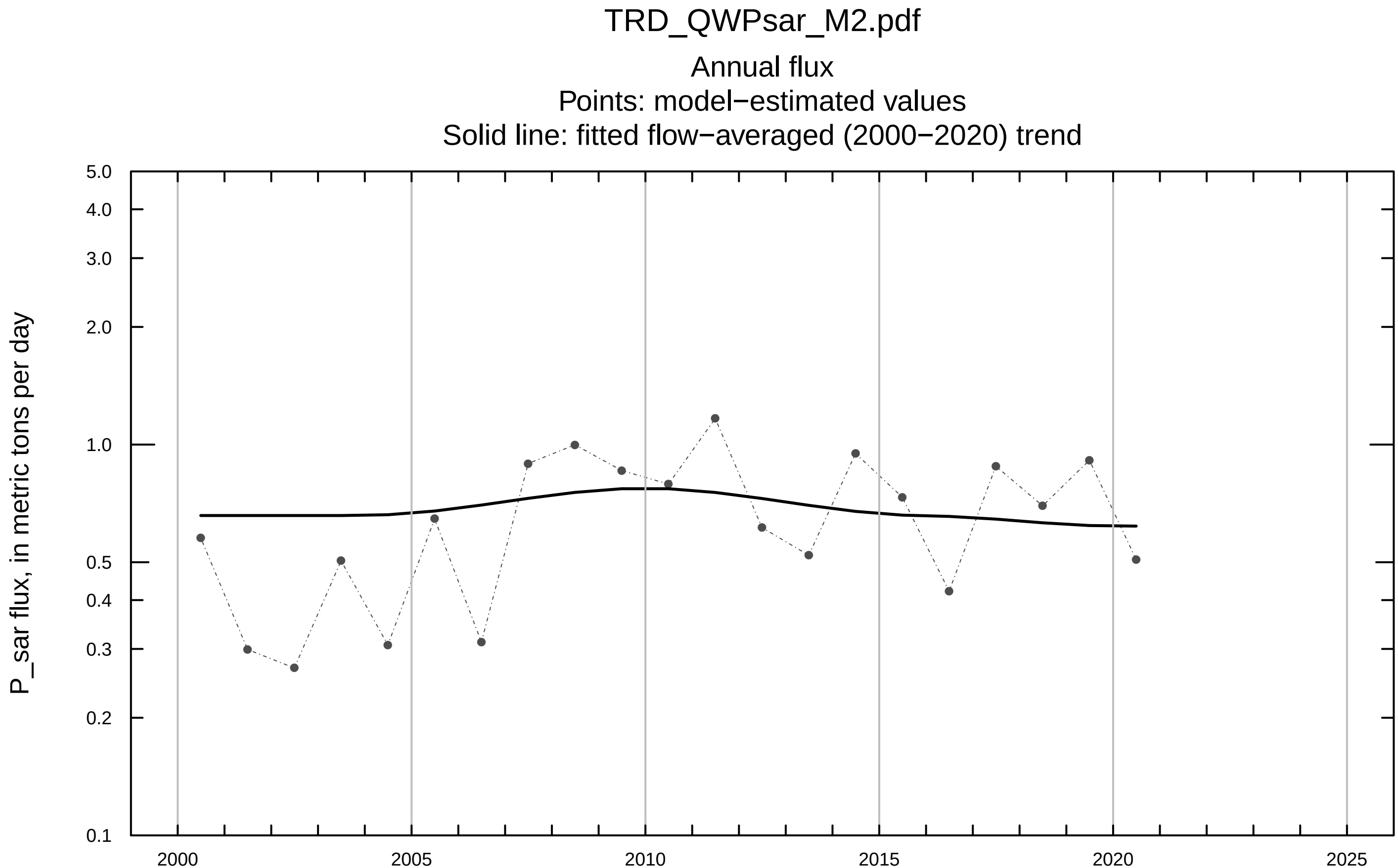



TRD_QWPsar_M2.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

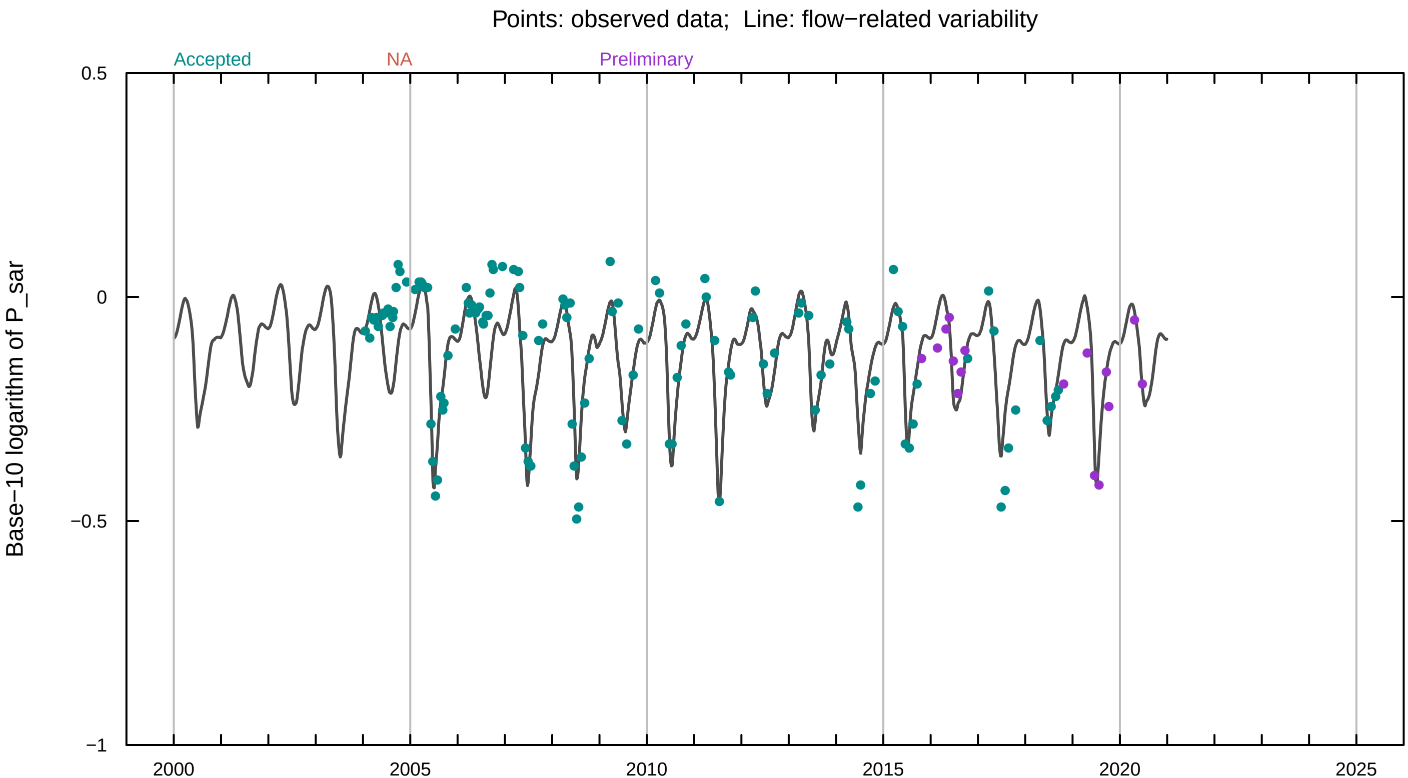
TRD_QWPsar_M2.pdf

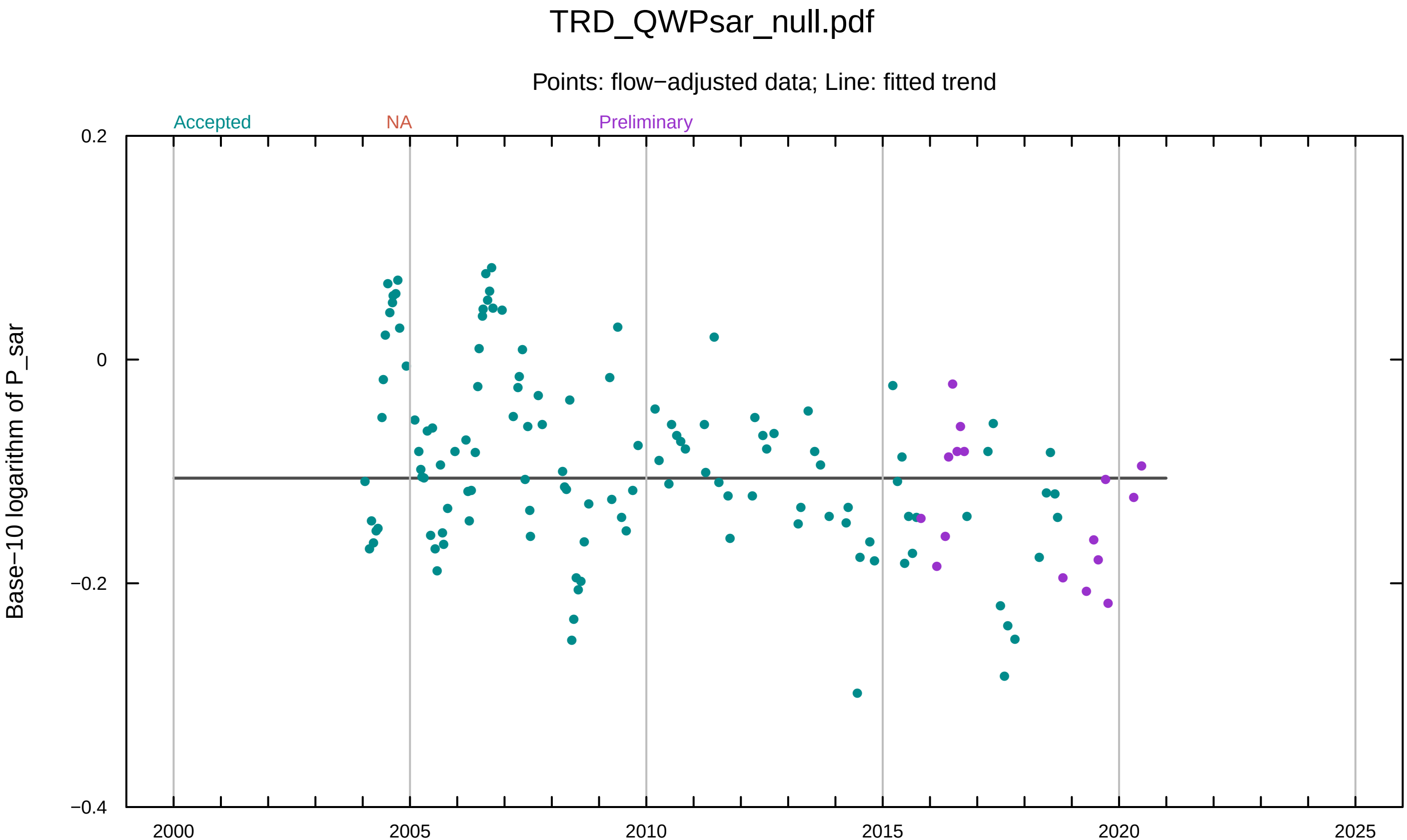
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend




TRD_QWPsar_M2.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar flux, in metric tons per day
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

TRD_QWPsar_null.pdf

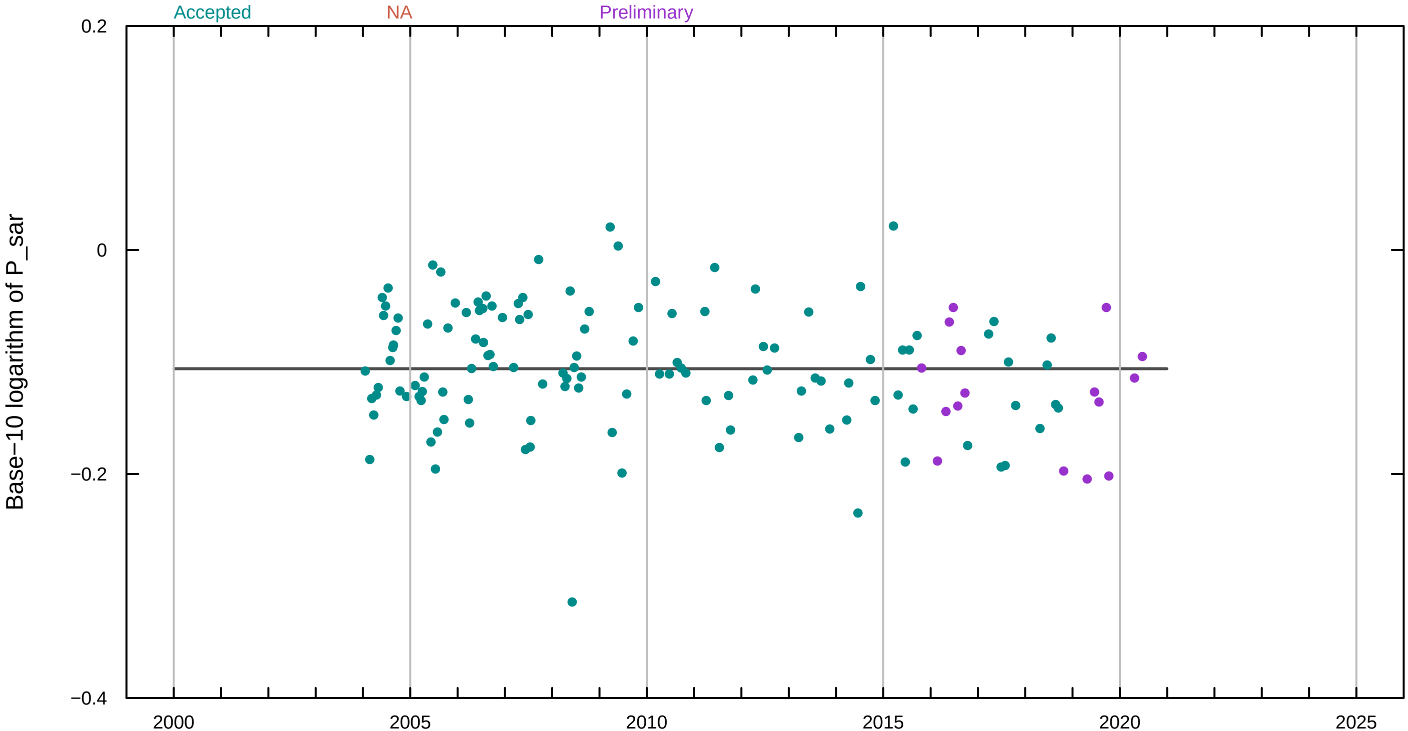


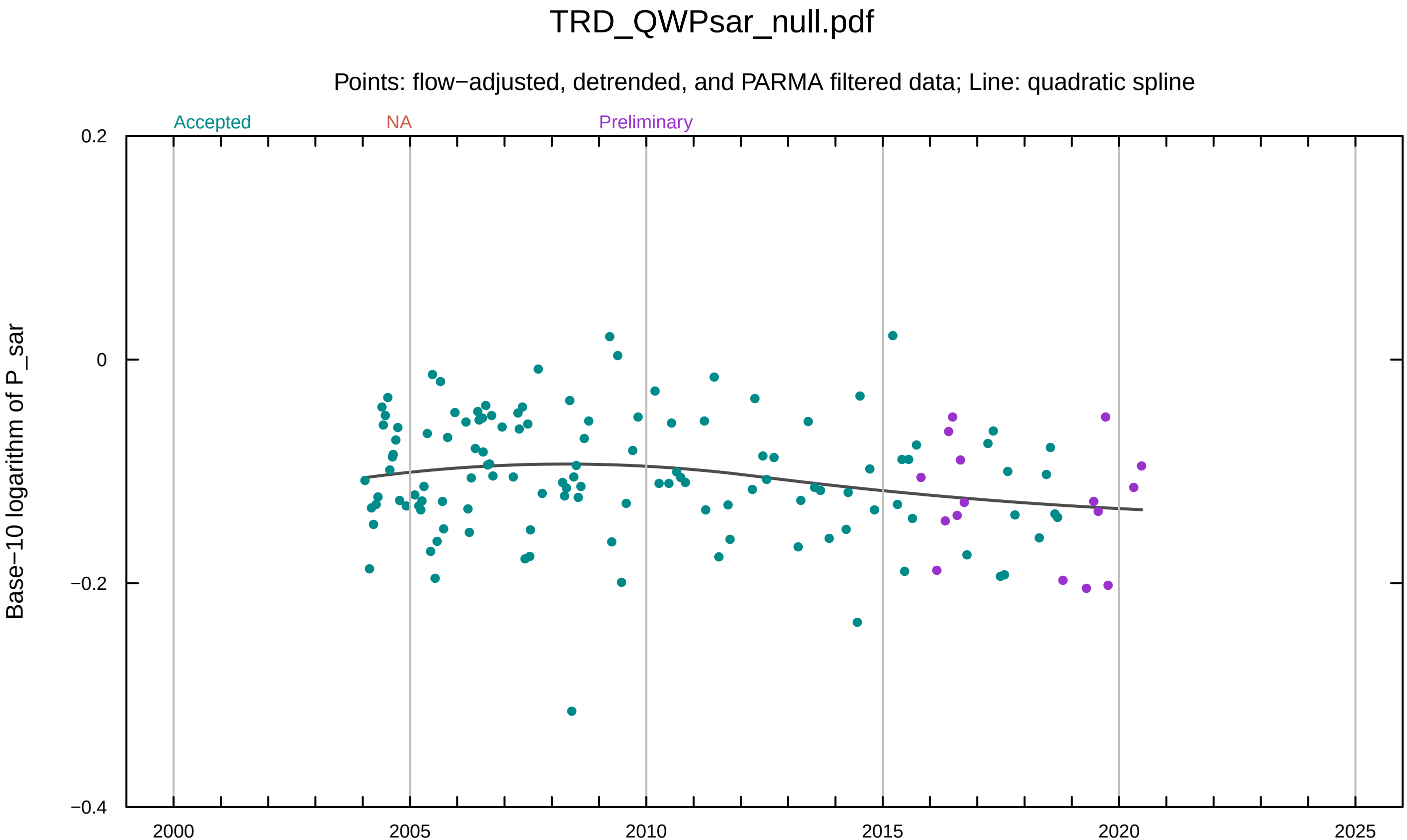


TRD_QWPsar_null.pdf
Points: flow−adjusted data; Line: fitted trend
Accepted
NA
Preliminary
0.2
0
−0.2
−0.4
Base−10 logarithm of P_sar
2000
2005
2010
2015
2020
2025

TRD_QWPsar_null.pdf

Points: flow−adjusted and PARMA filtered data; Line: fitted trend

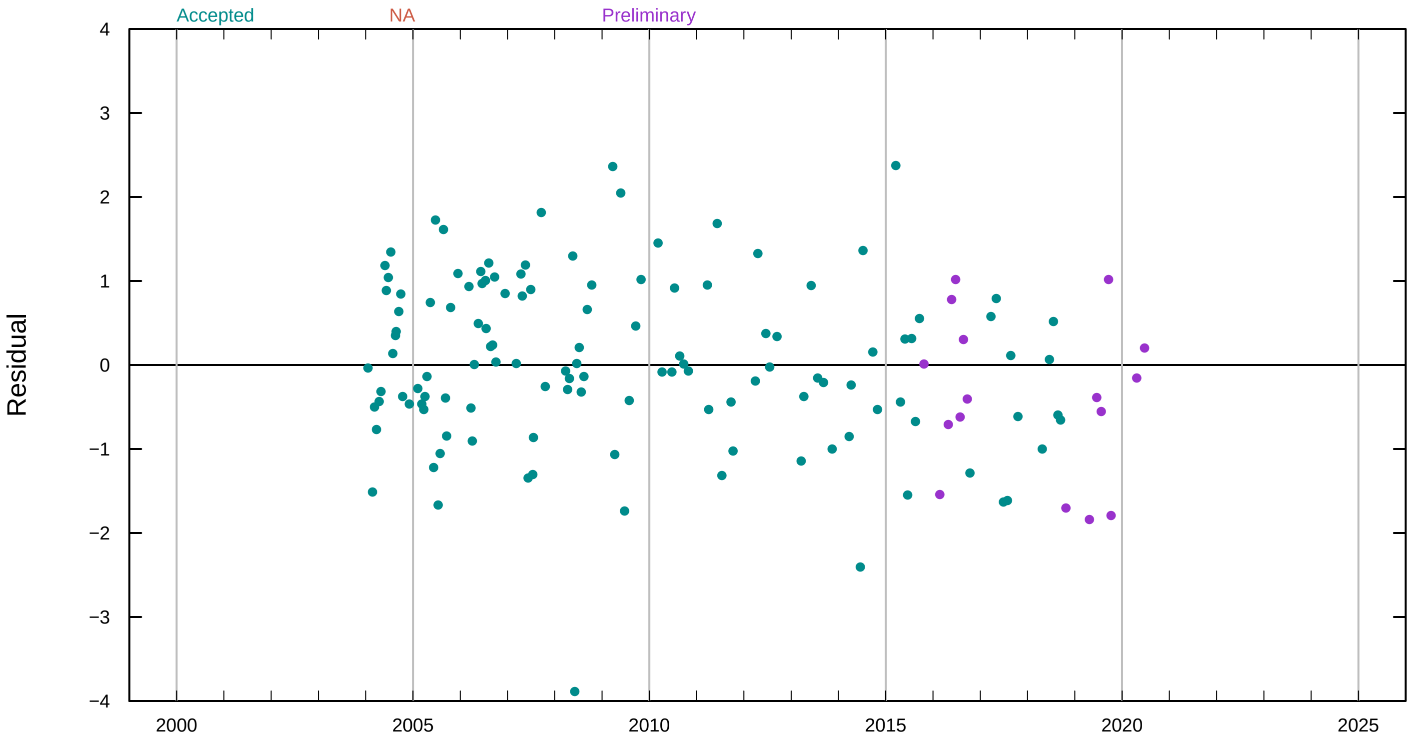


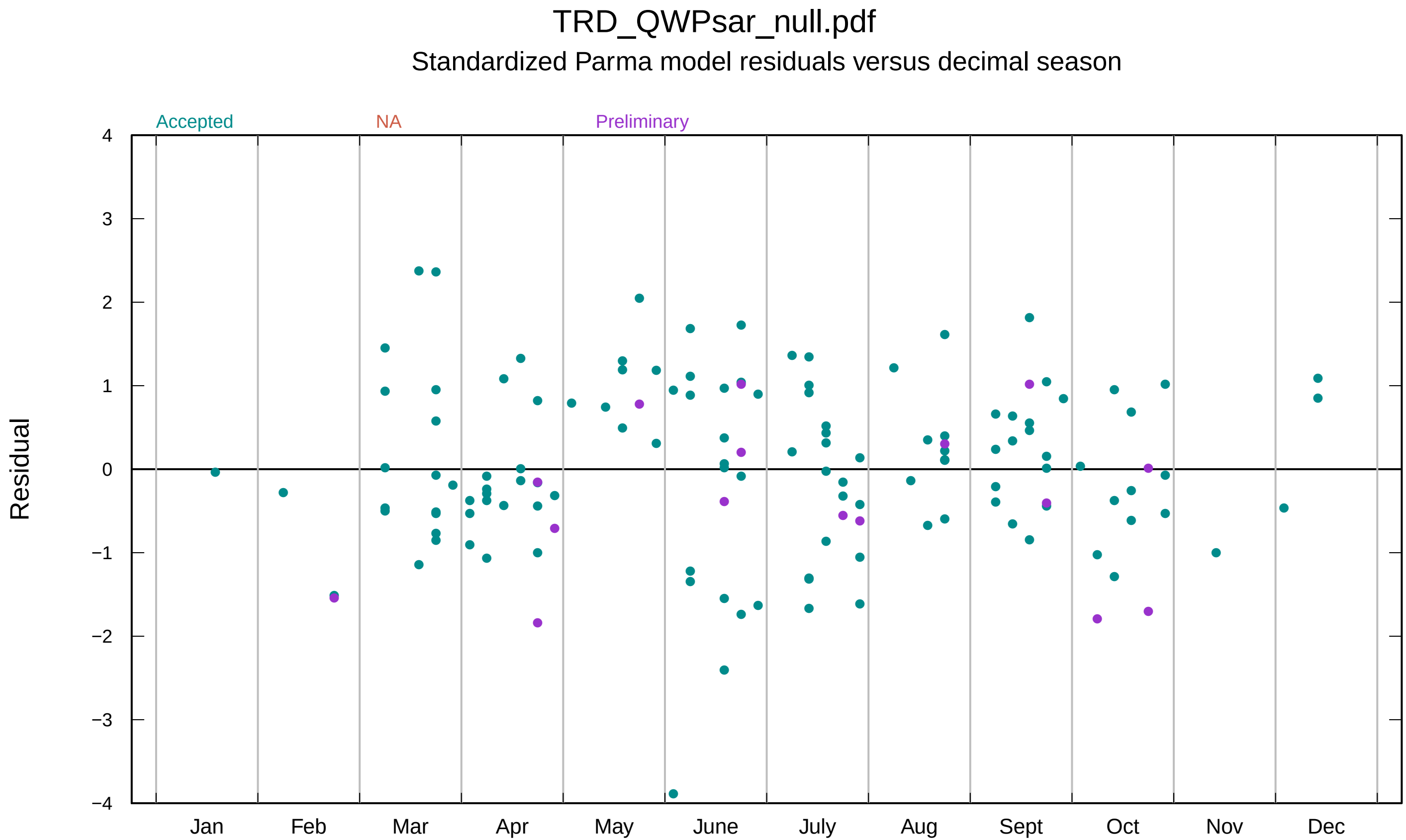


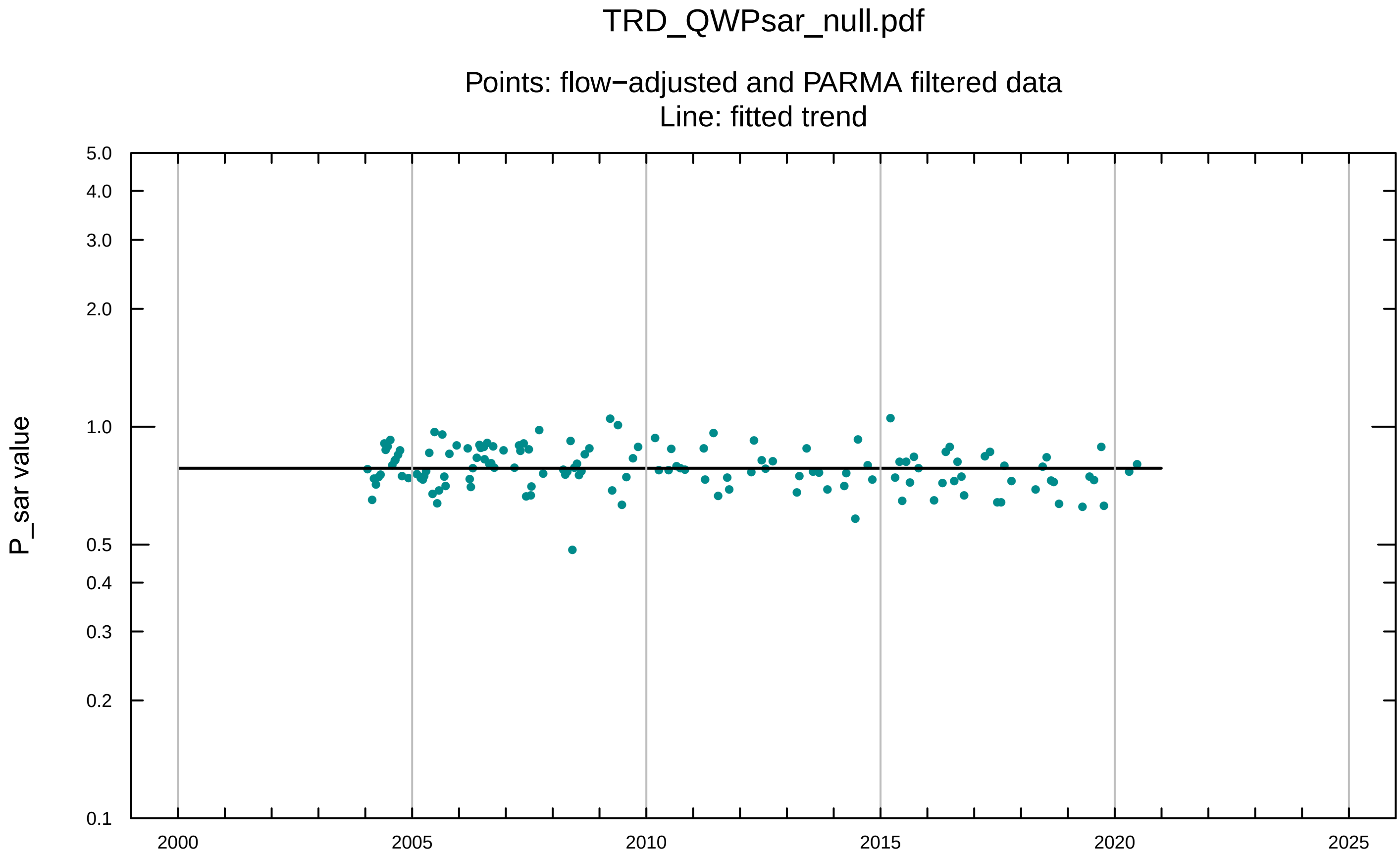
TRD_QWPsar_null.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
Accepted
NA
Preliminary
Base−10 logarithm of P_sar
0.2
0
−0.2
−0.4
2000
2005
2010
2015
2020
2025

TRD_QWPsar_null.pdf

Standardized PARMA model residuals versus decimal year




TRD_QWPsar_null.pdf
Standardized Parma model residuals versus decimal season
Accepted
NA
Preliminary
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

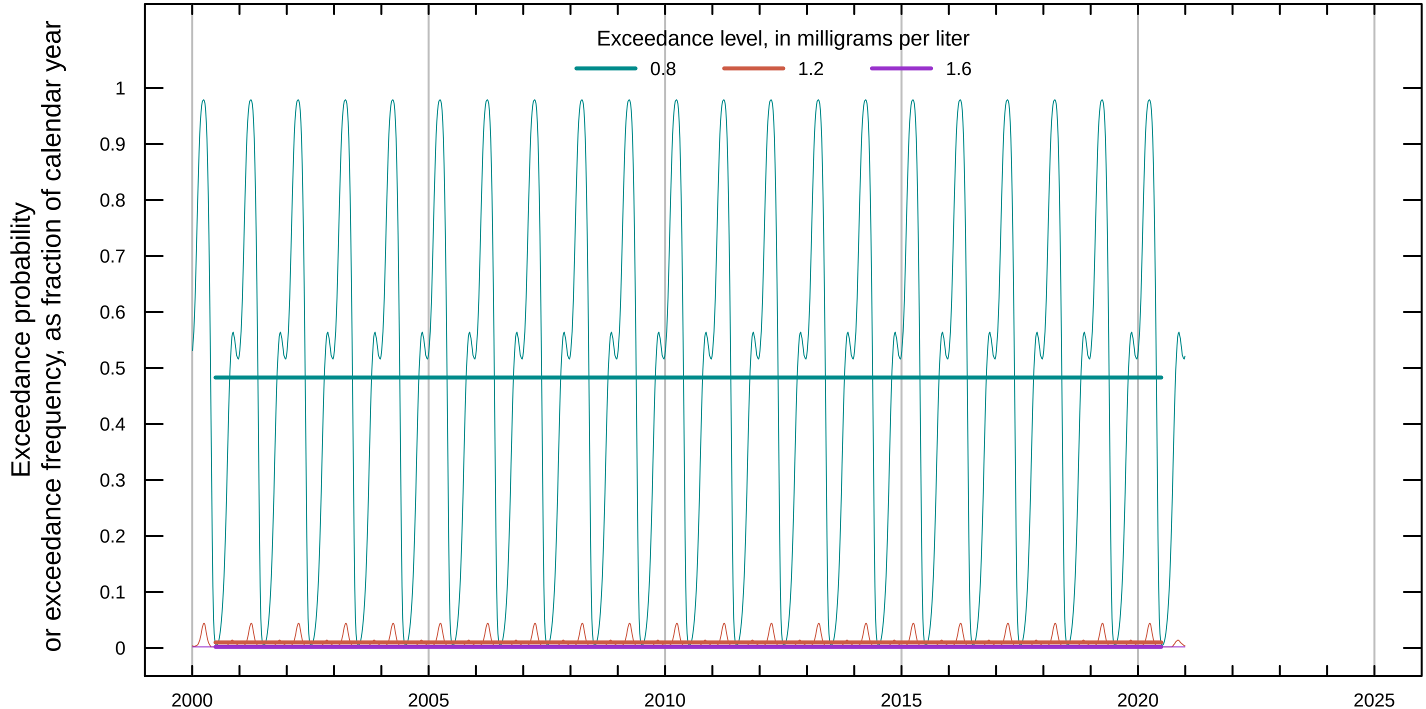

TRD_QWPsar_null.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sar value
5.0
4.0
3.0
2.0
1.0
0.5
0.4
0.3
0.2
0.1
2000
2005
2010
2015
2020
2025

TRD_QWPsar_null.pdf

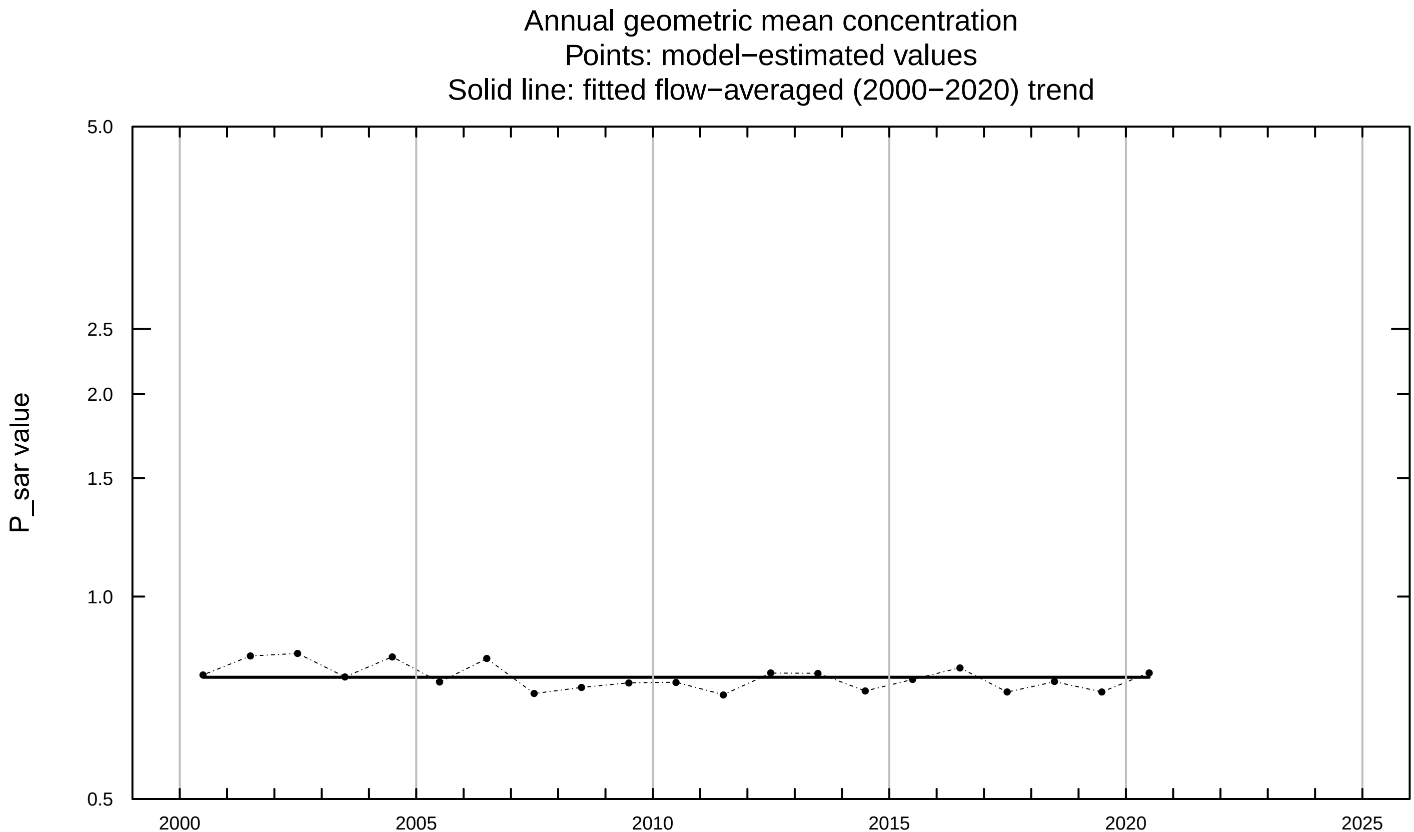
Flow−averaged exceedance probability and expected annual exceedance frequency

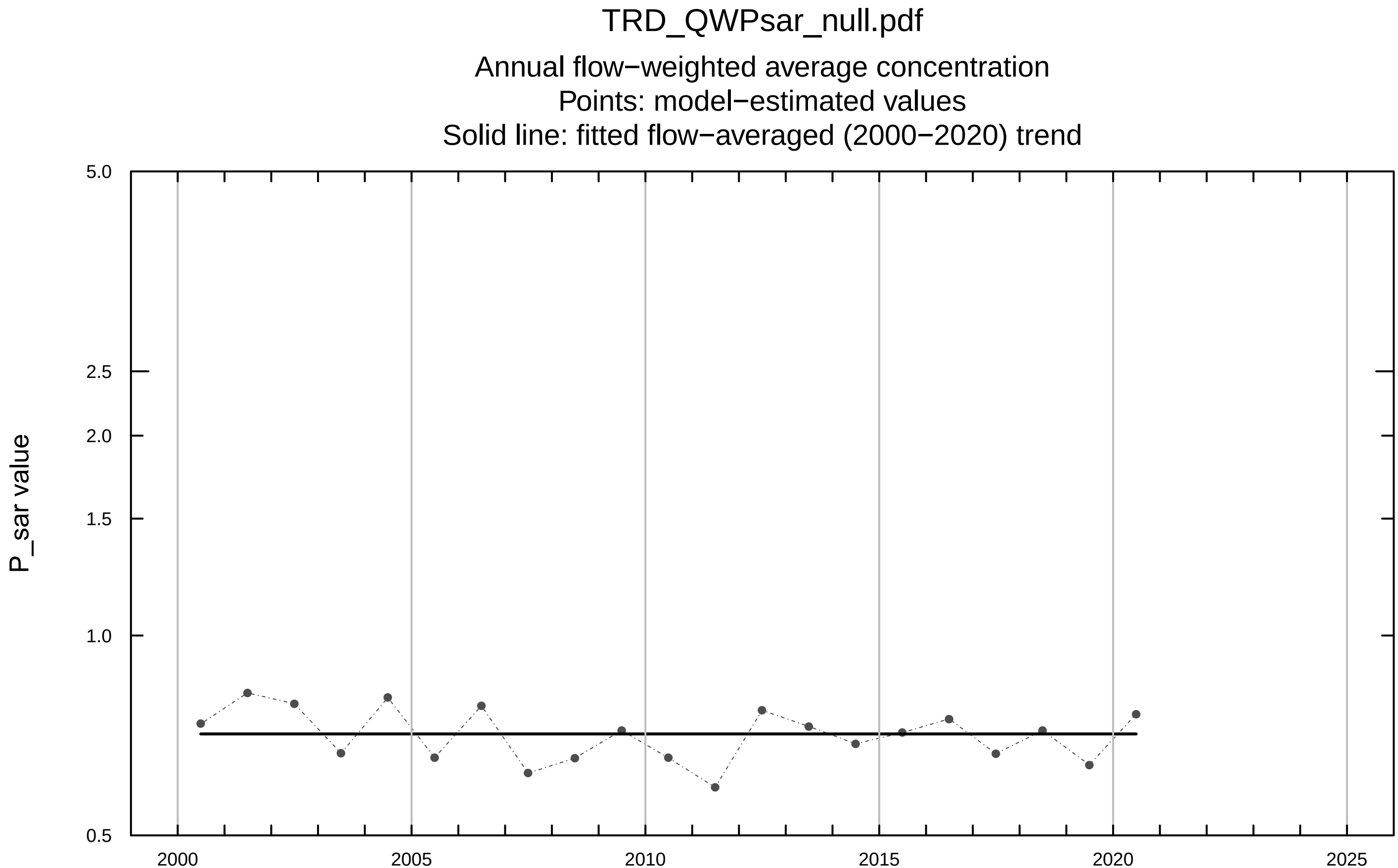
Thin line: Flow−averaged exceedance probability

Heavy line: Expected annual flow−averaged exceedance frequency

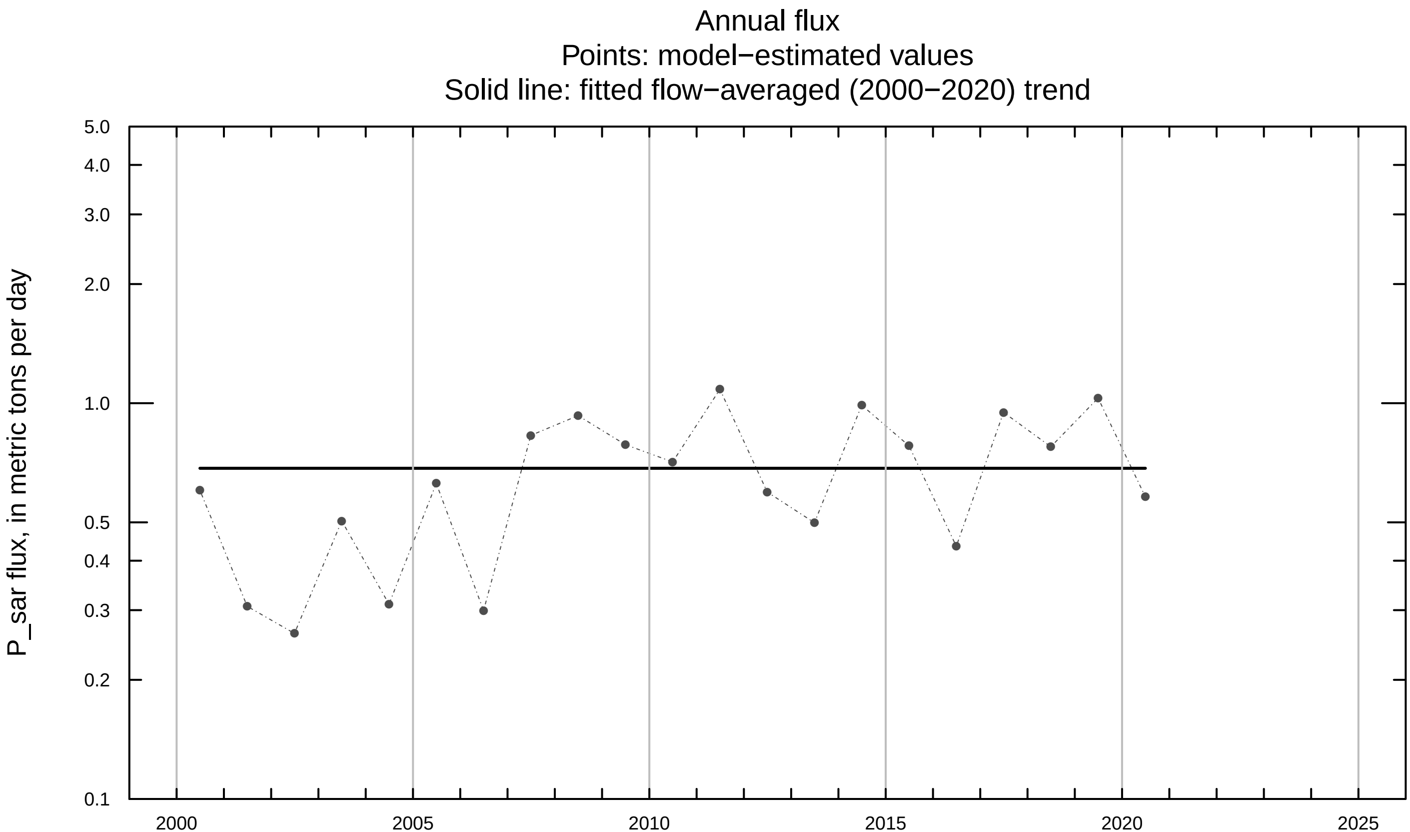


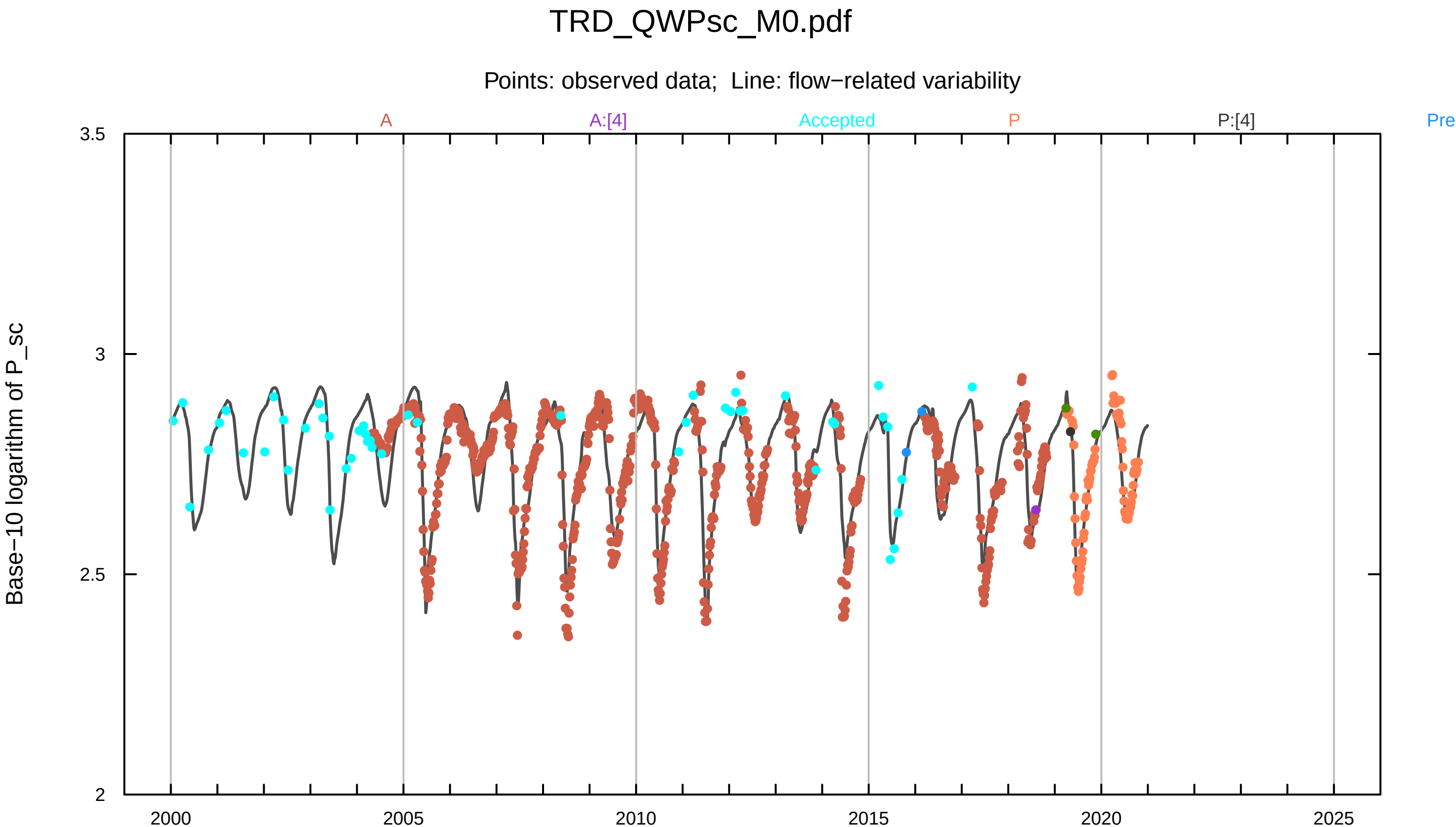
TRD_QWPsar_null.pdf

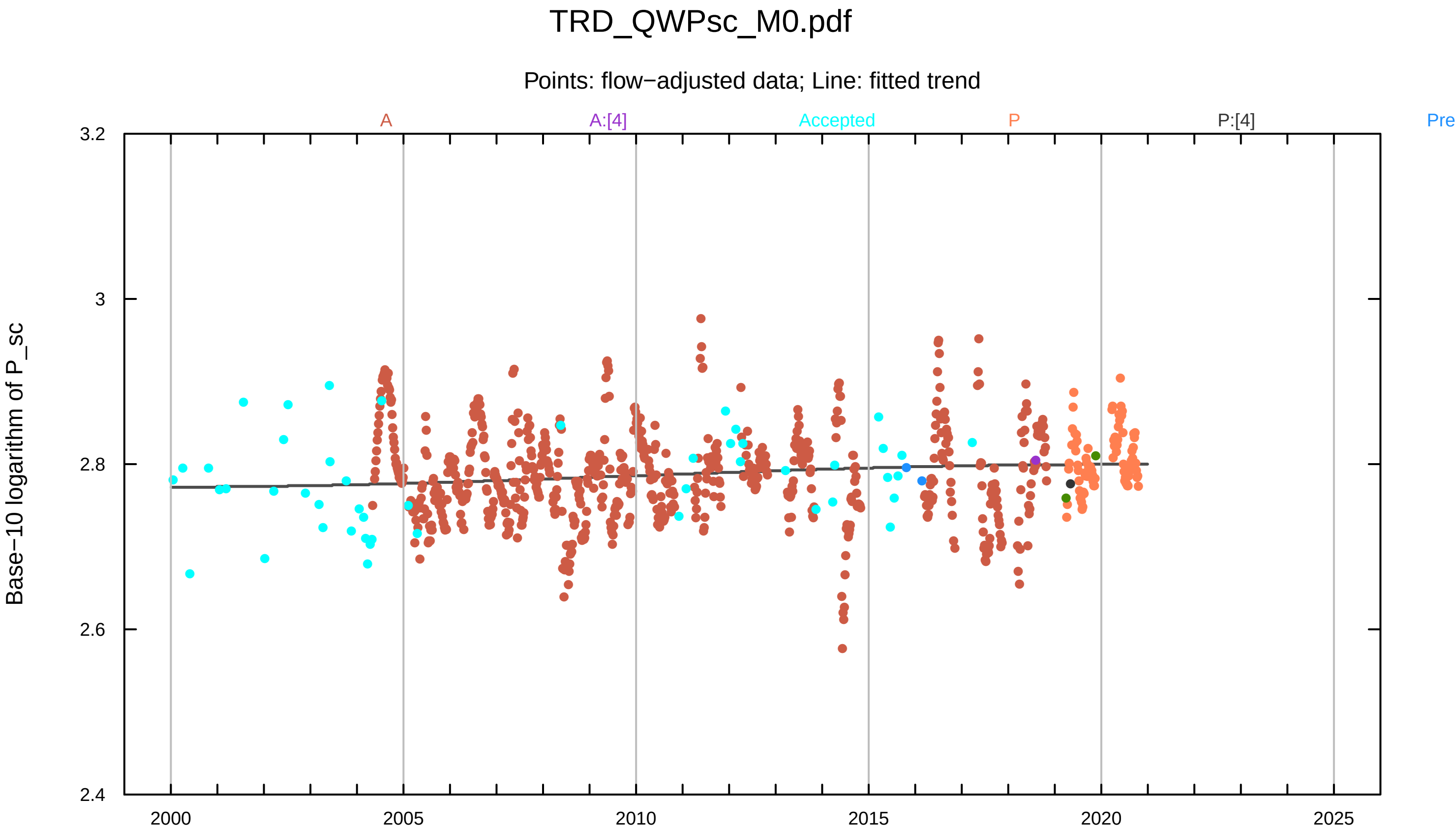



TRD_QWPsar_null.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sar value
5.0
2.5
2.0
1.5
1.0
0.5
2000
2005
2010
2015
2020
2025

TRD_QWPsar_null.pdf



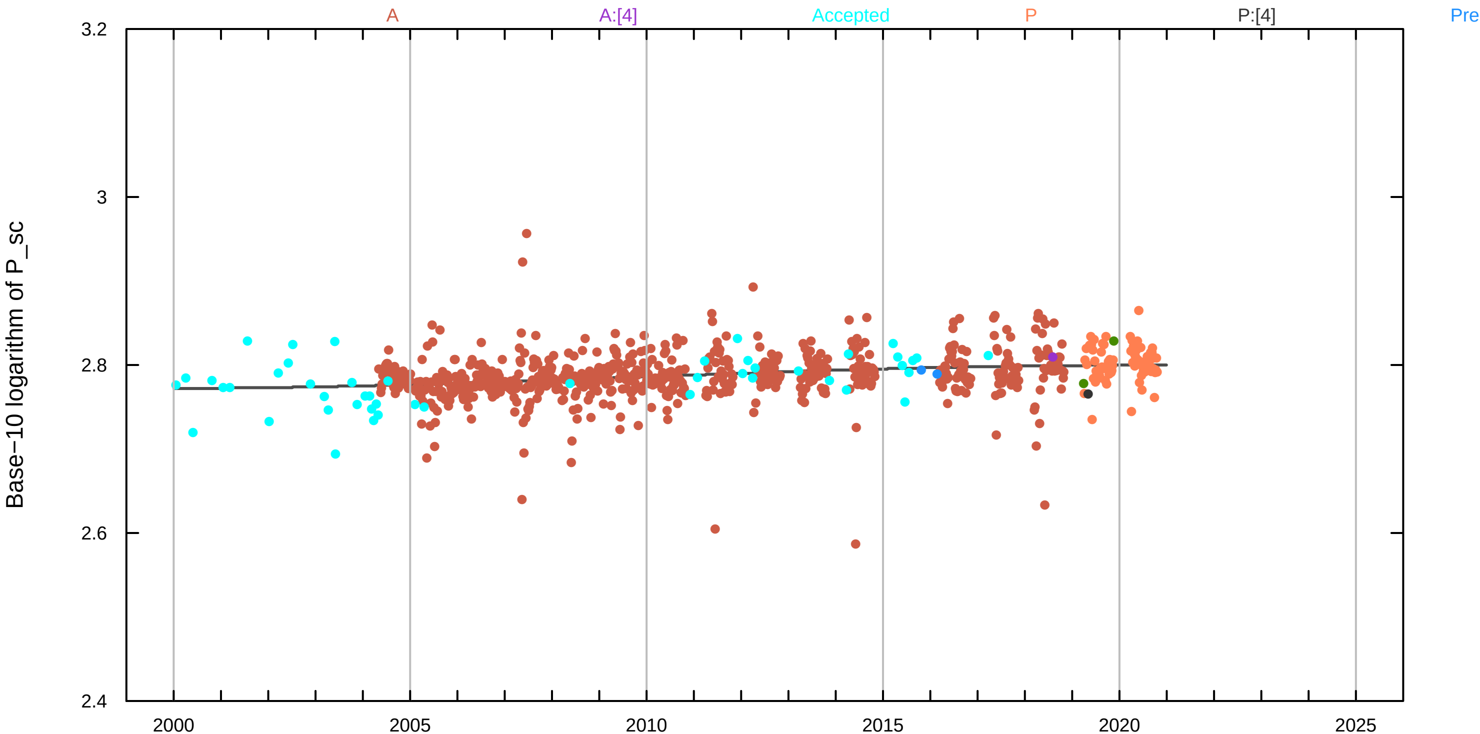

TRD_QWPsc_M0.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.5
3
2.5
2
2000
2005
2010
2015
2020
2025

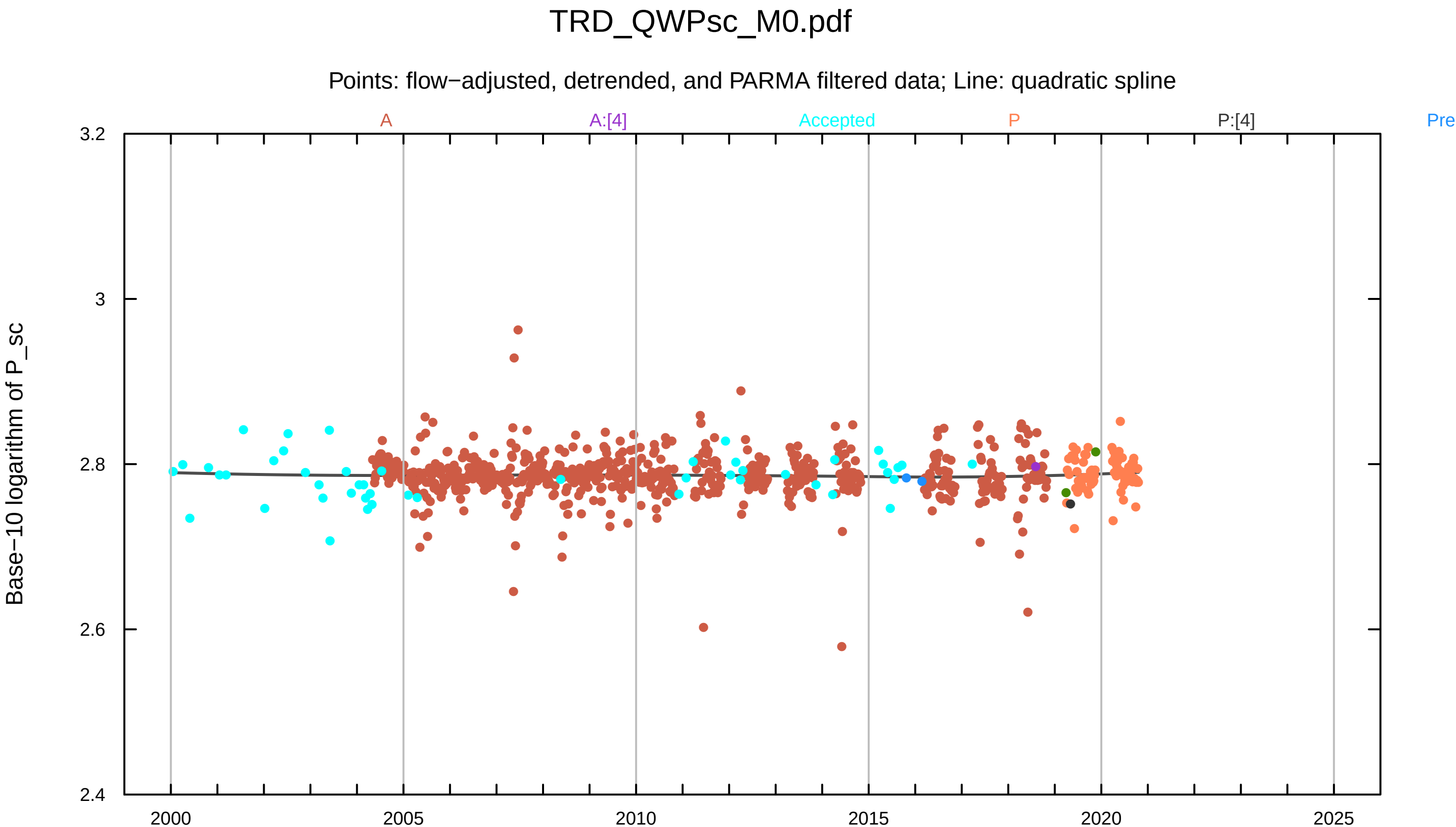


TRD_QWPsc_M0.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
P:[4]
Pre
3.2
3
2.8
2.6
2.4
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020
2025

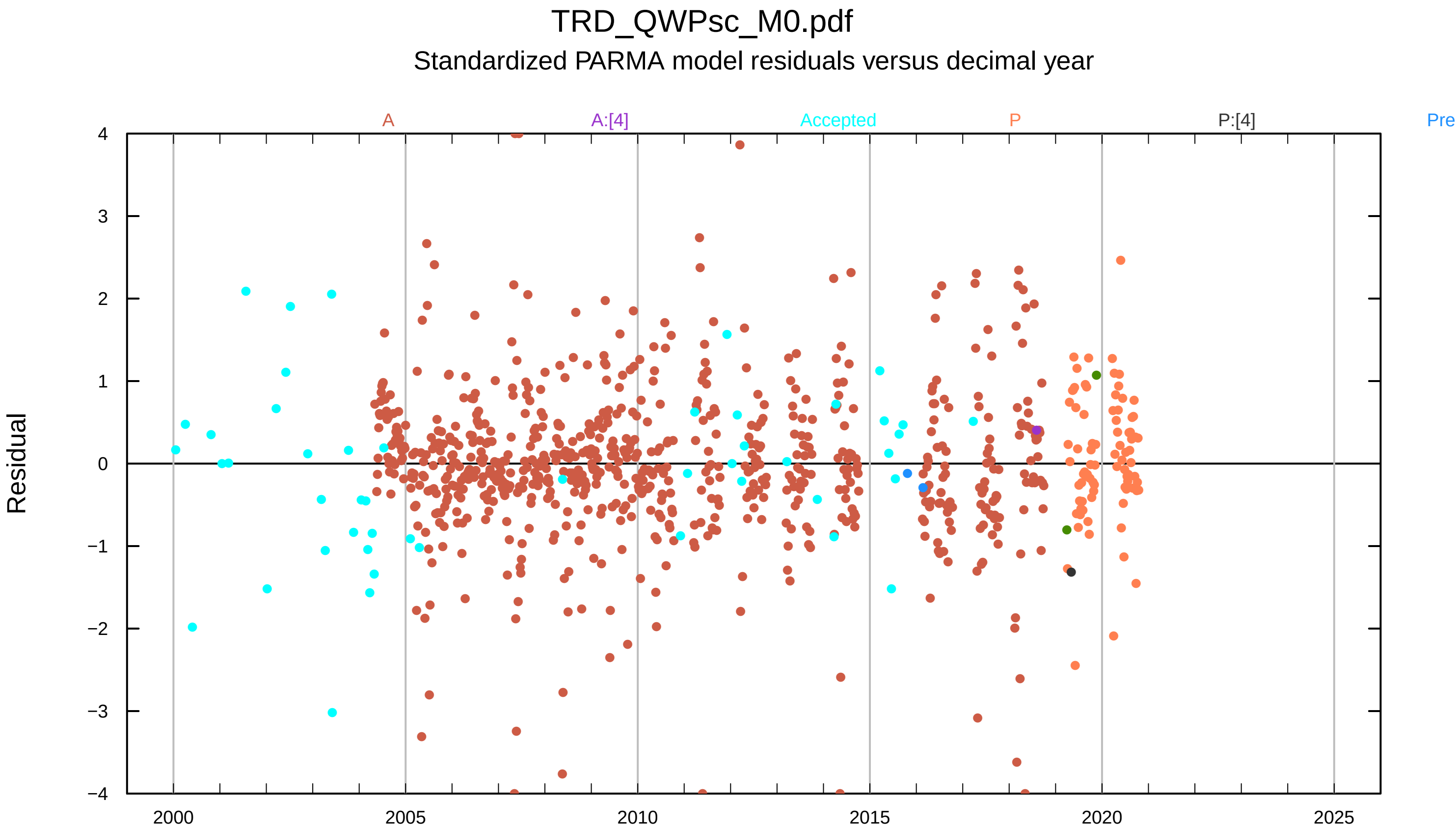
TRD_QWPsc_M0.pdf

Points: flow−adjusted and PARMA filtered data; Line: fitted trend

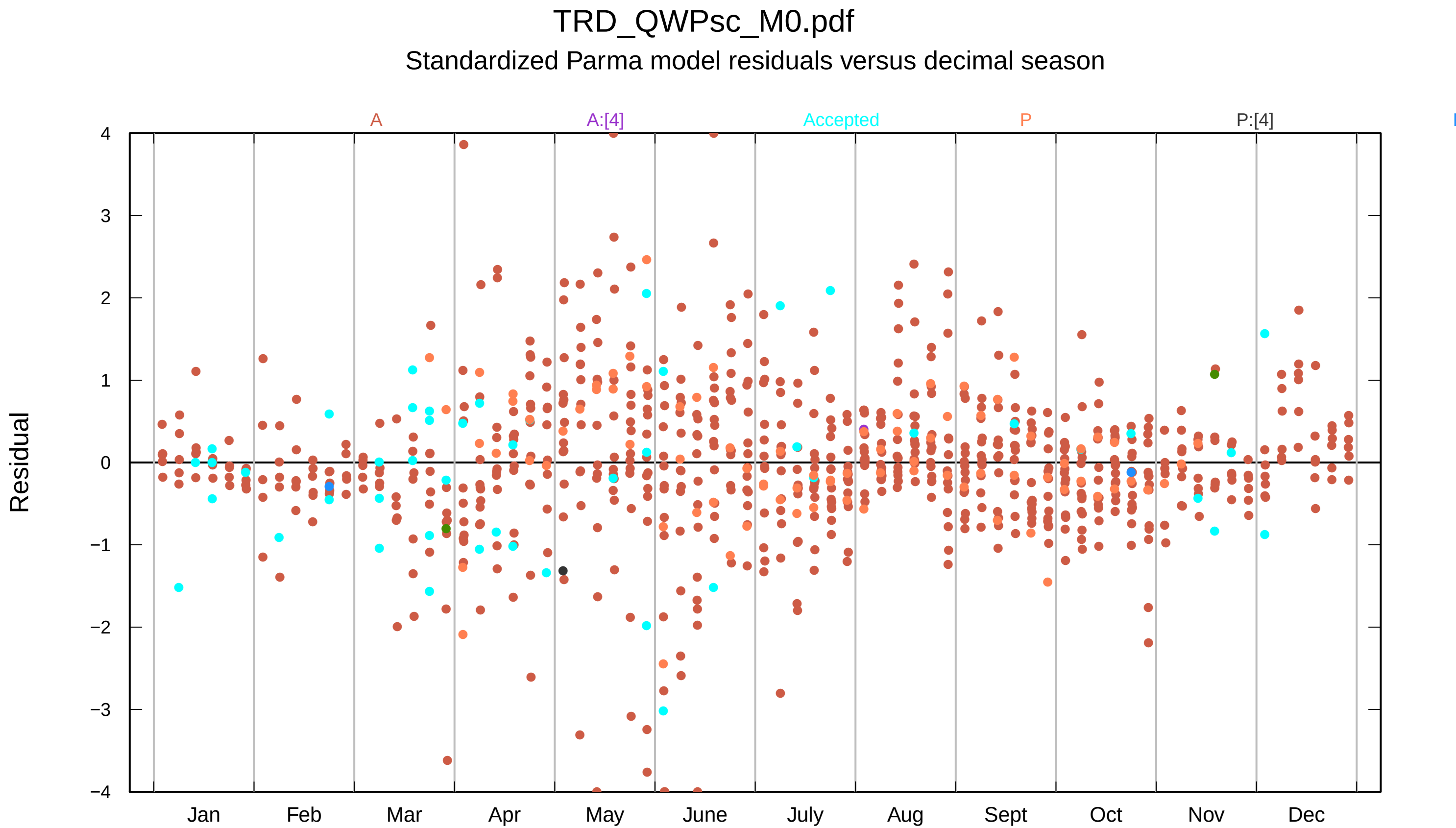




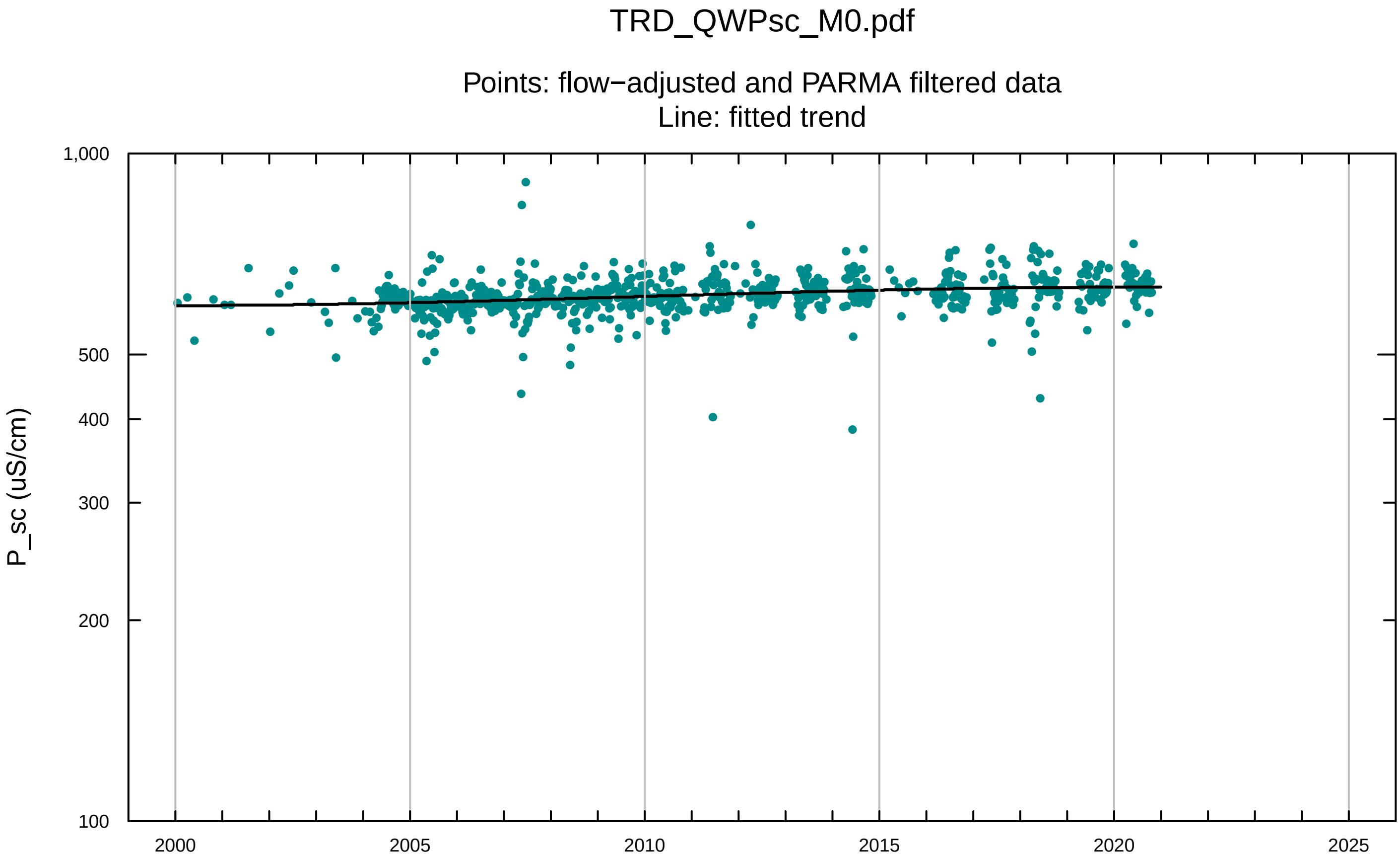
TRD_QWPsc_M0.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

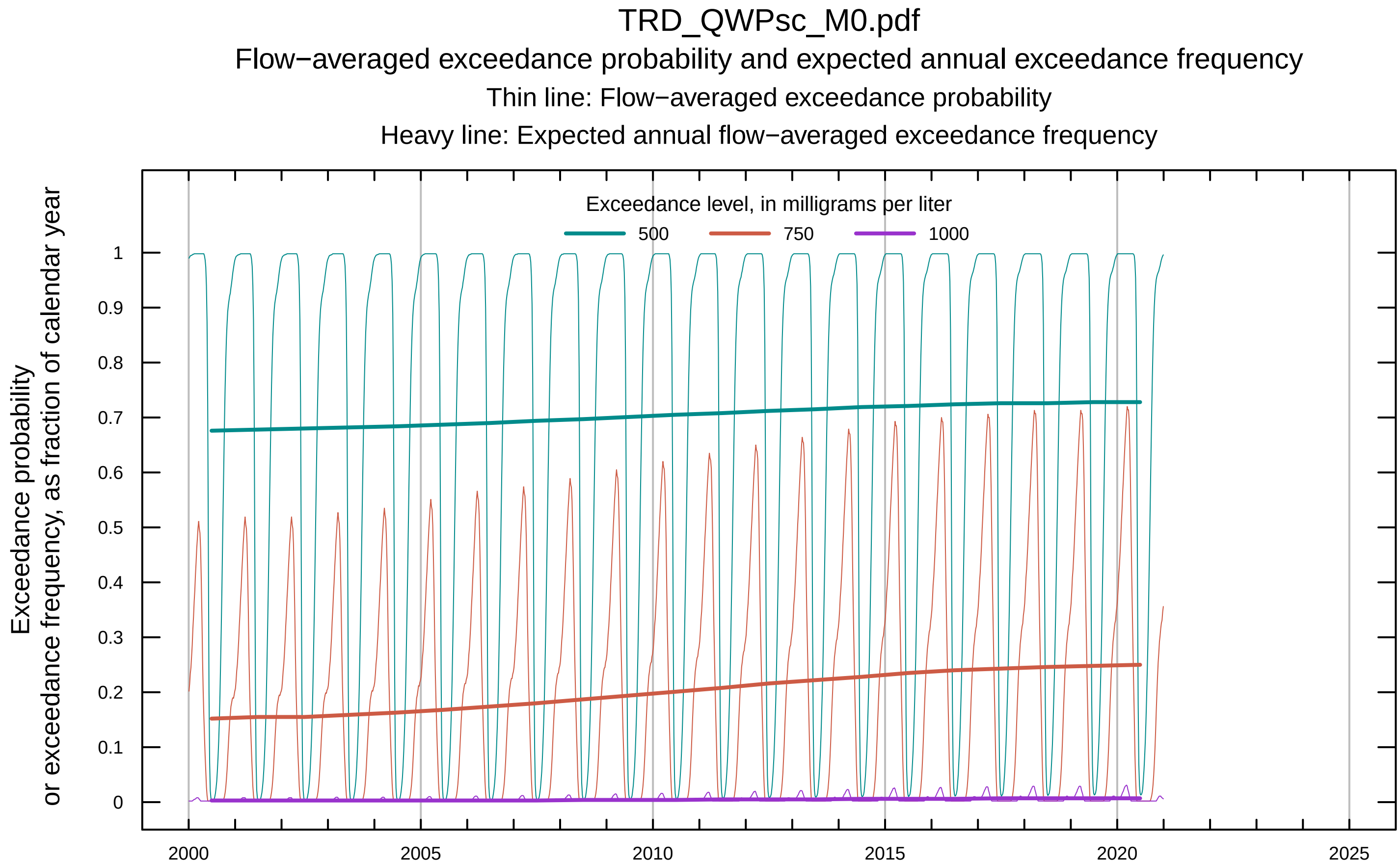


TRD_QWPsc_M0.pdf
Standardized PARMA model residuals versus decimal year
A
A:[4]
Accepted
P
P:[4]
Pre
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025

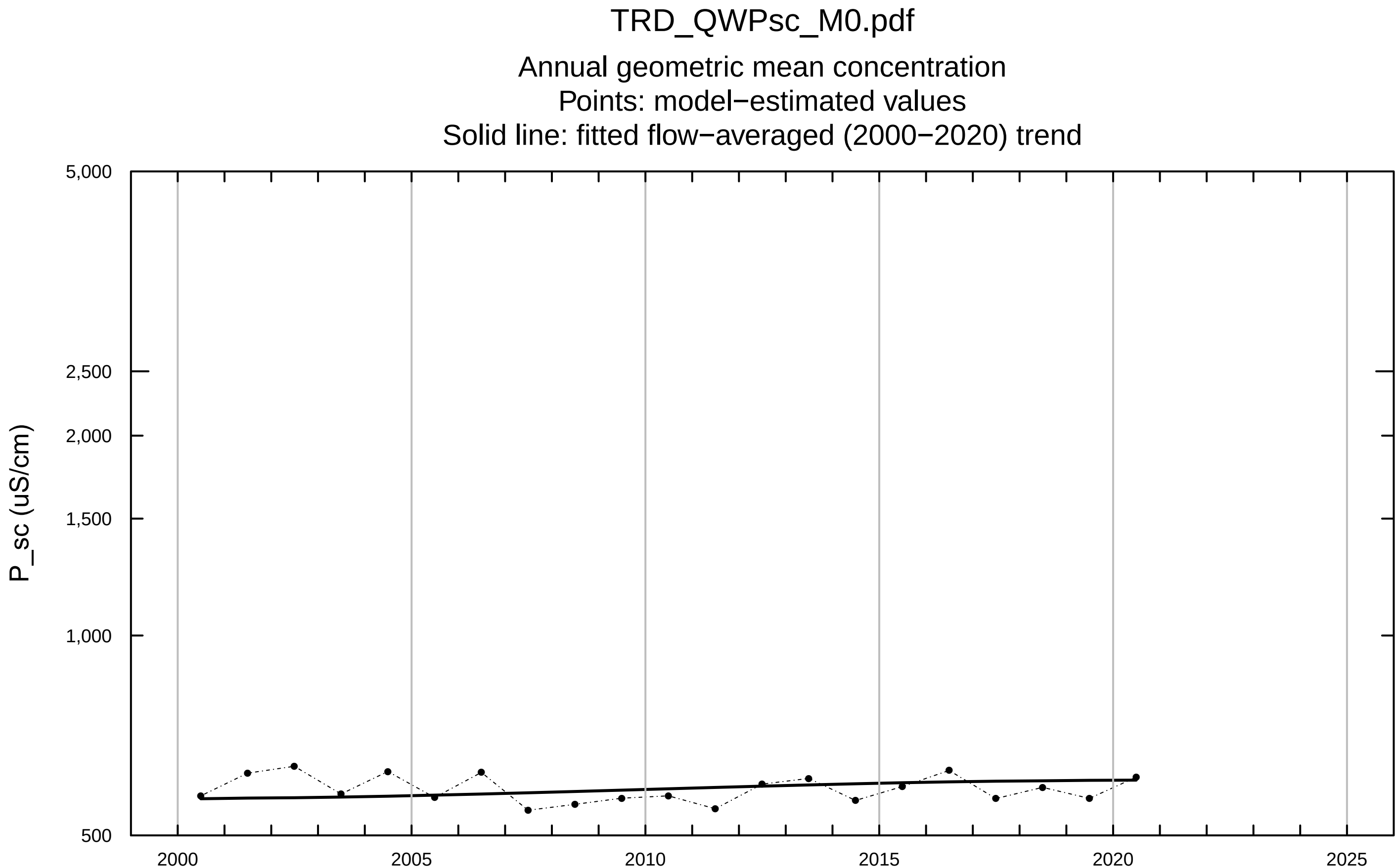


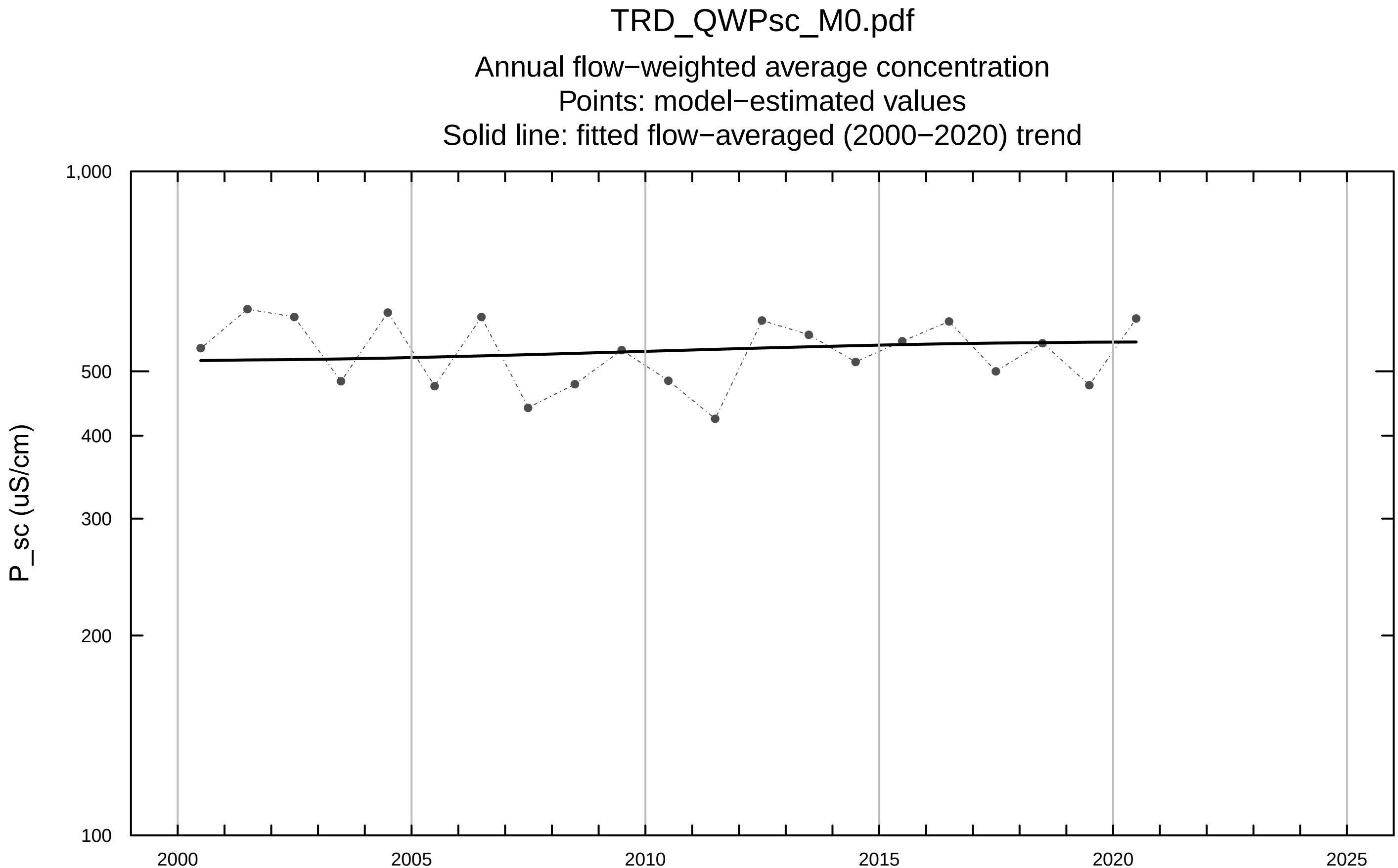
TRD_QWPsc_M0.pdf
Standardized Parma model residuals versus decimal season
A
A:[4]
Accepted
P
P:[4]
Residual
4
3
2
1
0
−1
−2
−3
−4
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

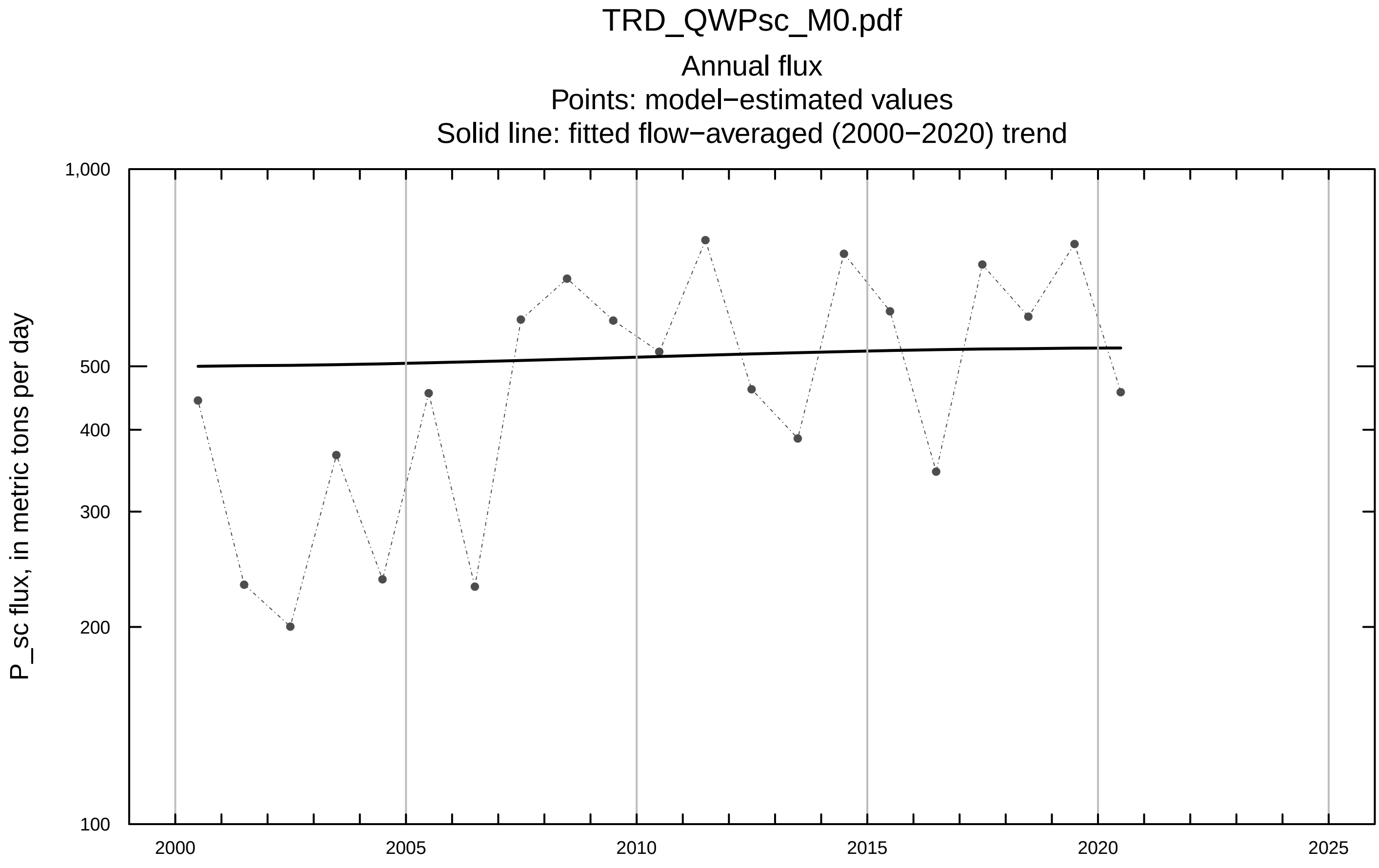

TRD_QWPsc_M0.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

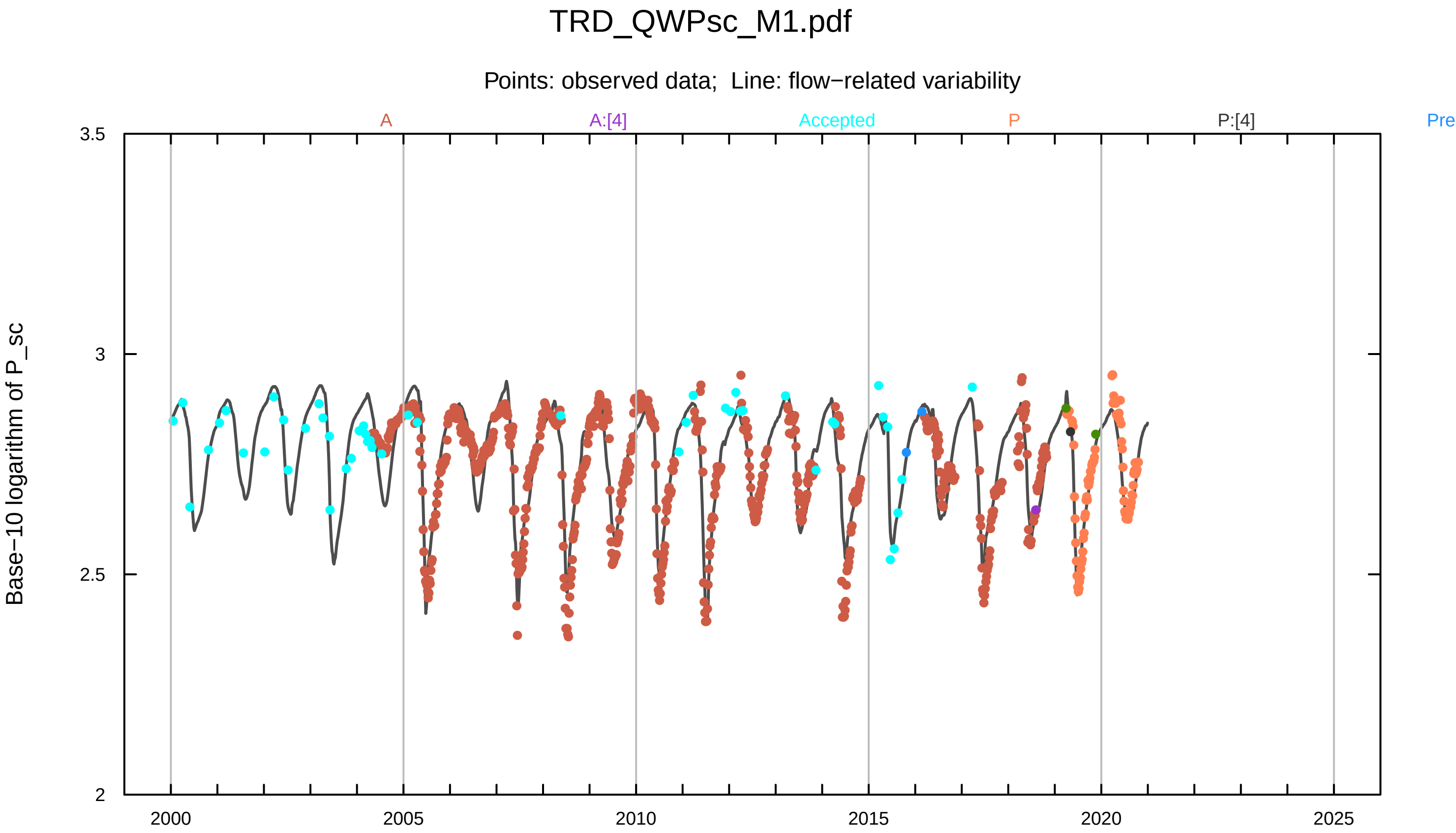


TRD_QWPsc_M0.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
500
750
1000
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025

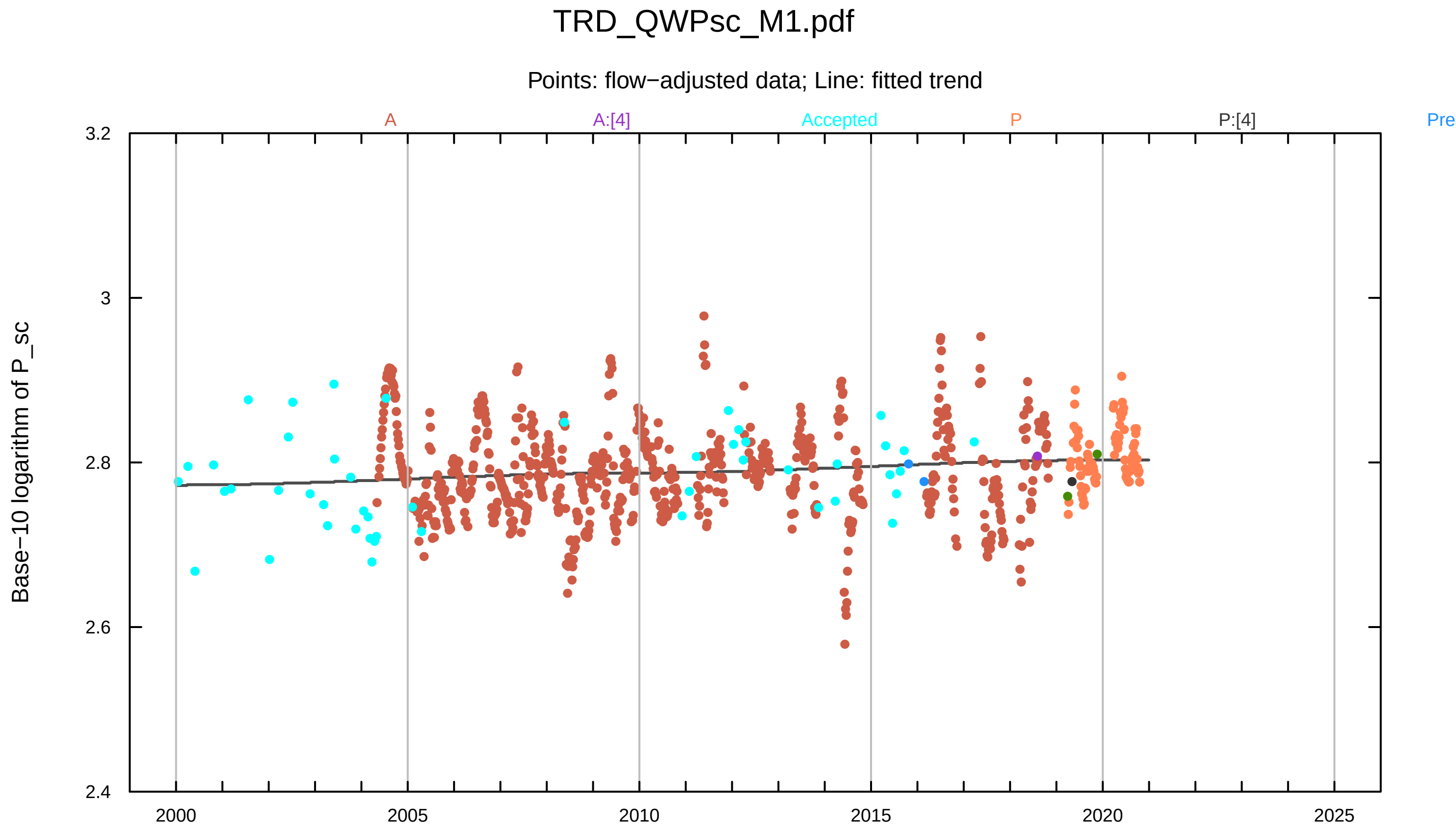

TRD_QWPsc_M0.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M0.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

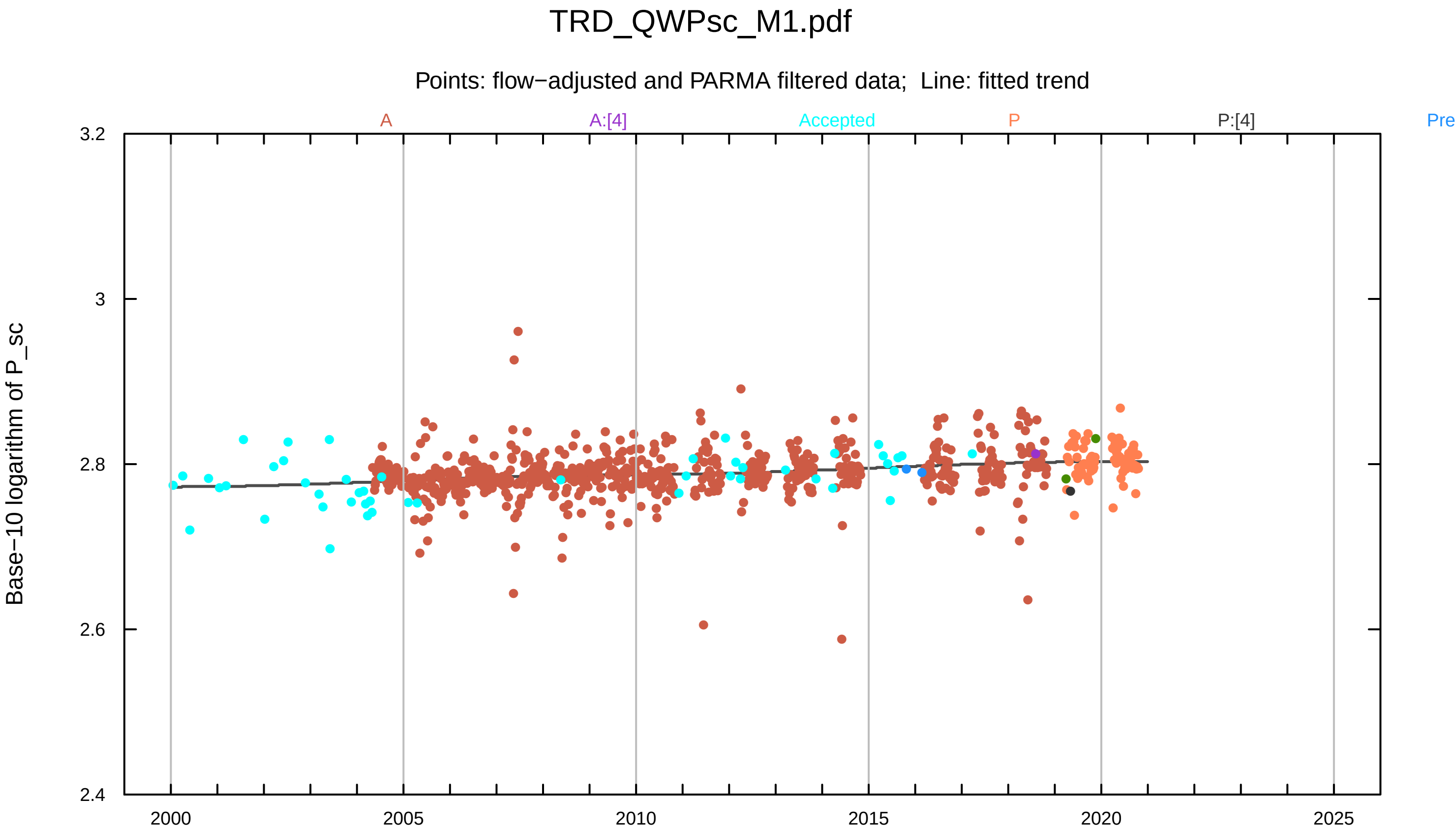

TRD_QWPsc_M0.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

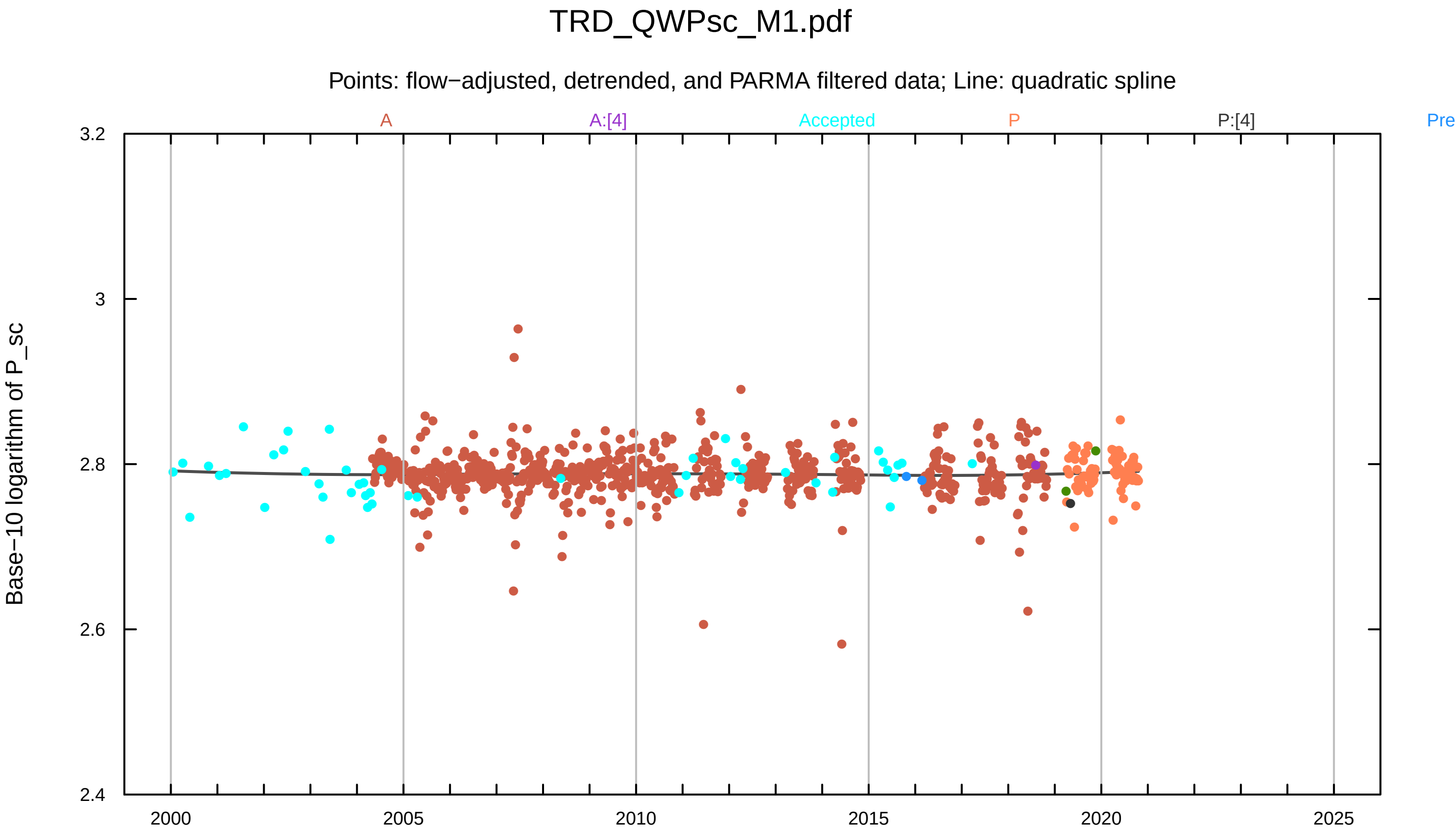


TRD_QWPsc_M1.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.5
3
2.5
2
2000
2005
2010
2015
2020
2025



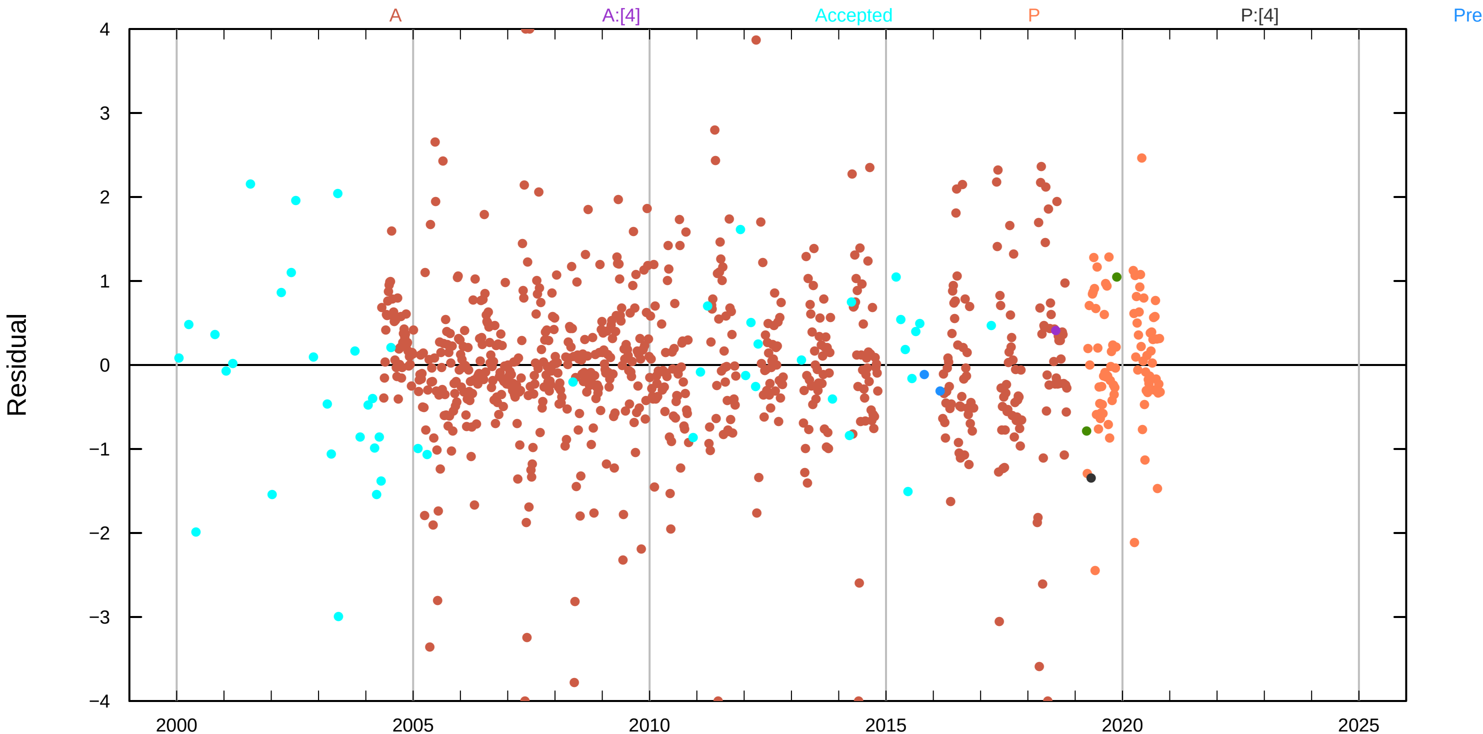
TRD_QWPsc_M1.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
P:[4]
Pre
3.2
3
2.8
2.6
2.4
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M1.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

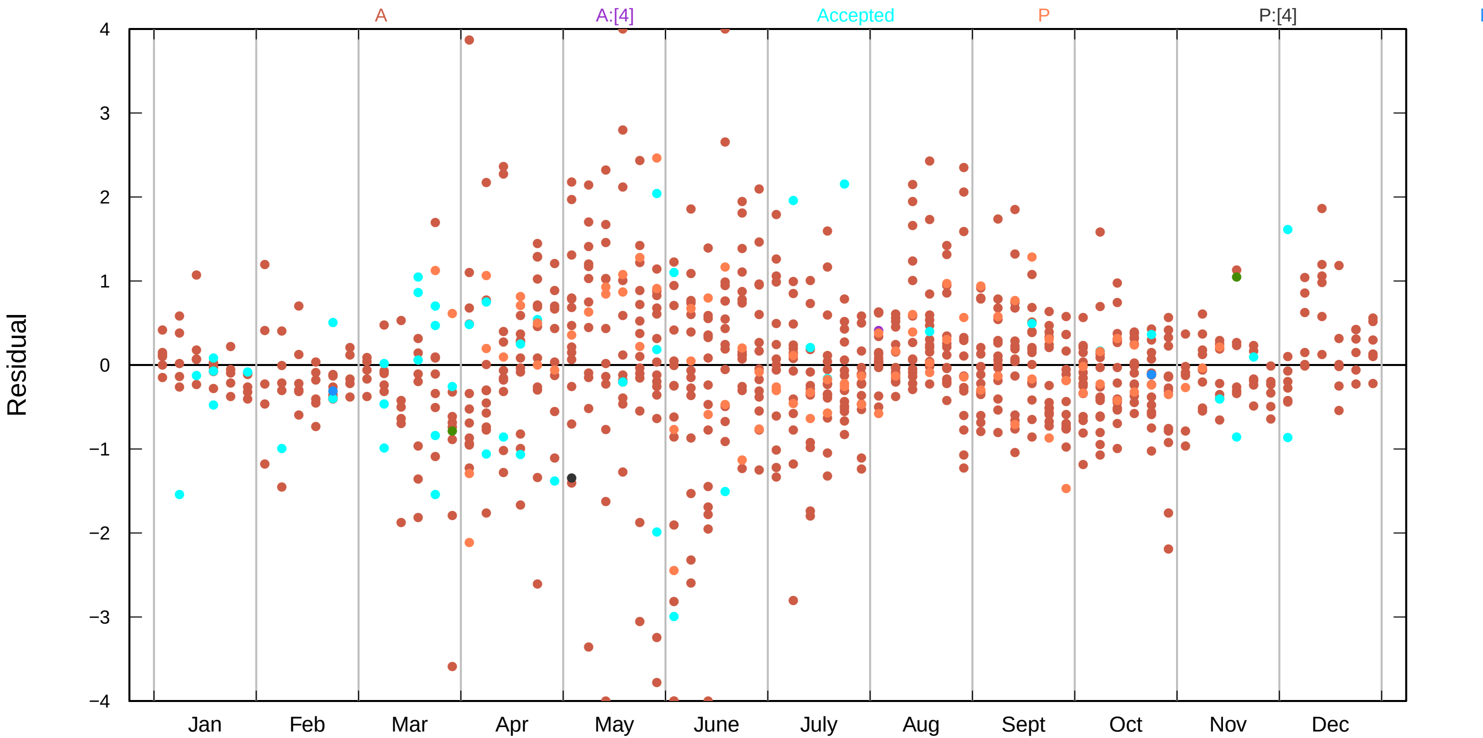
TRD_QWPsc_M1.pdf

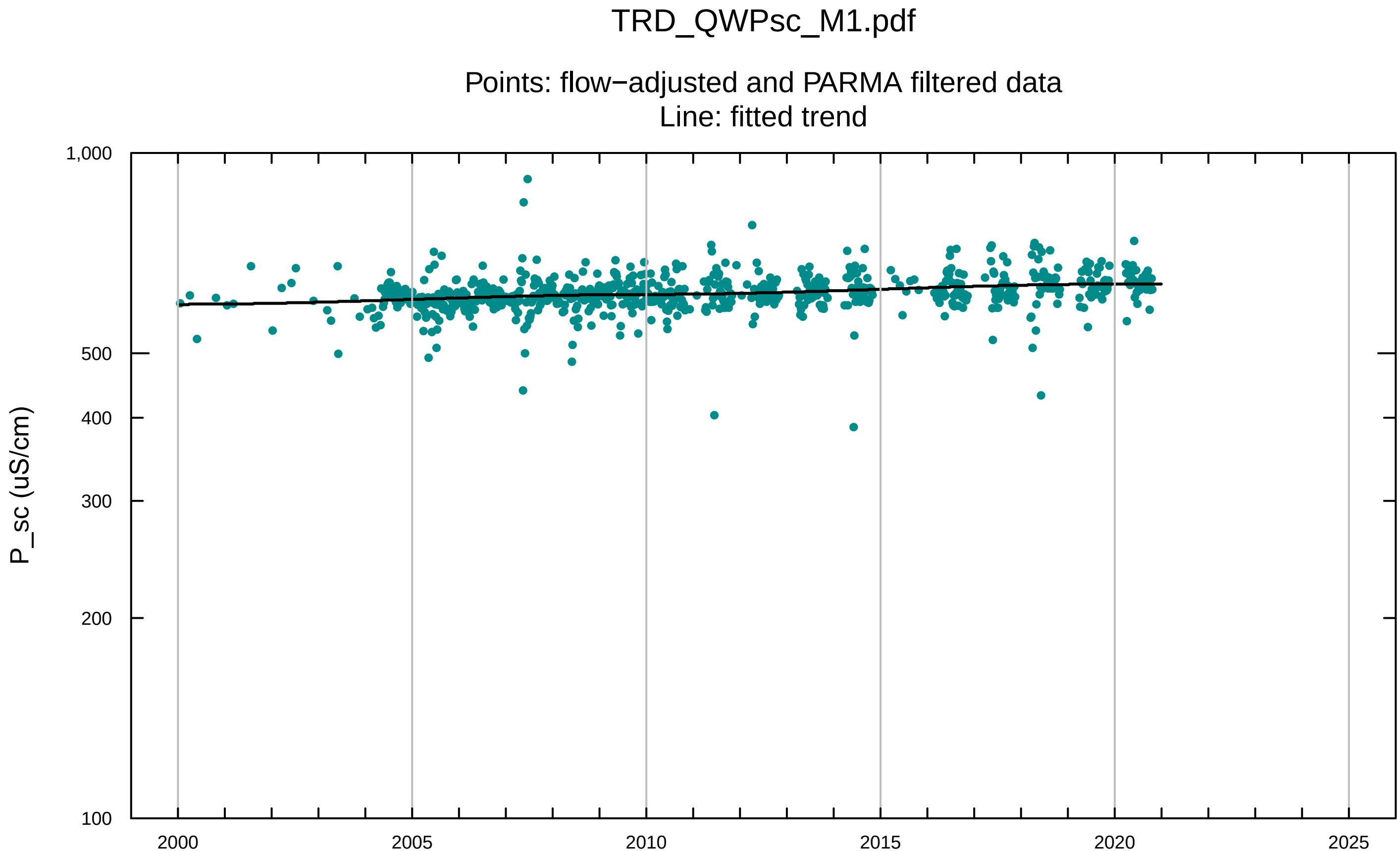
Standardized PARMA model residuals versus decimal year



TRD_QWPsc_M1.pdf

Standardized Parma model residuals versus decimal season





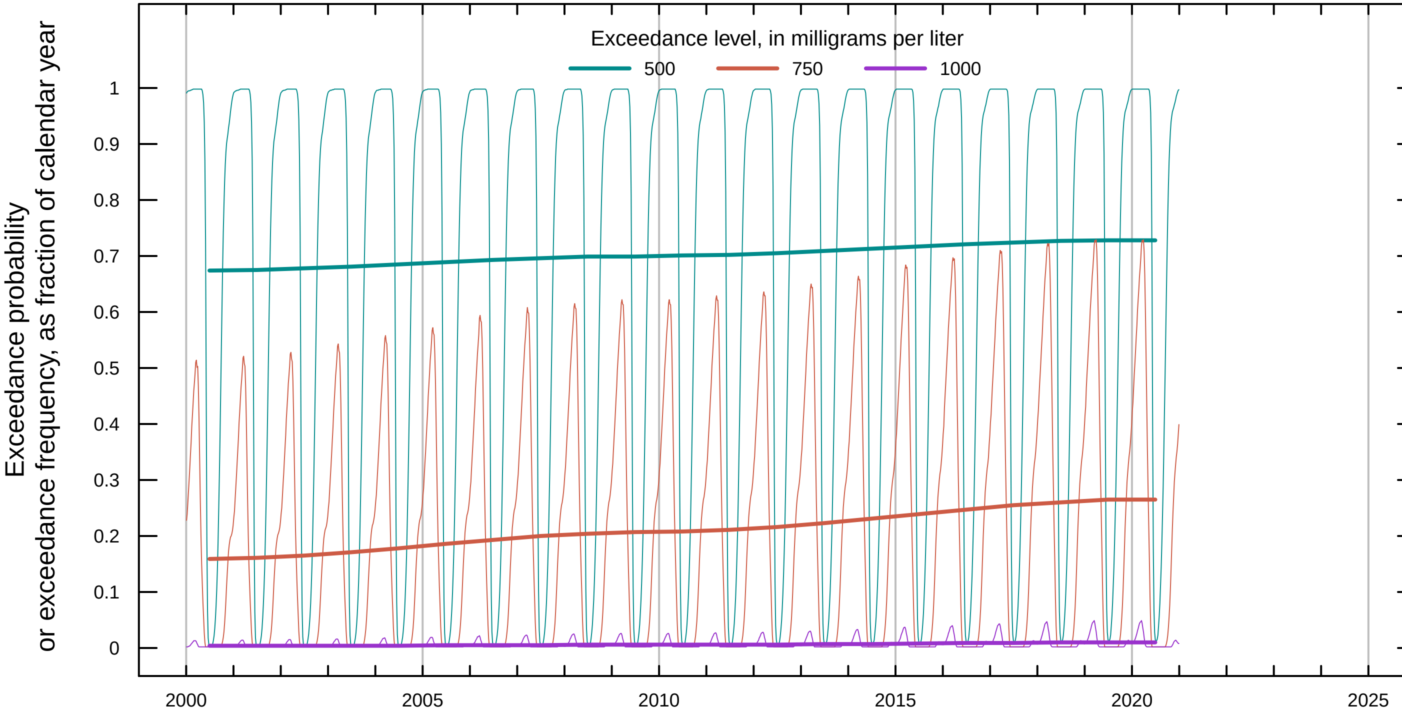
TRD_QWPsc_M1.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

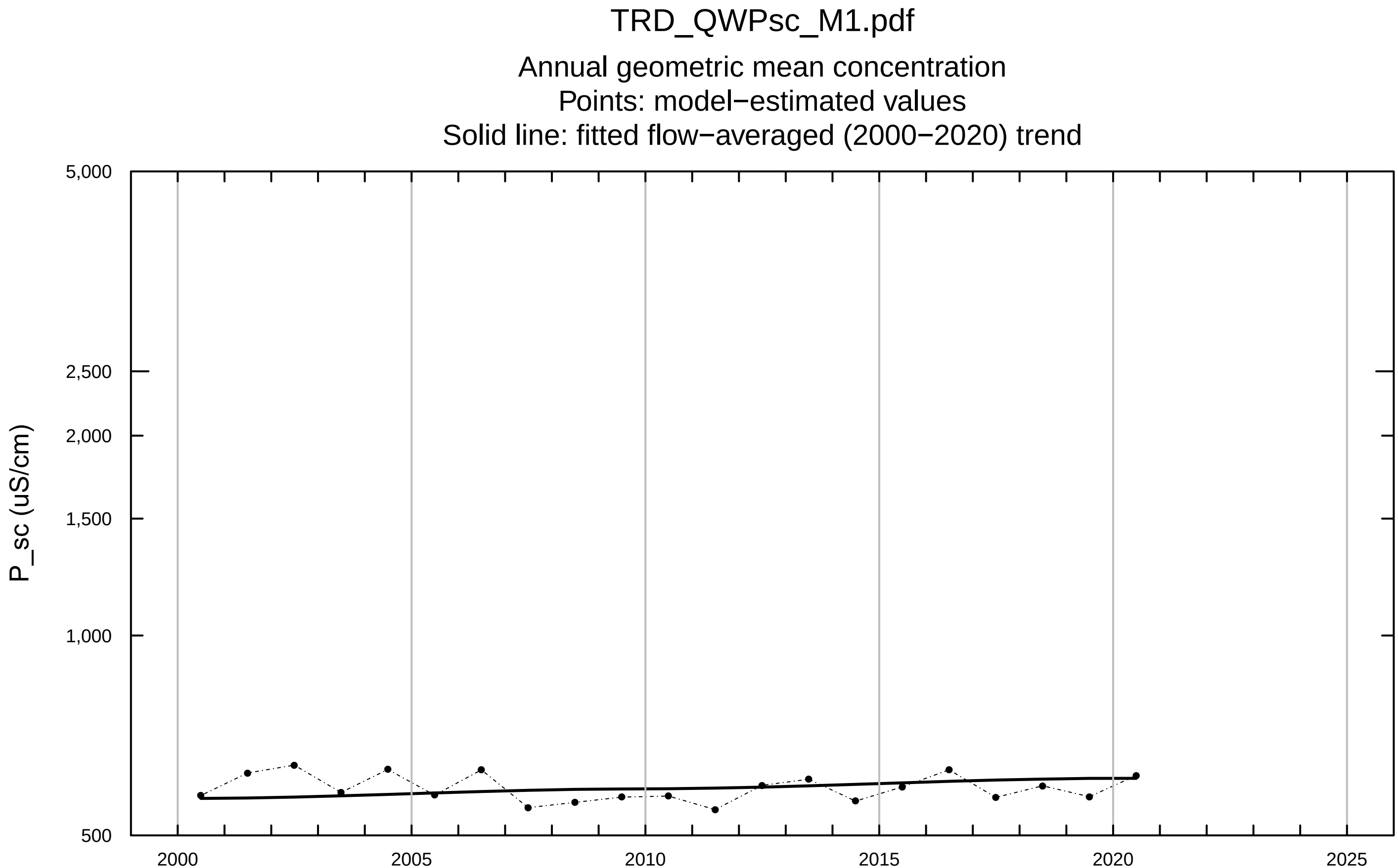
TRD_QWPsc_M1.pdf

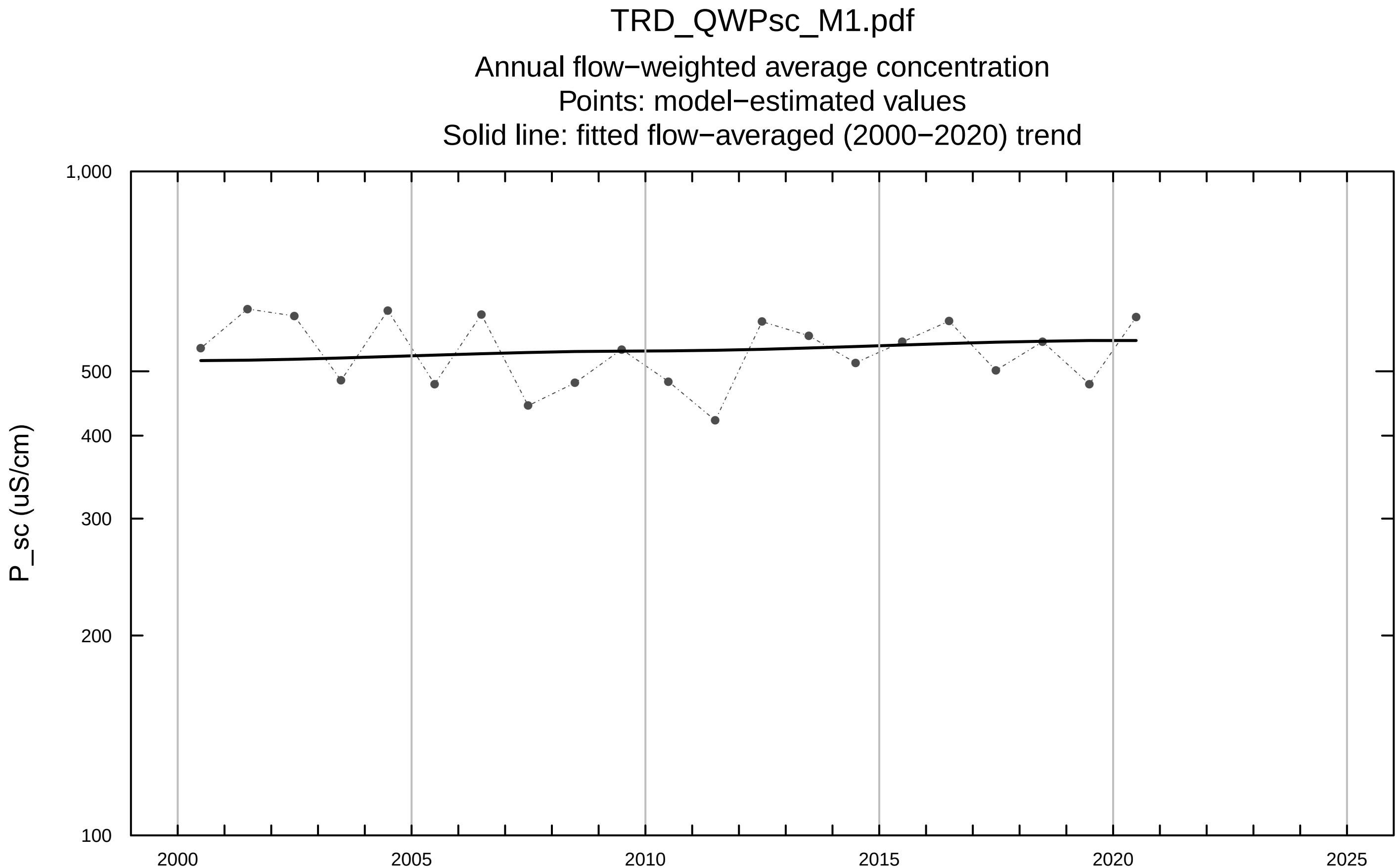
Flow−averaged exceedance probability and expected annual exceedance frequency

Thin line: Flow−averaged exceedance probability

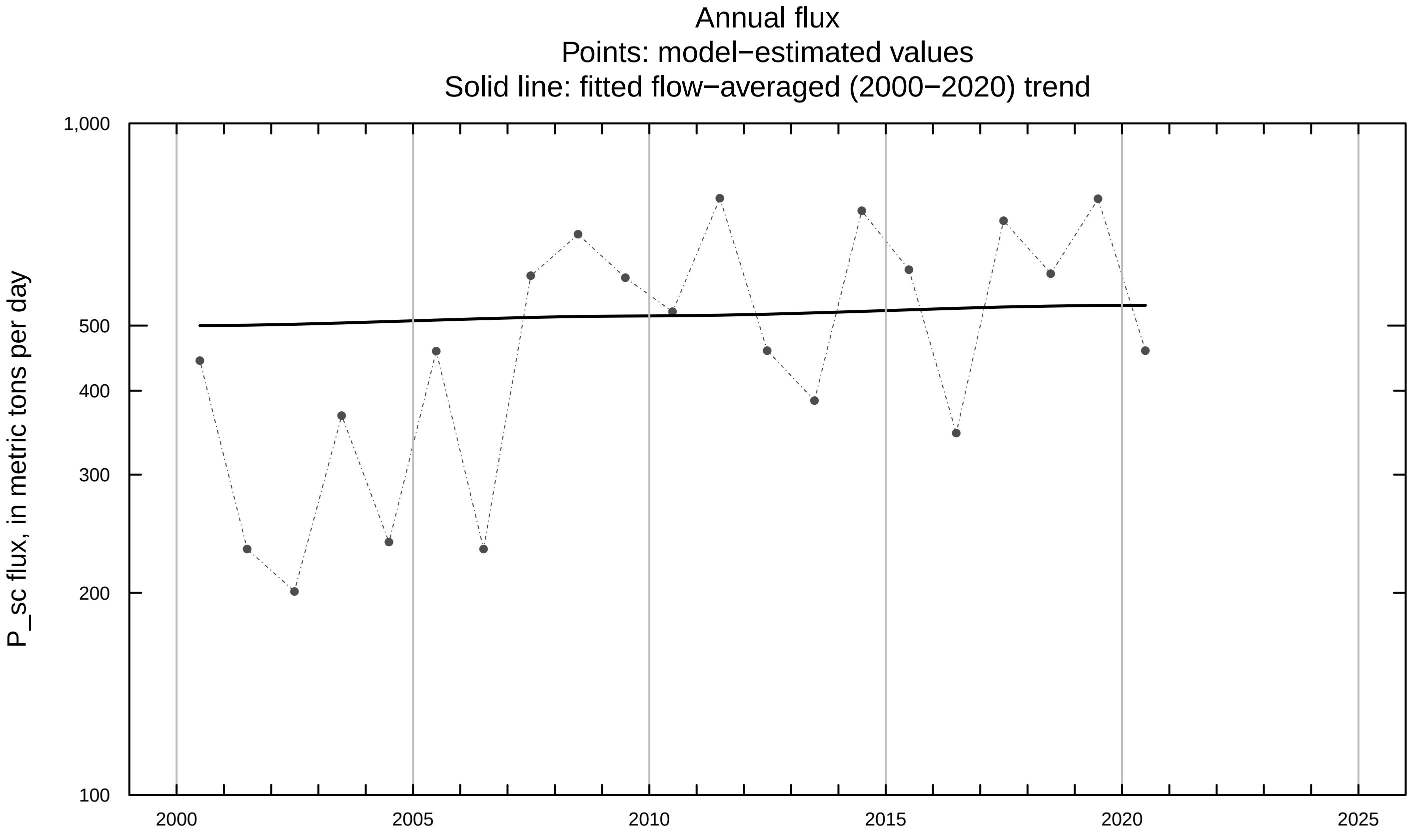
Heavy line: Expected annual flow−averaged exceedance frequency

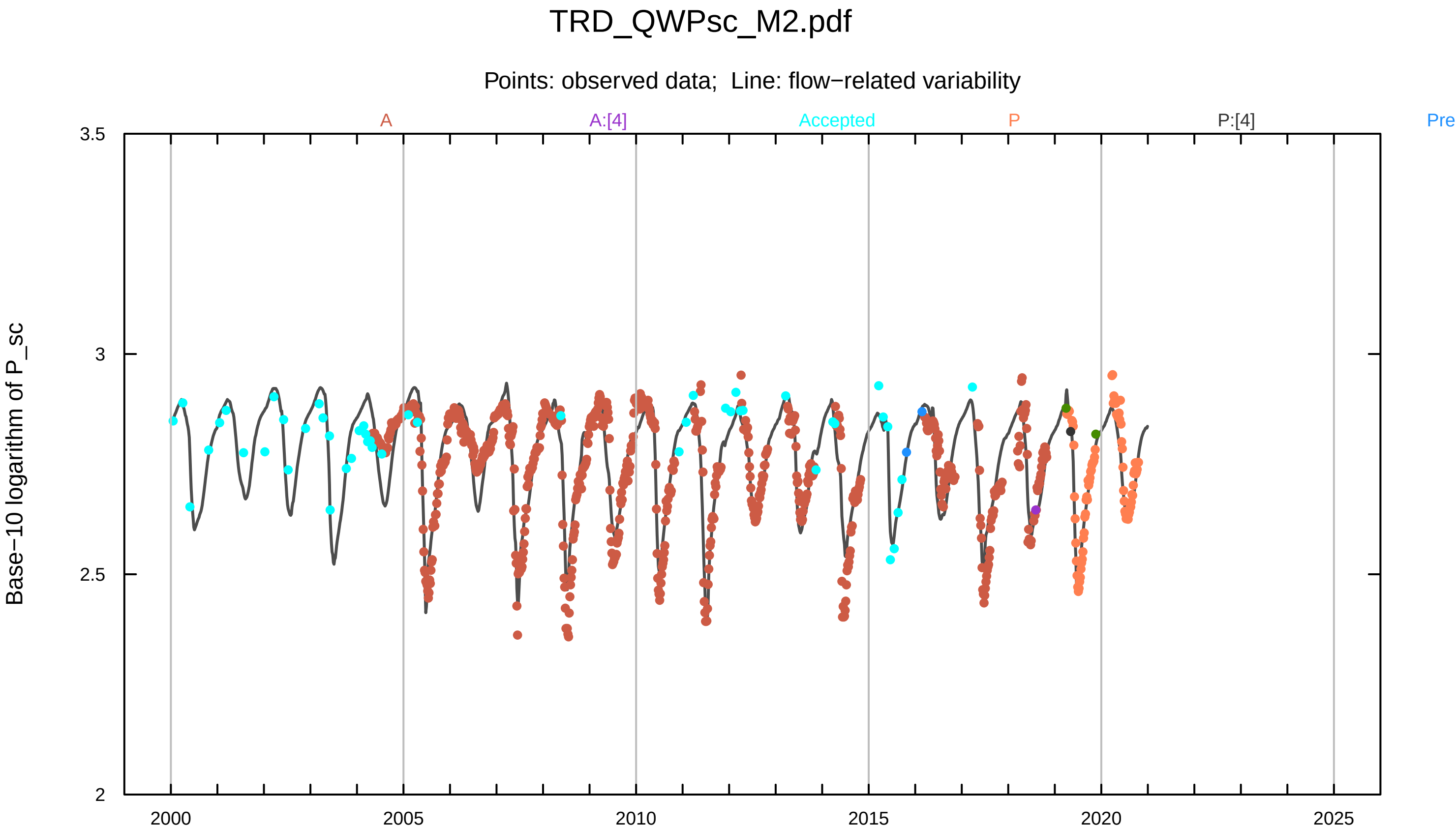



TRD_QWPsc_M1.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M1.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

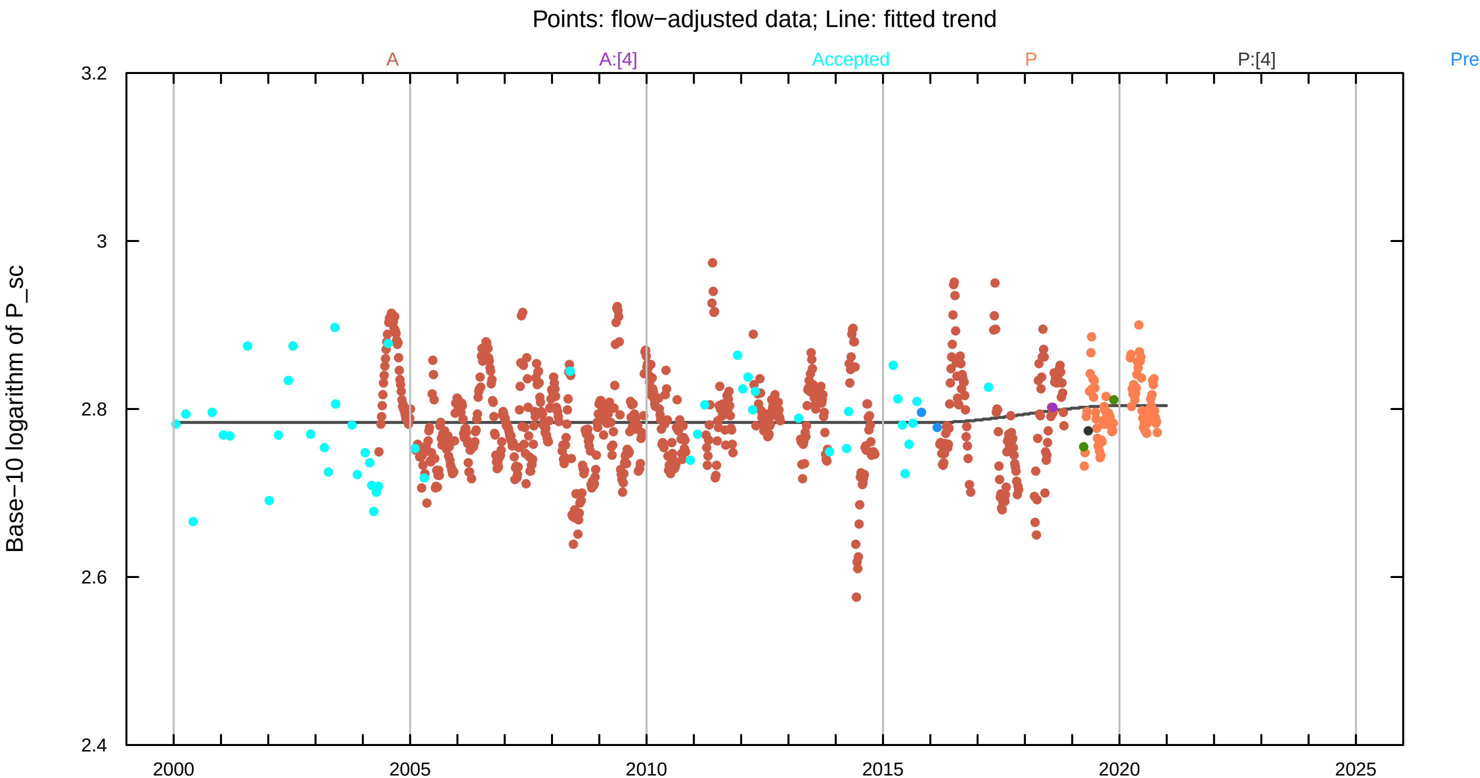
TRD_QWPsc_M1.pdf

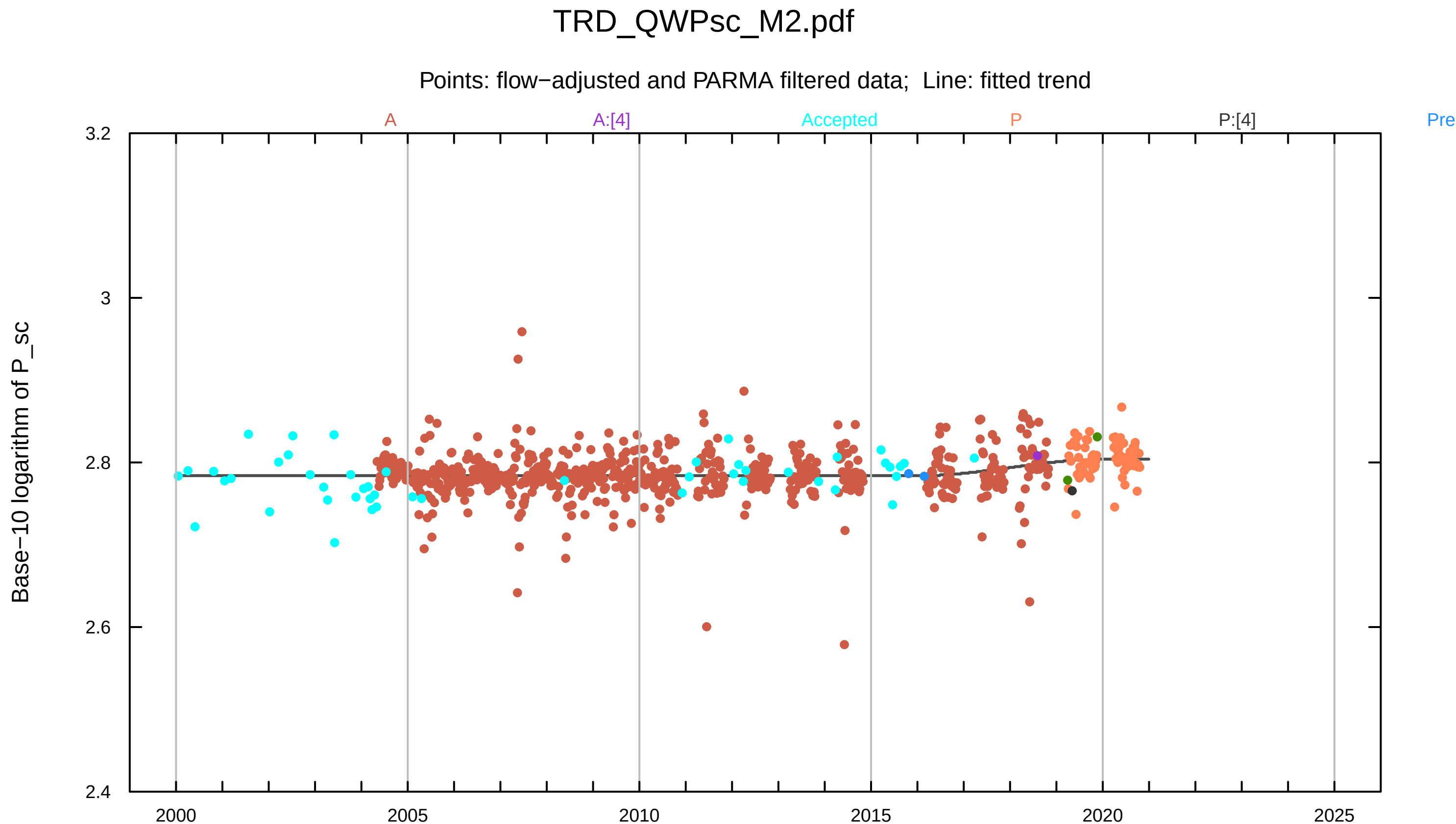


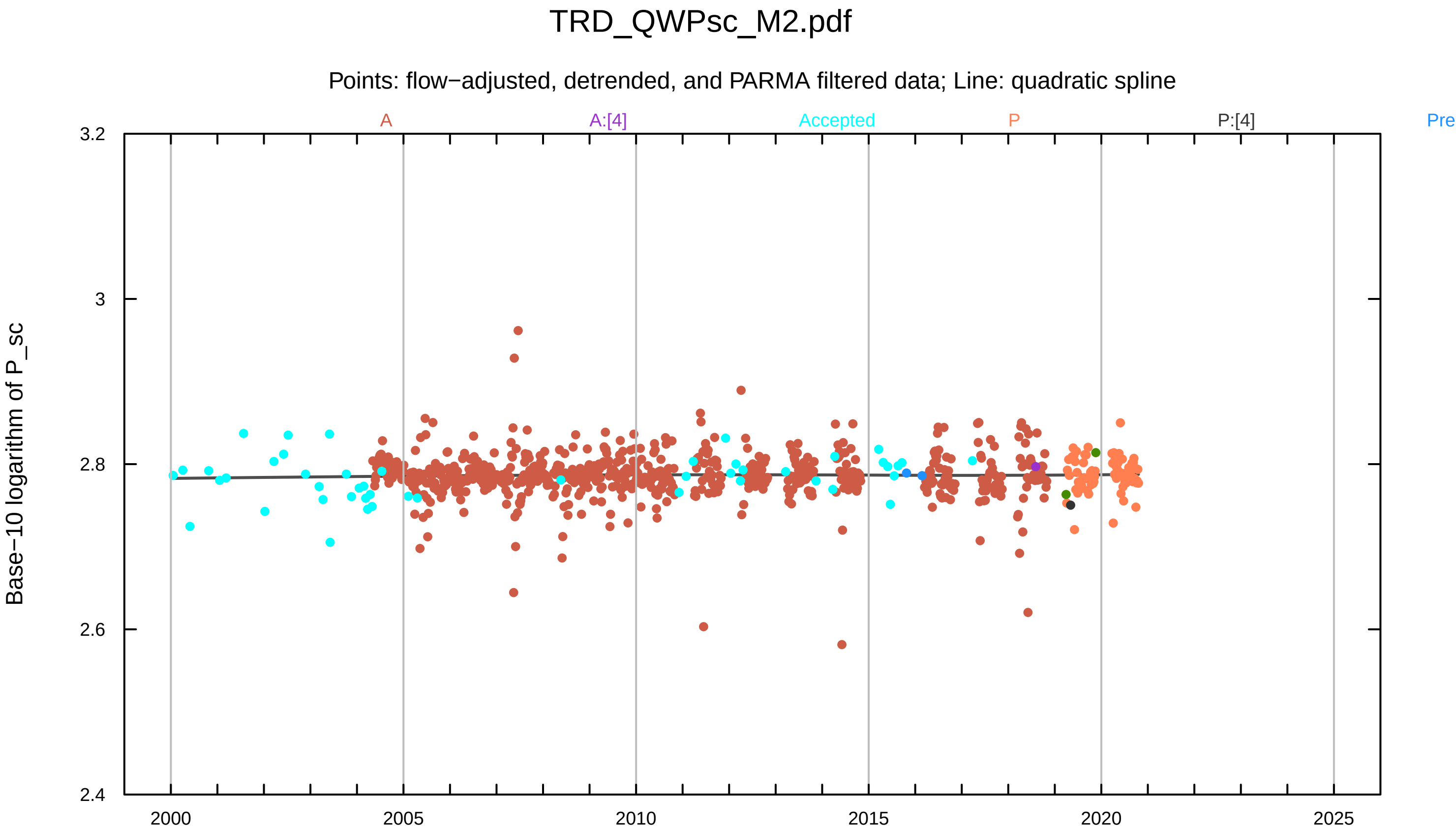


TRD_QWPsc_M2.pdf
Points: observed data; Line: flow−related variability
A
A:[4]
Accepted
P
P:[4]
Pre
3.5
3
2.5
2
Base−10 logarithm of P_sc
2000
2005
2010
2015
2020
2025

TRD_QWPsc_M2.pdf



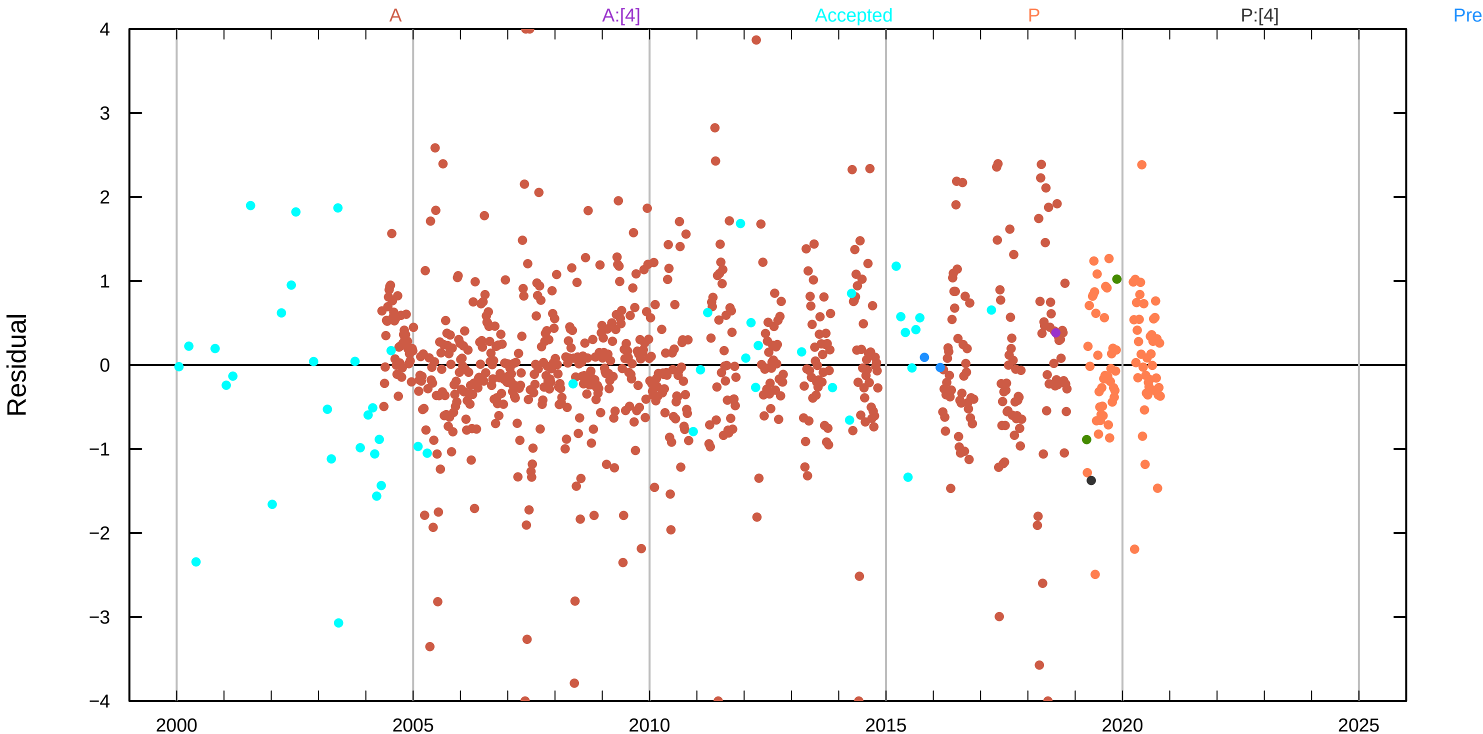

TRD_QWPsc_M2.pdf
Points: flow−adjusted and PARMA filtered data; Line: fitted trend
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025



TRD_QWPsc_M2.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

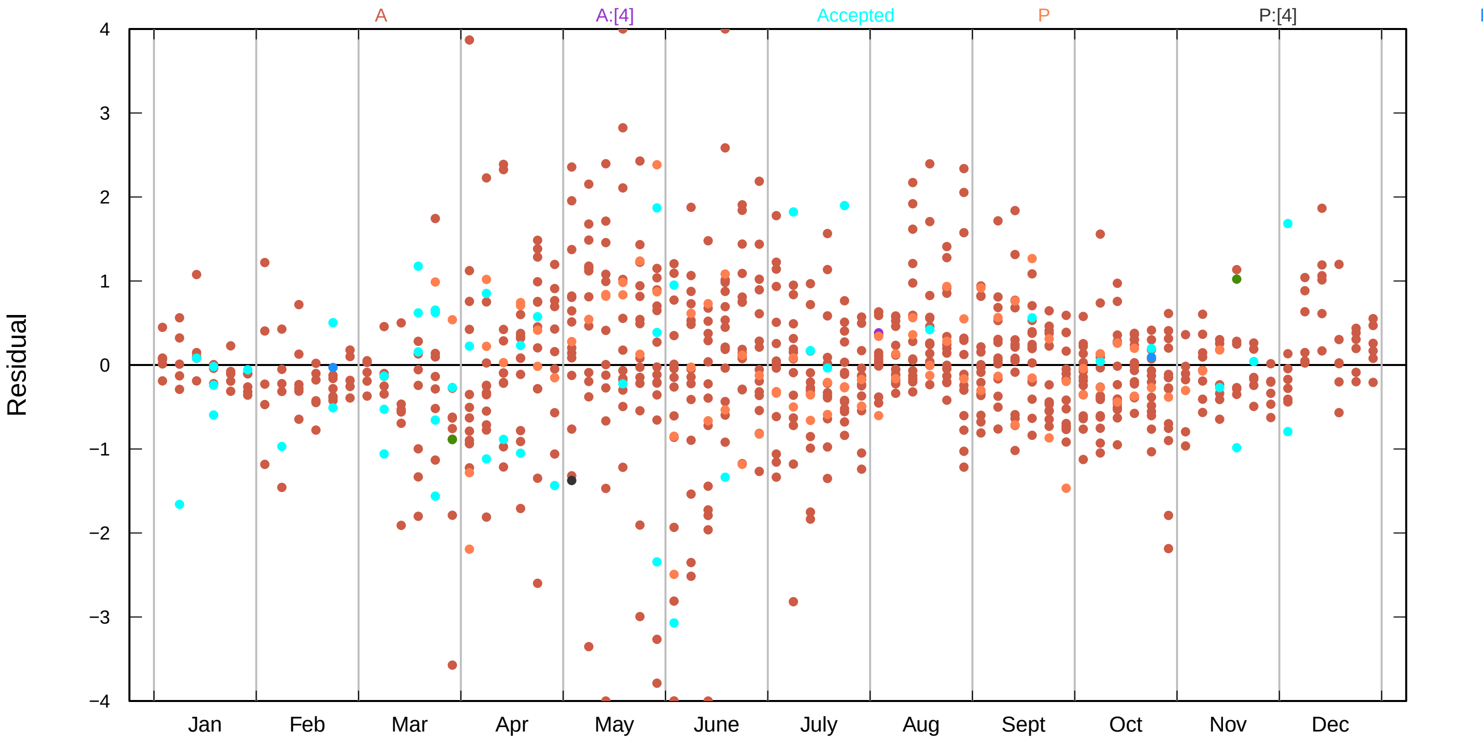
TRD_QWPsc_M2.pdf

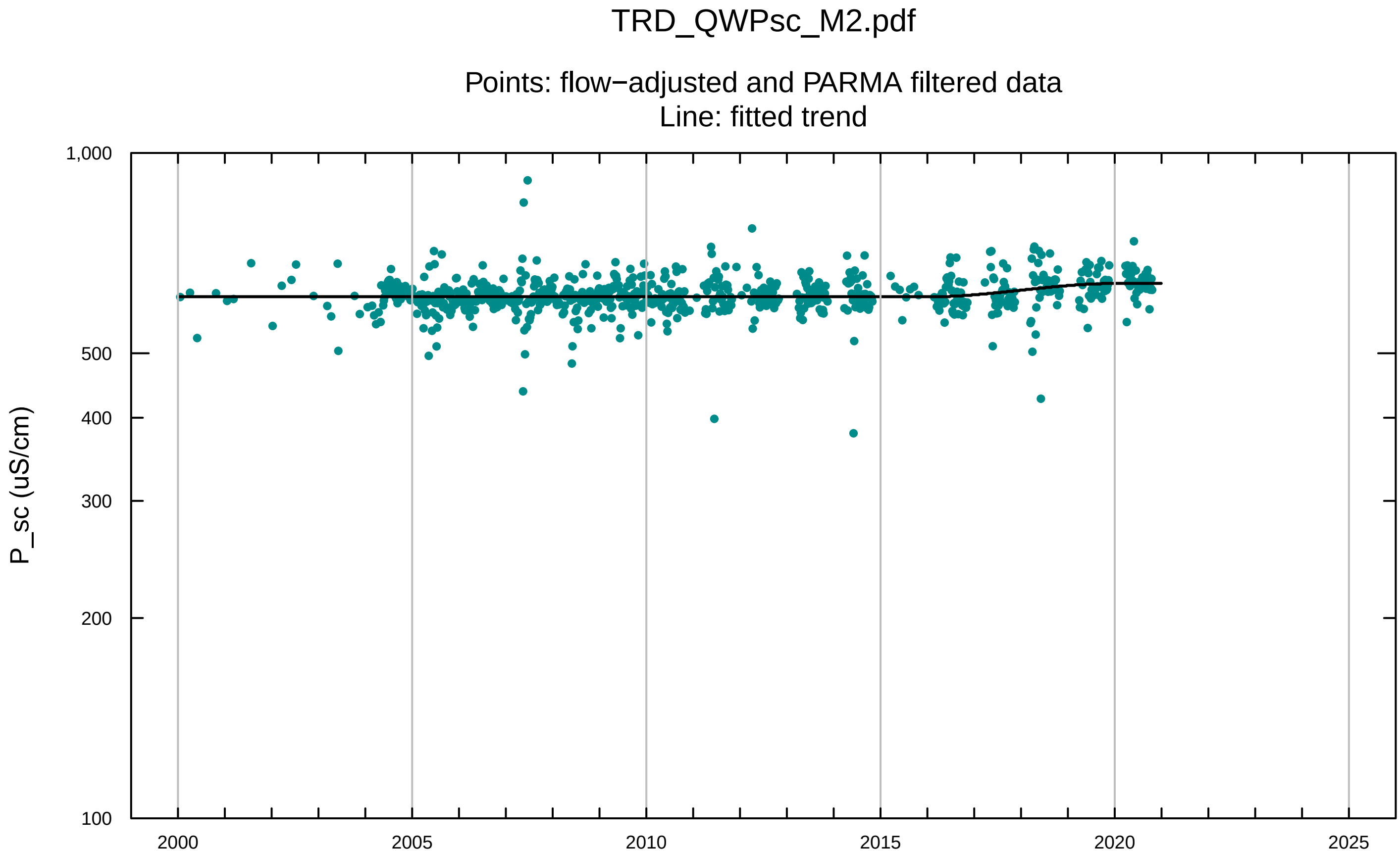
Standardized PARMA model residuals versus decimal year



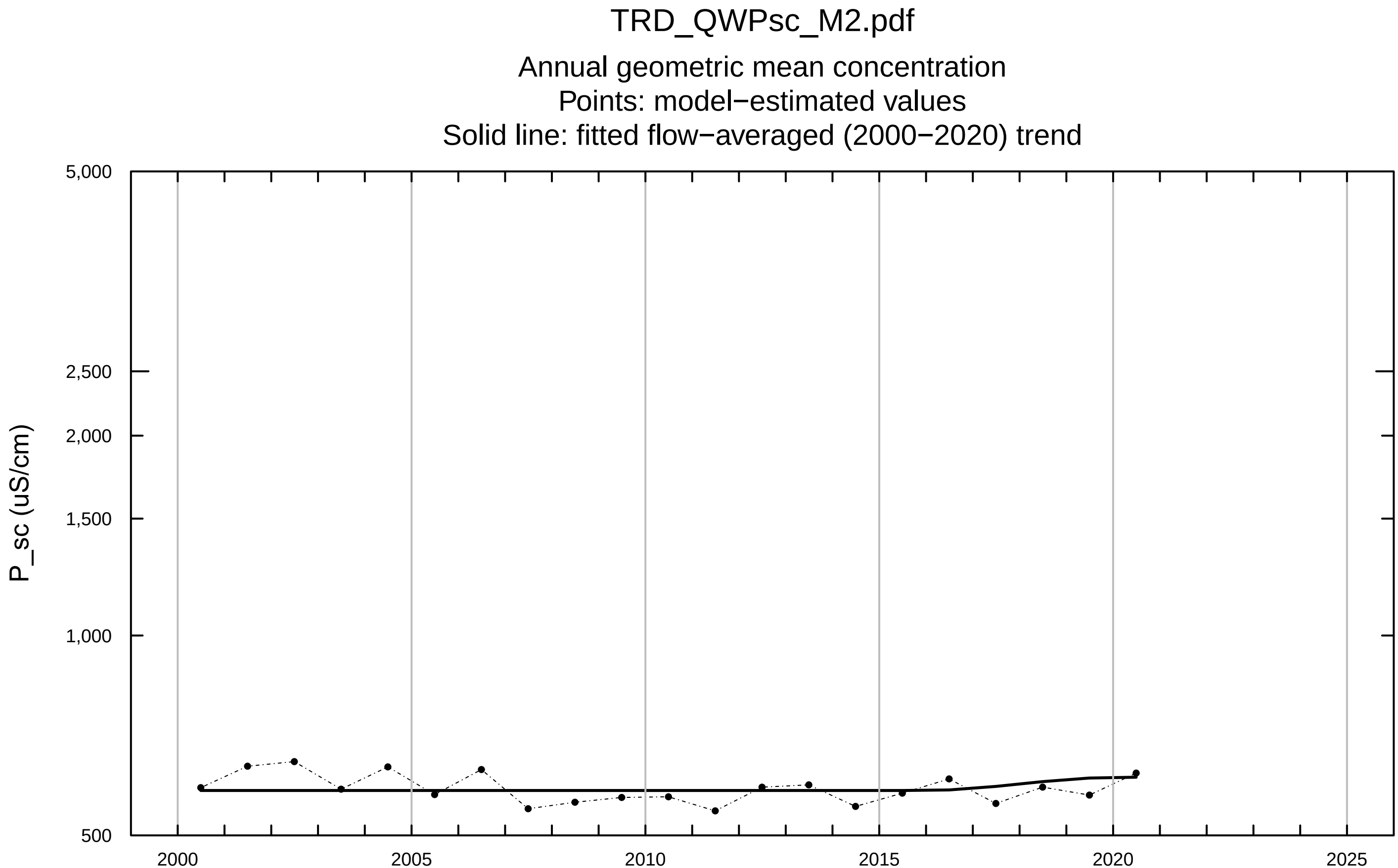
TRD_QWPsc_M2.pdf

Standardized Parma model residuals versus decimal season

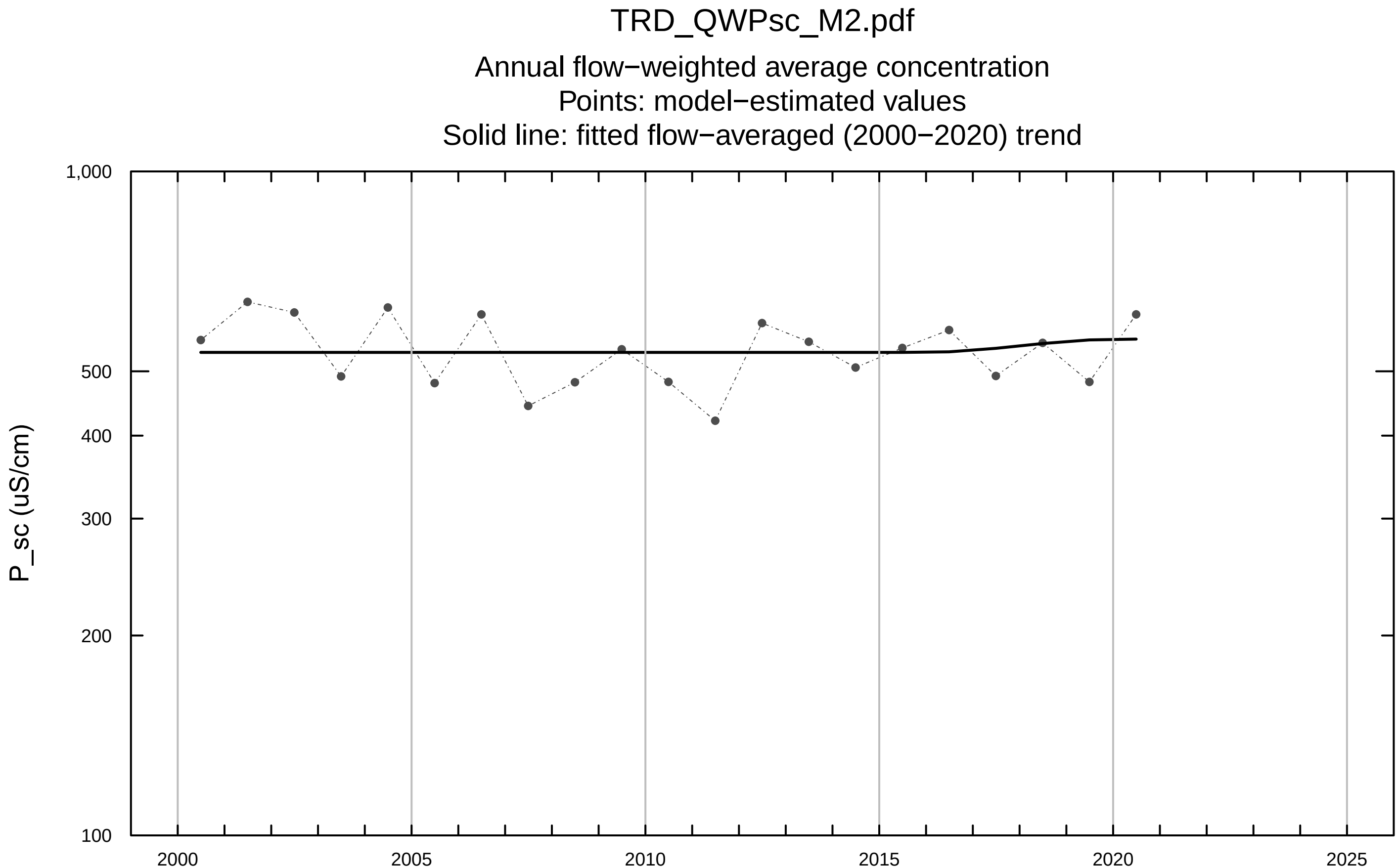


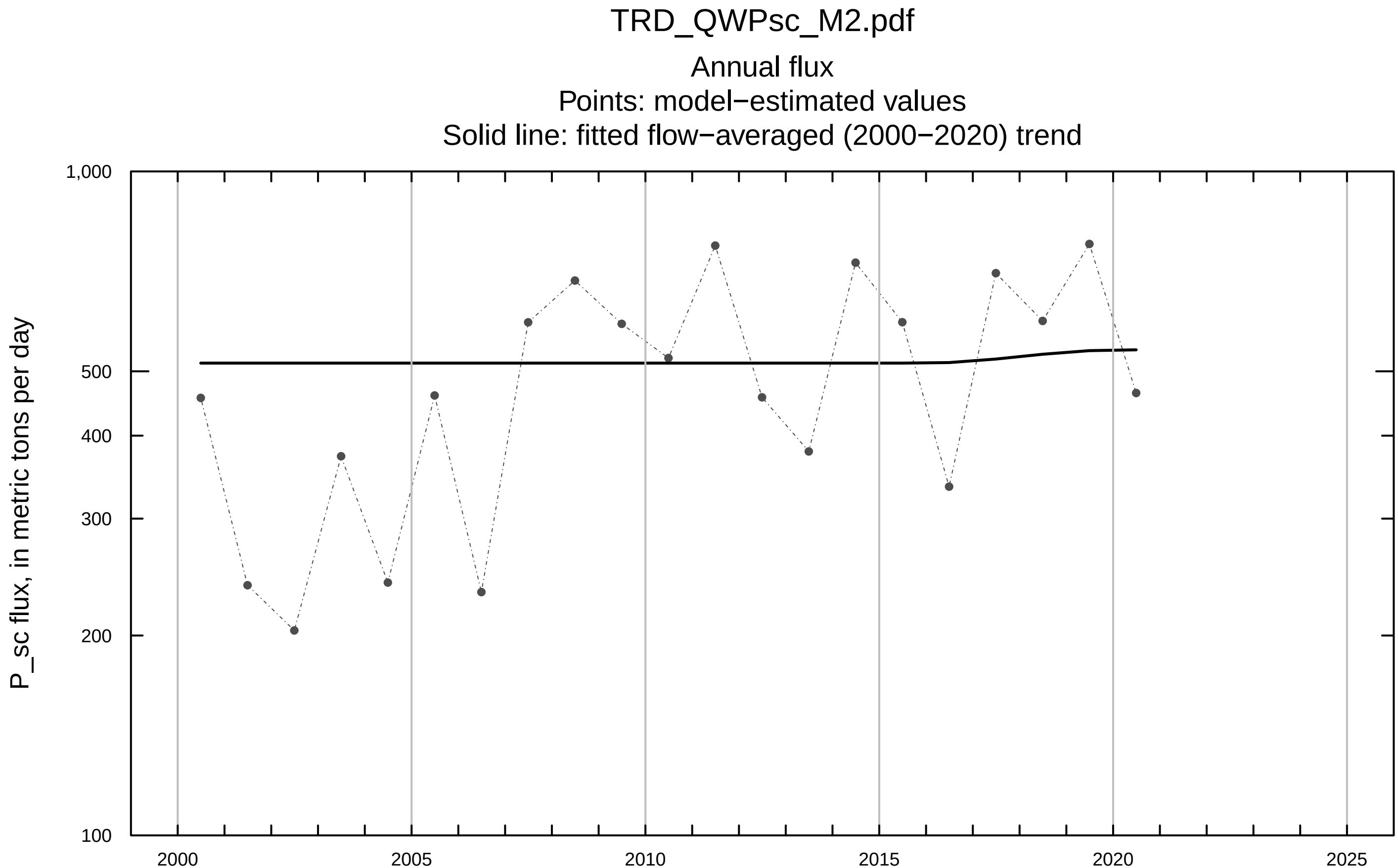


TRD_QWPsc_M2.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

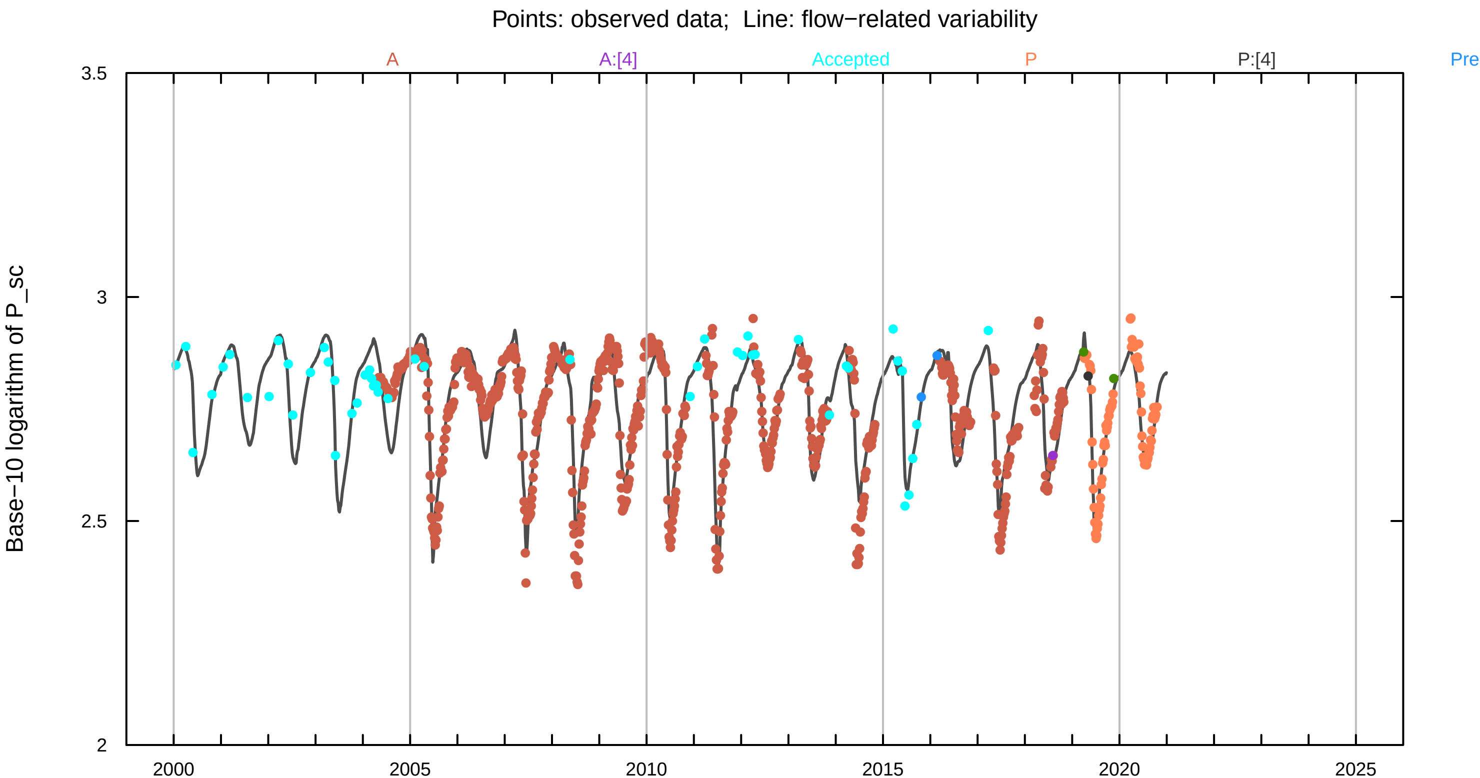


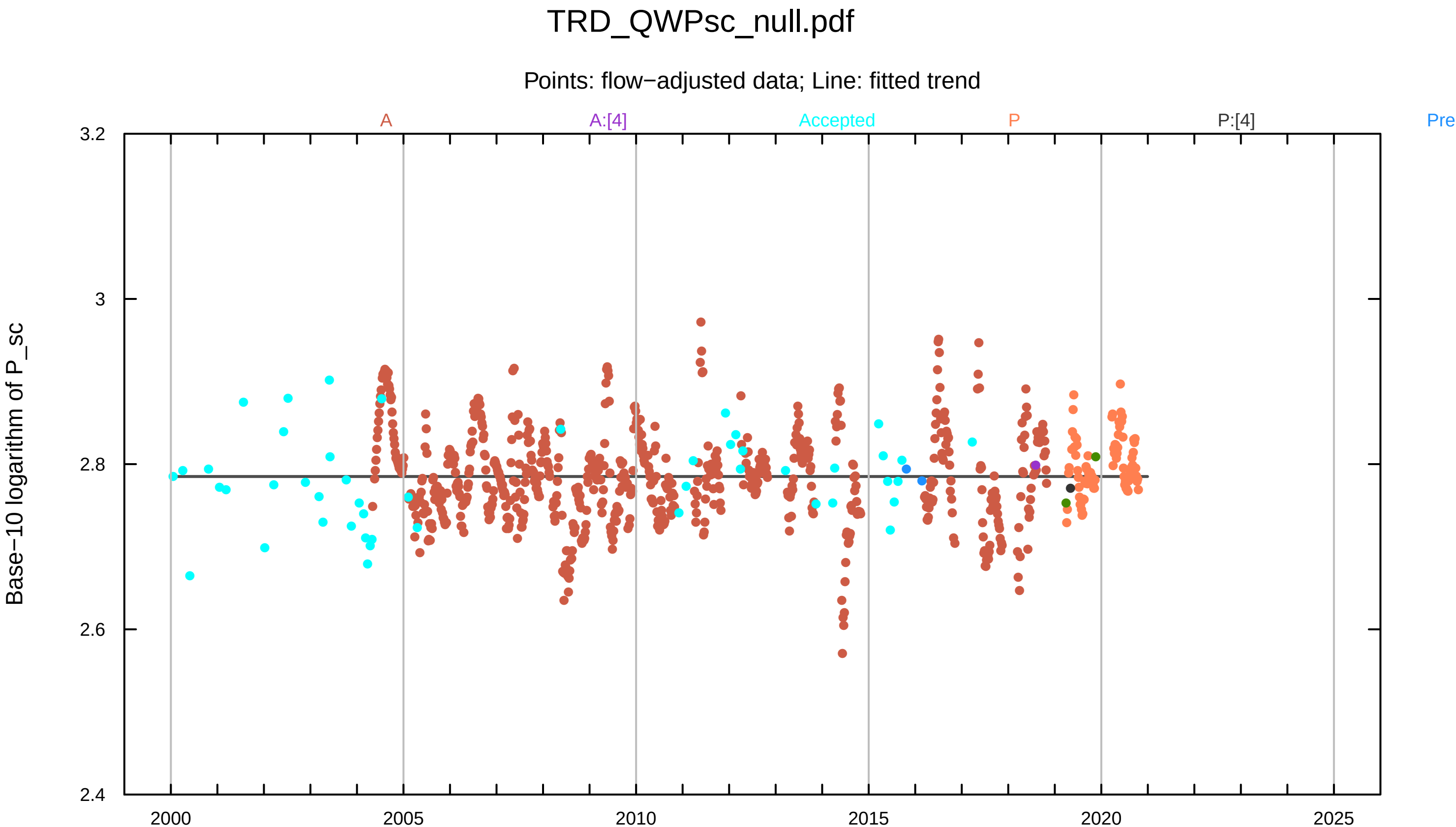
TRD_QWPsc_M2.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M2.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
1,000
500
400
300
200
100
P_sc (uS/cm)
2000
2005
2010
2015
2020
2025


TRD_QWPsc_M2.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

TRD_QWPsc_null.pdf

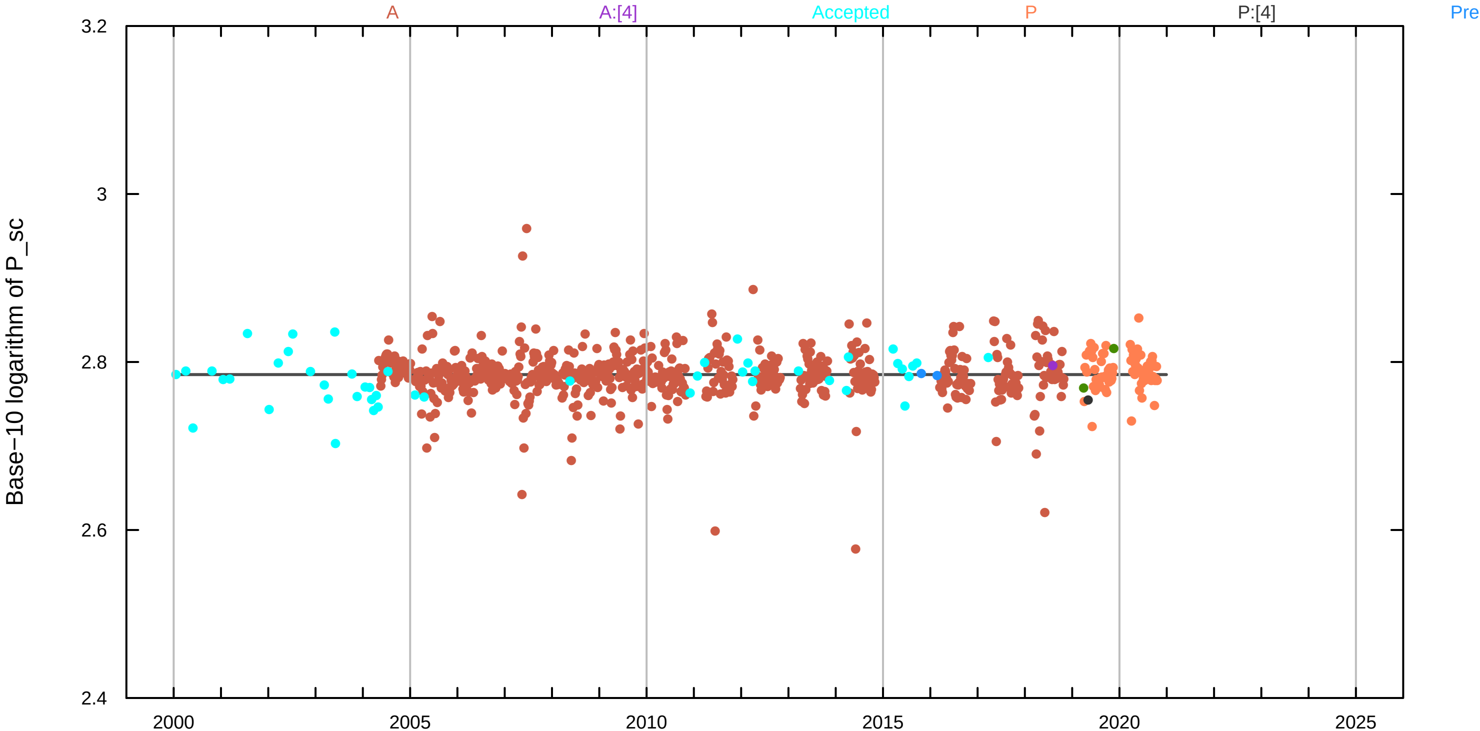


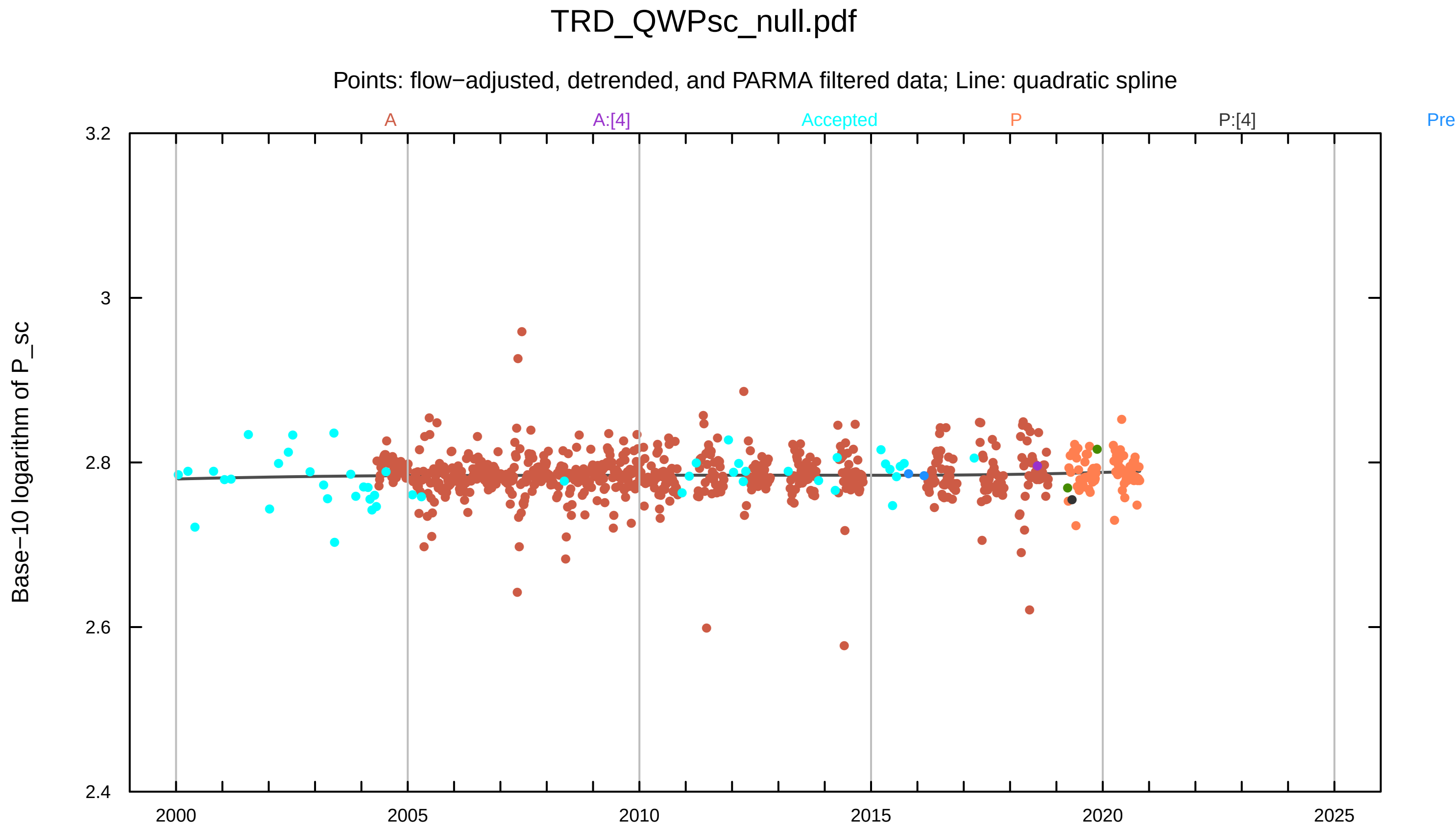


TRD_QWPsc_null.pdf
Points: flow−adjusted data; Line: fitted trend
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

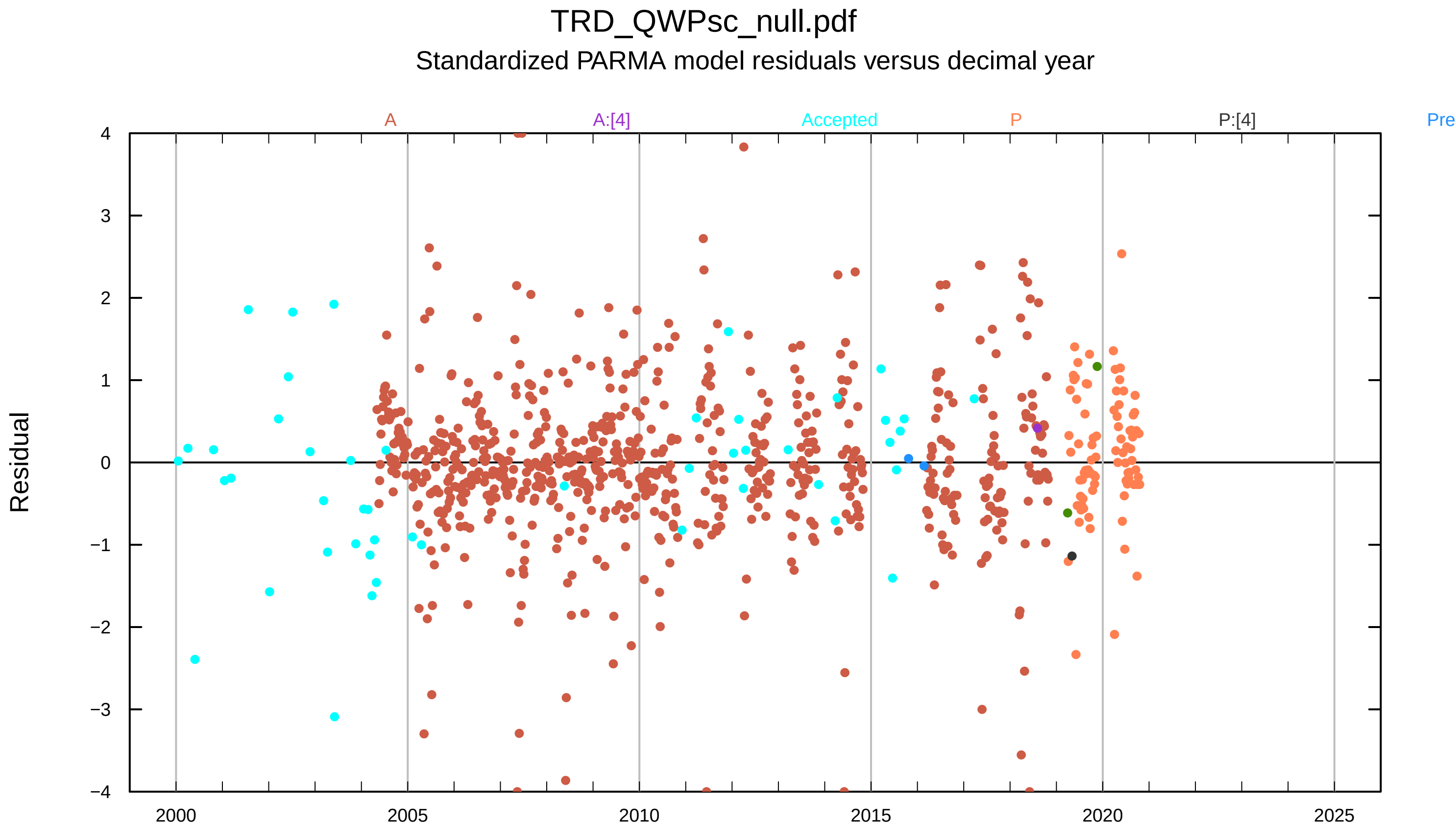
TRD_QWPsc_null.pdf

Points: flow−adjusted and PARMA filtered data; Line: fitted trend





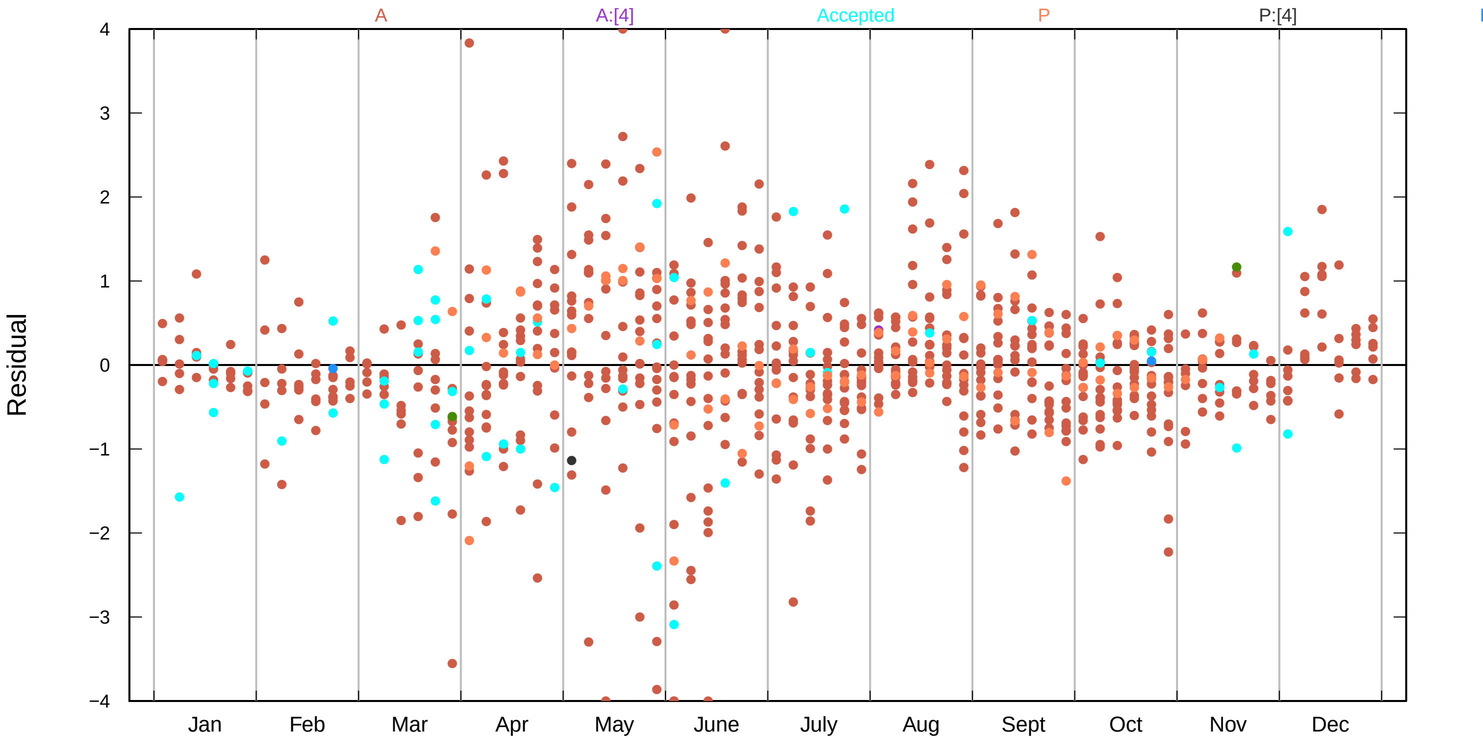
TRD_QWPsc_null.pdf
Points: flow−adjusted, detrended, and PARMA filtered data; Line: quadratic spline
A
A:[4]
Accepted
P
P:[4]
Pre
Base−10 logarithm of P_sc
3.2
3
2.8
2.6
2.4
2000
2005
2010
2015
2020
2025

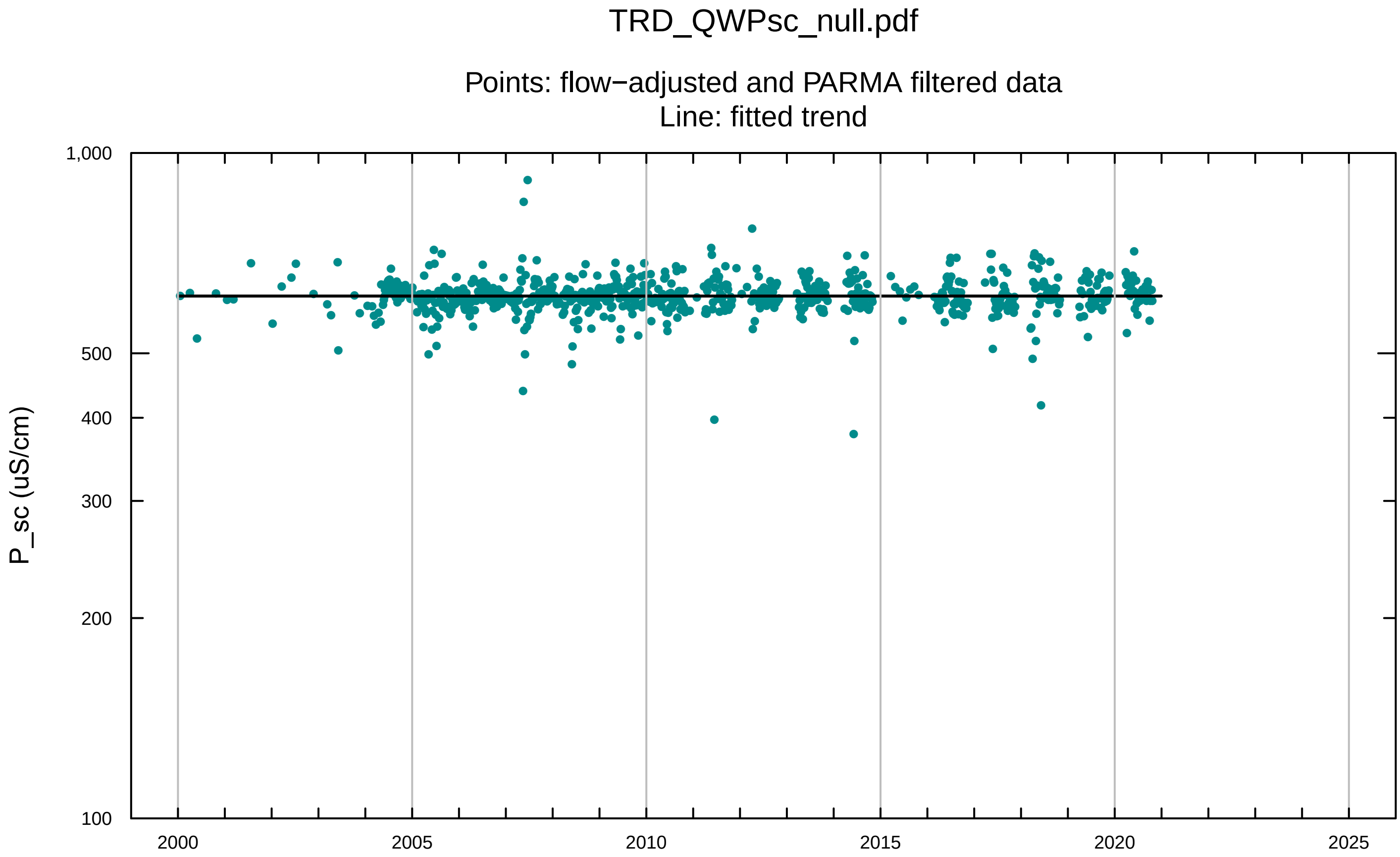


TRD_QWPsc_null.pdf
Standardized PARMA model residuals versus decimal year
A
A:[4]
Accepted
P
P:[4]
Pre
Residual
4
3
2
1
0
−1
−2
−3
−4
2000
2005
2010
2015
2020
2025

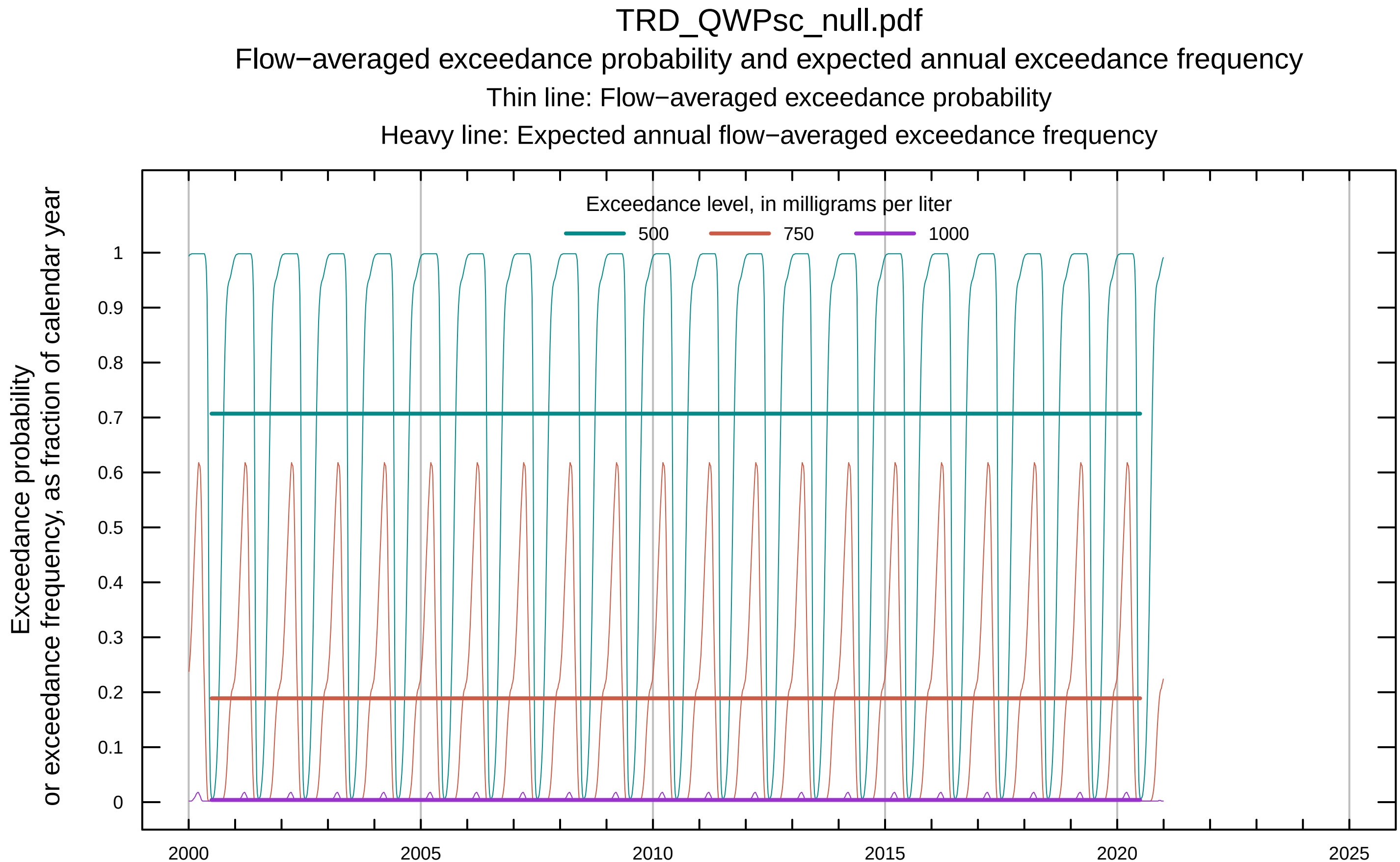
TRD_QWPsc_null.pdf

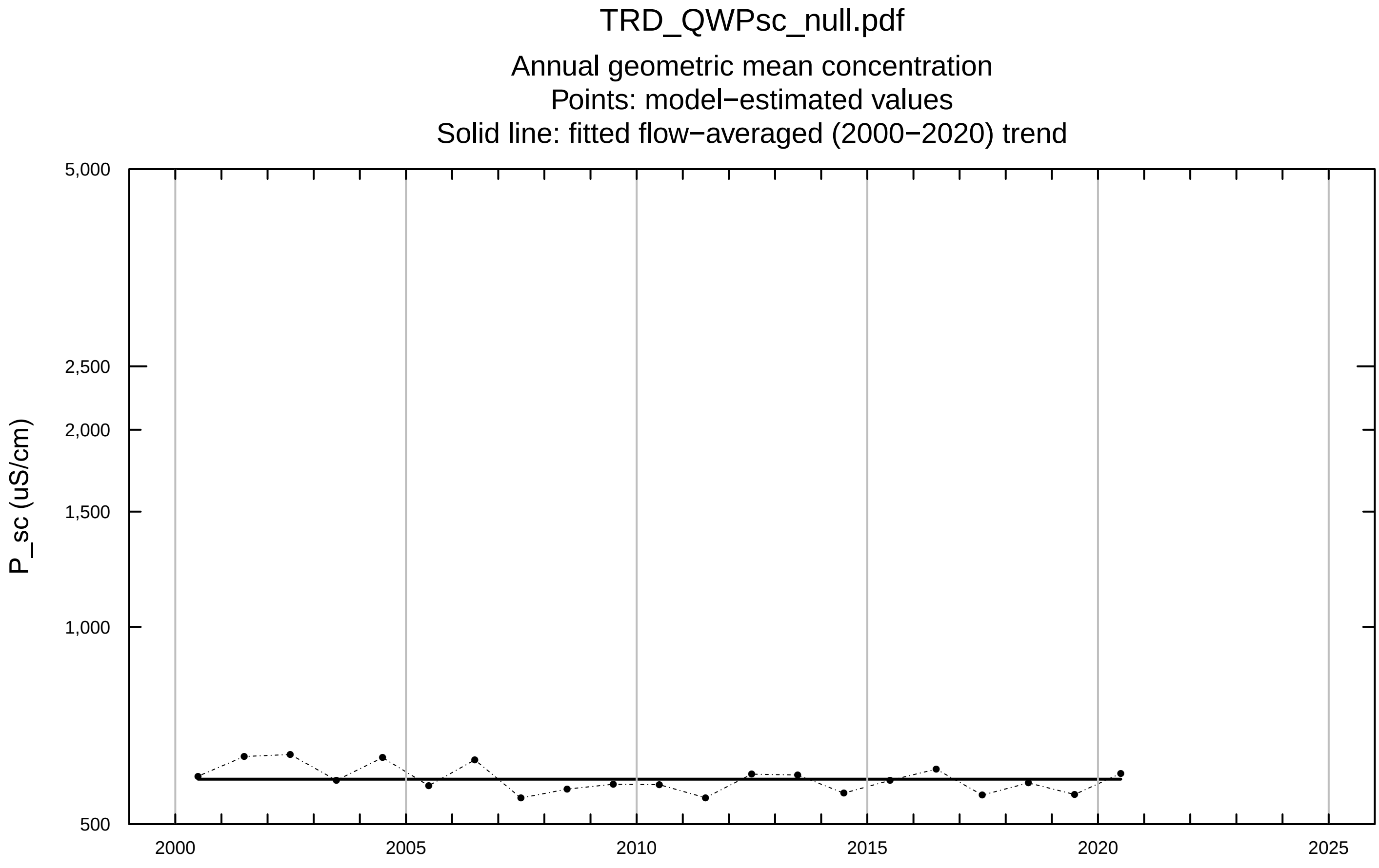
Standardized Parma model residuals versus decimal season



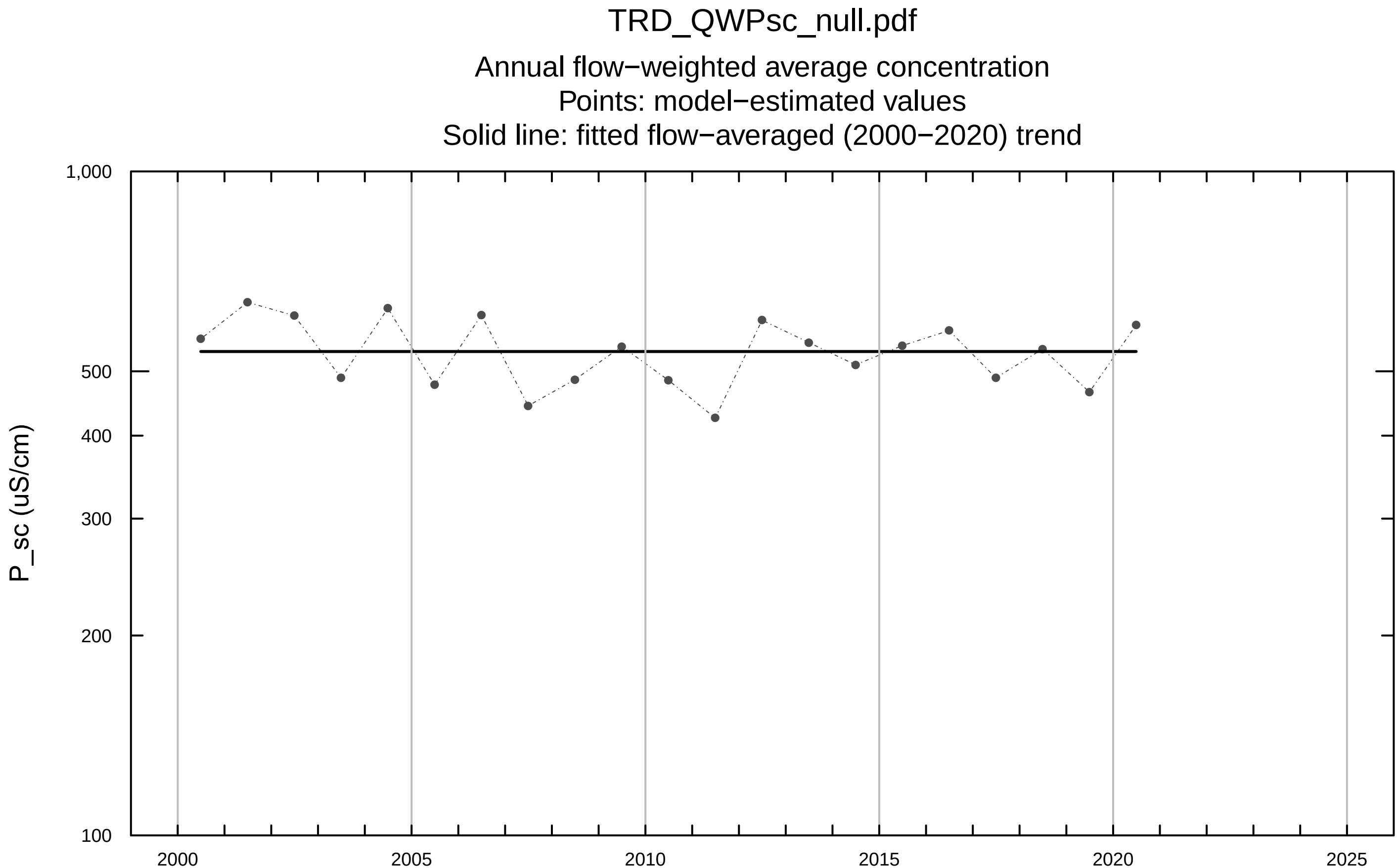


TRD_QWPsc_null.pdf
Points: flow−adjusted and PARMA filtered data
Line: fitted trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

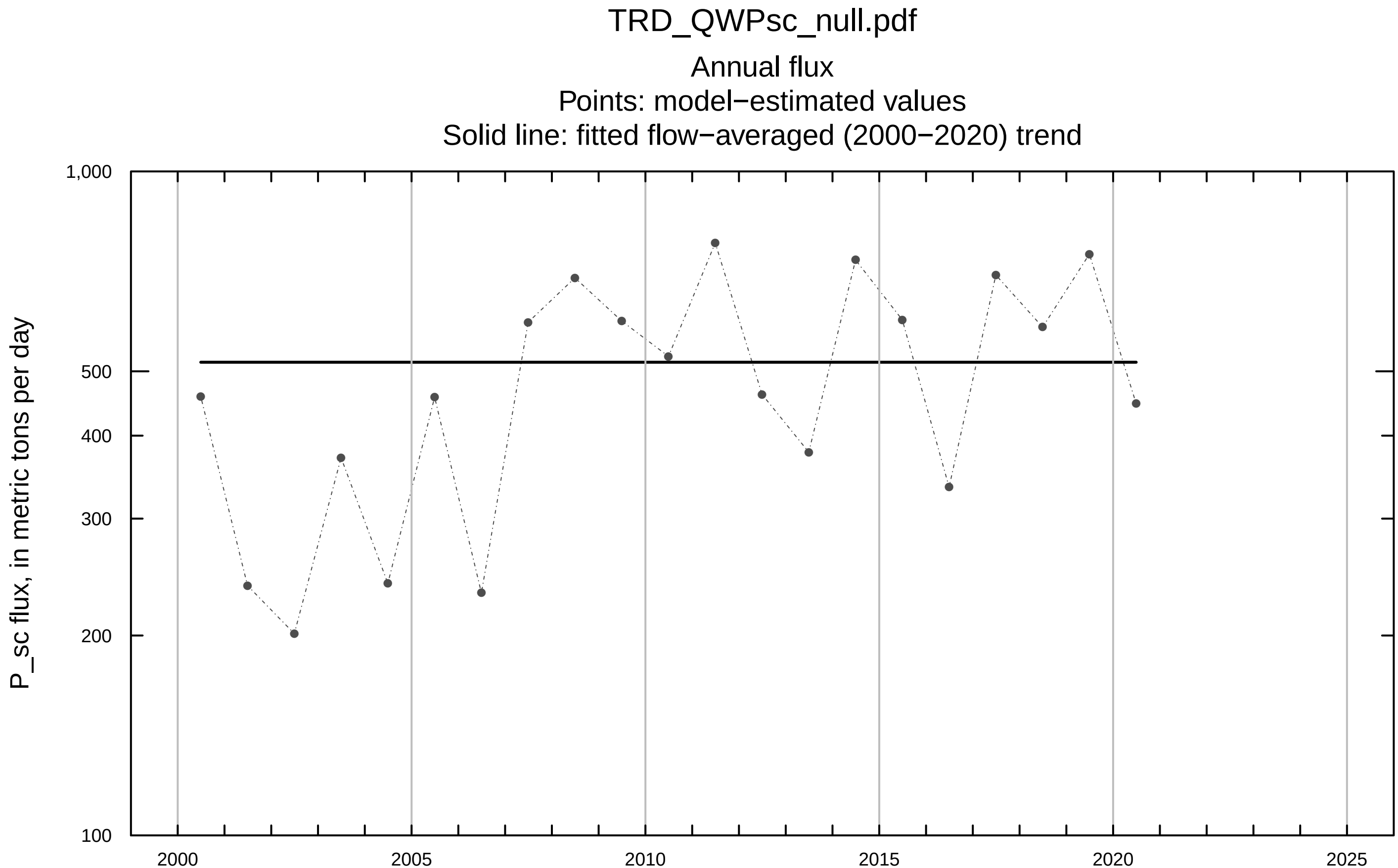

TRD_QWPsc_null.pdf
Flow−averaged exceedance probability and expected annual exceedance frequency
Thin line: Flow−averaged exceedance probability
Heavy line: Expected annual flow−averaged exceedance frequency
Exceedance level, in milligrams per liter
500
750
1000
Exceedance probability
or exceedance frequency, as fraction of calendar year
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2000
2005
2010
2015
2020
2025



TRD_QWPsc_null.pdf
Annual geometric mean concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
5,000
2,500
2,000
1,500
1,000
500
2000
2005
2010
2015
2020
2025

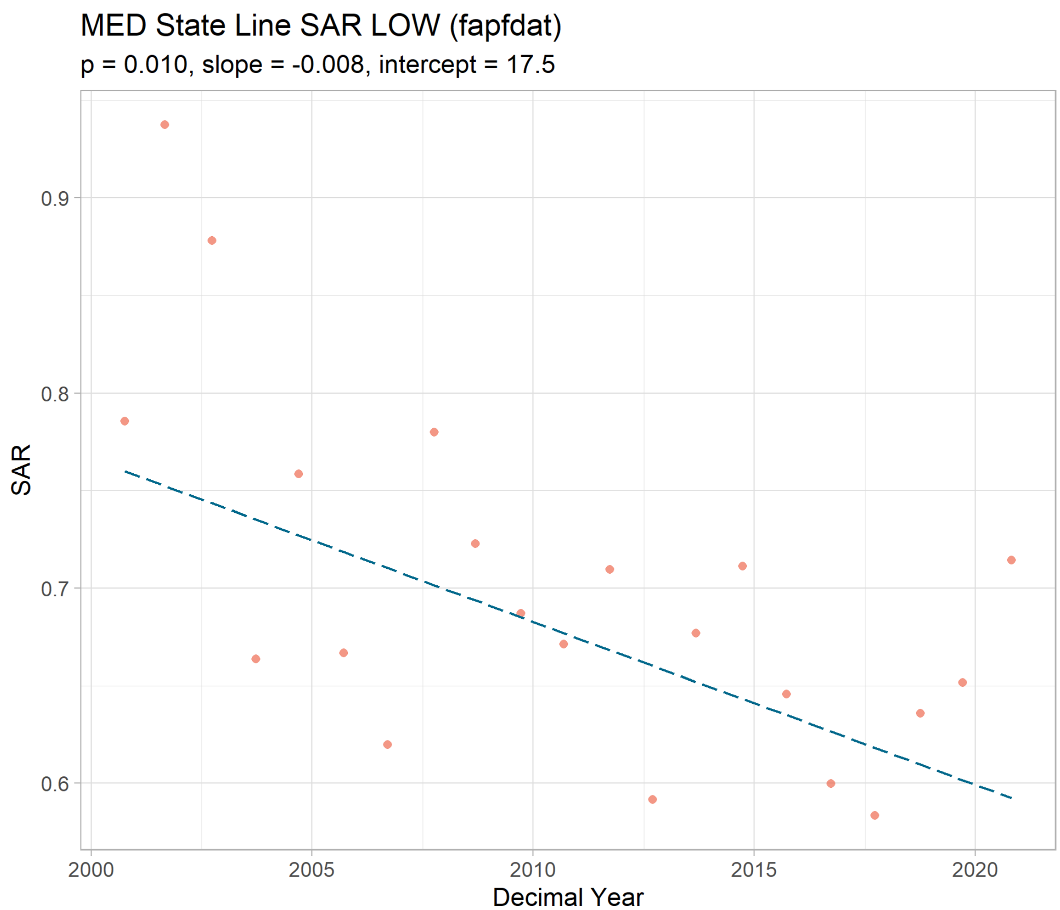


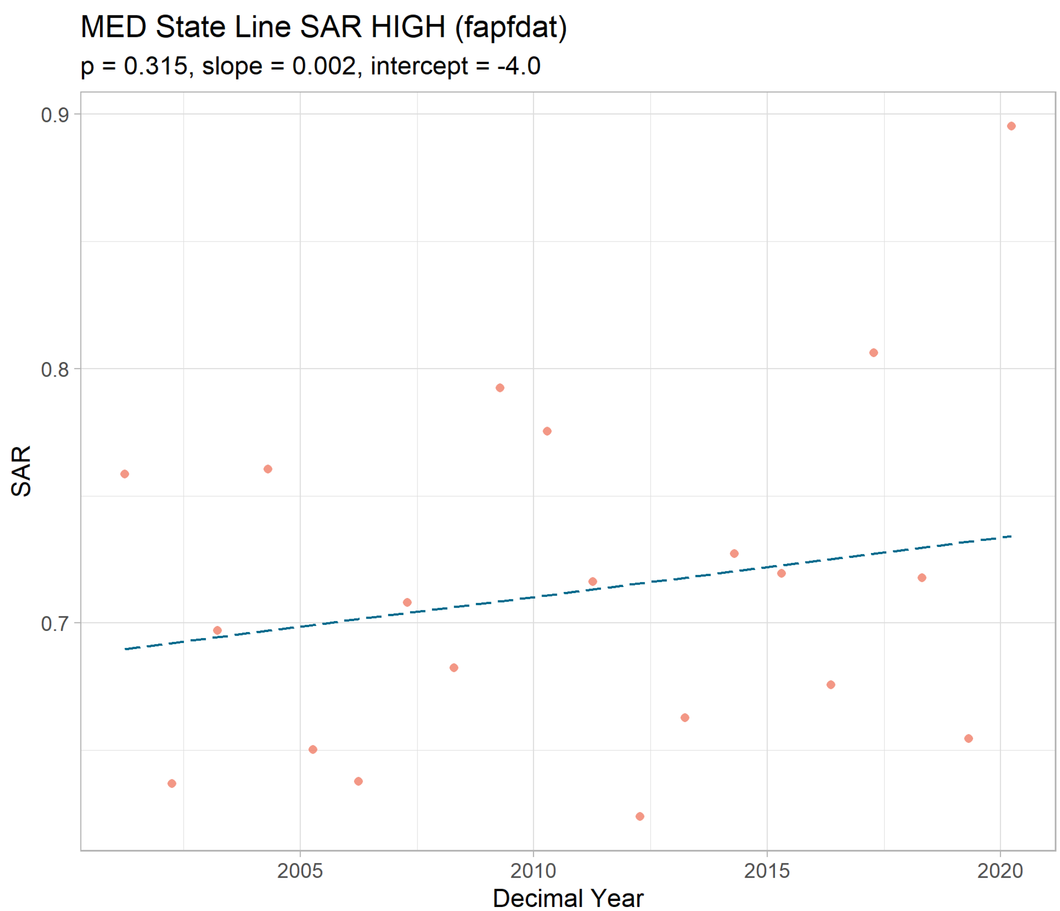
TRD_QWPsc_null.pdf
Annual flow−weighted average concentration
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc (uS/cm)
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025



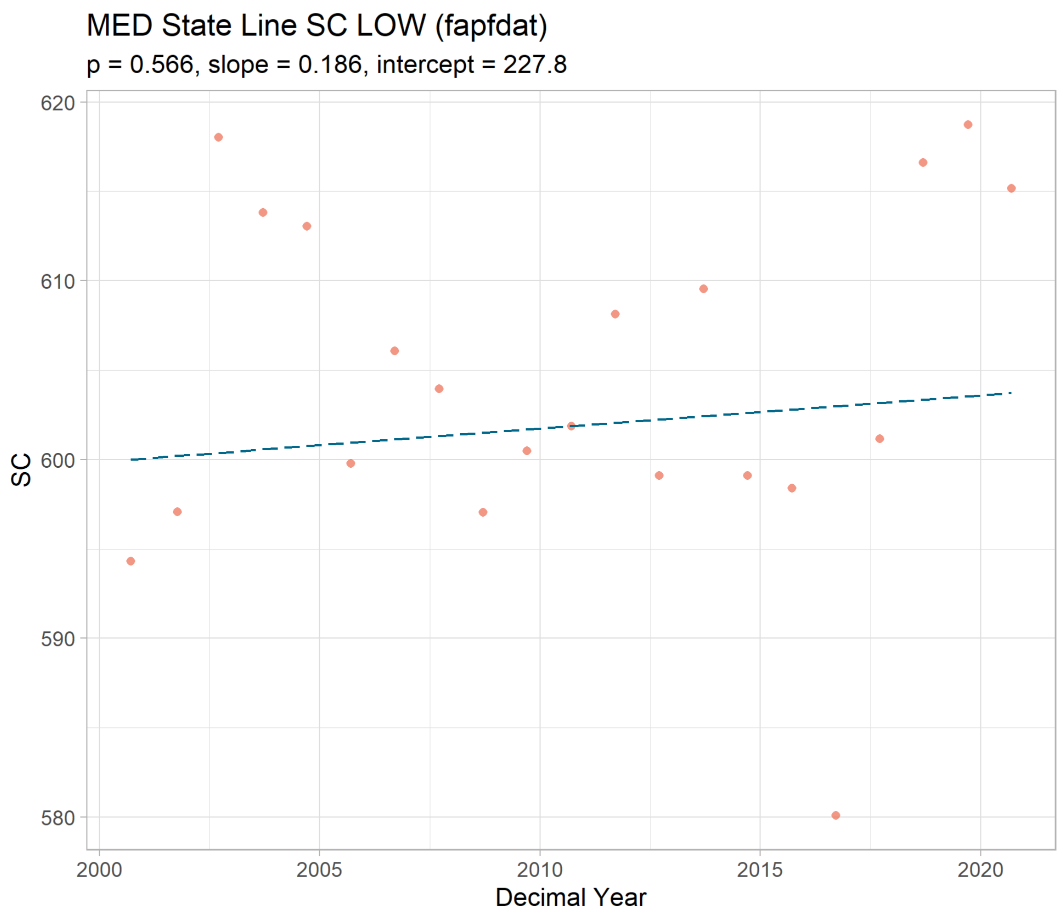
TRD_QWPsc_null.pdf
Annual flux
Points: model−estimated values
Solid line: fitted flow−averaged (2000−2020) trend
P_sc flux, in metric tons per day
1,000
500
400
300
200
100
2000
2005
2010
2015
2020
2025

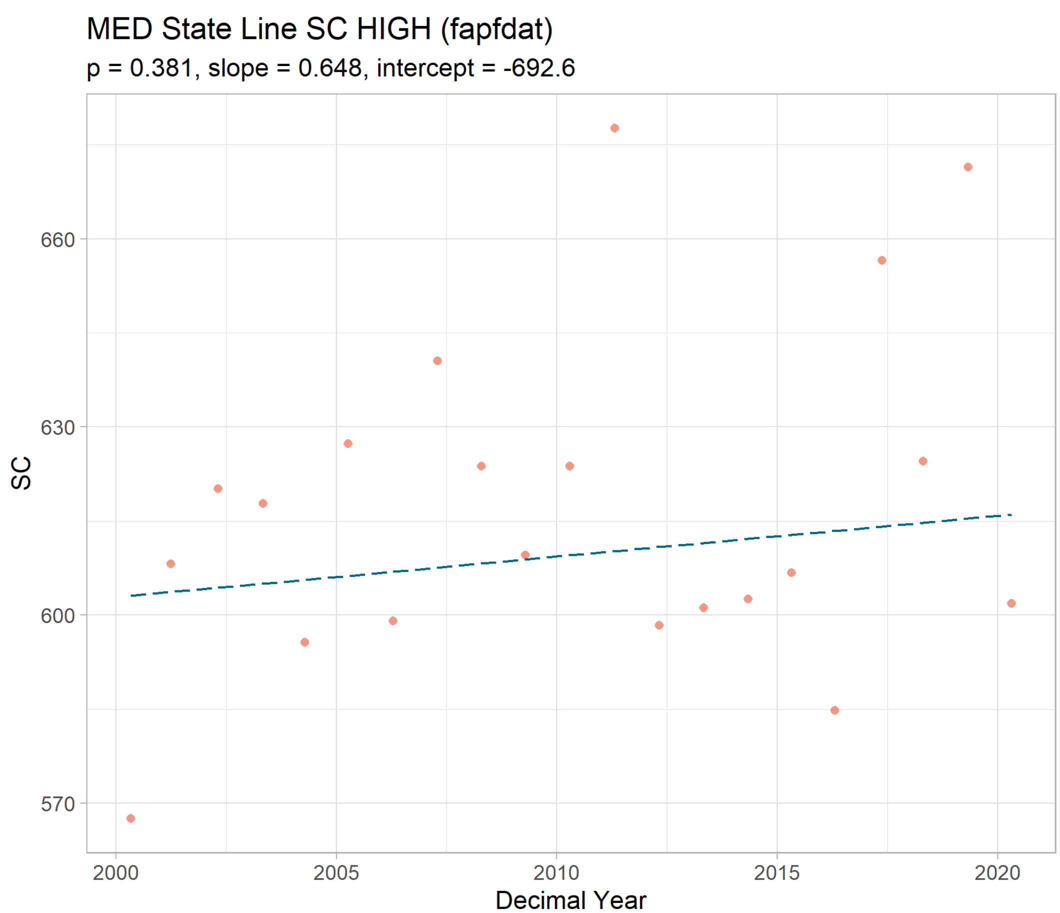
Appendix E – Plots of Mann-Kendall Trend Analyses



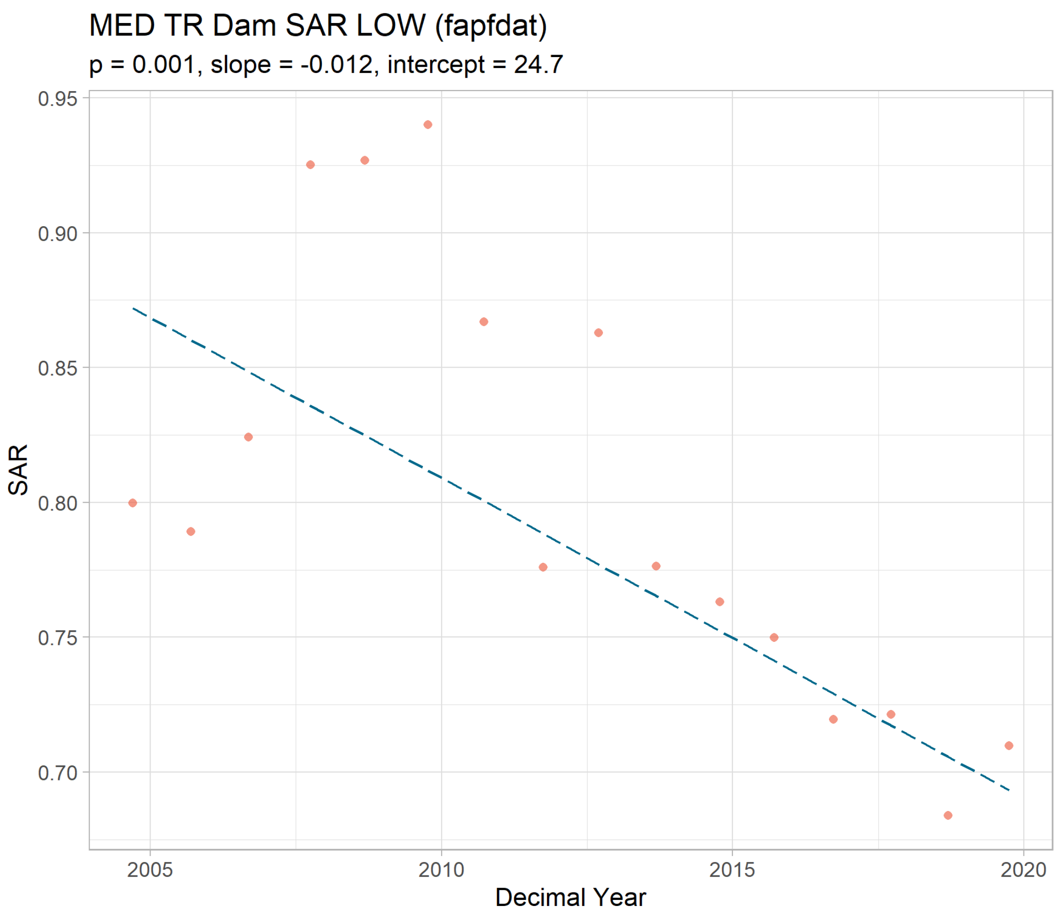


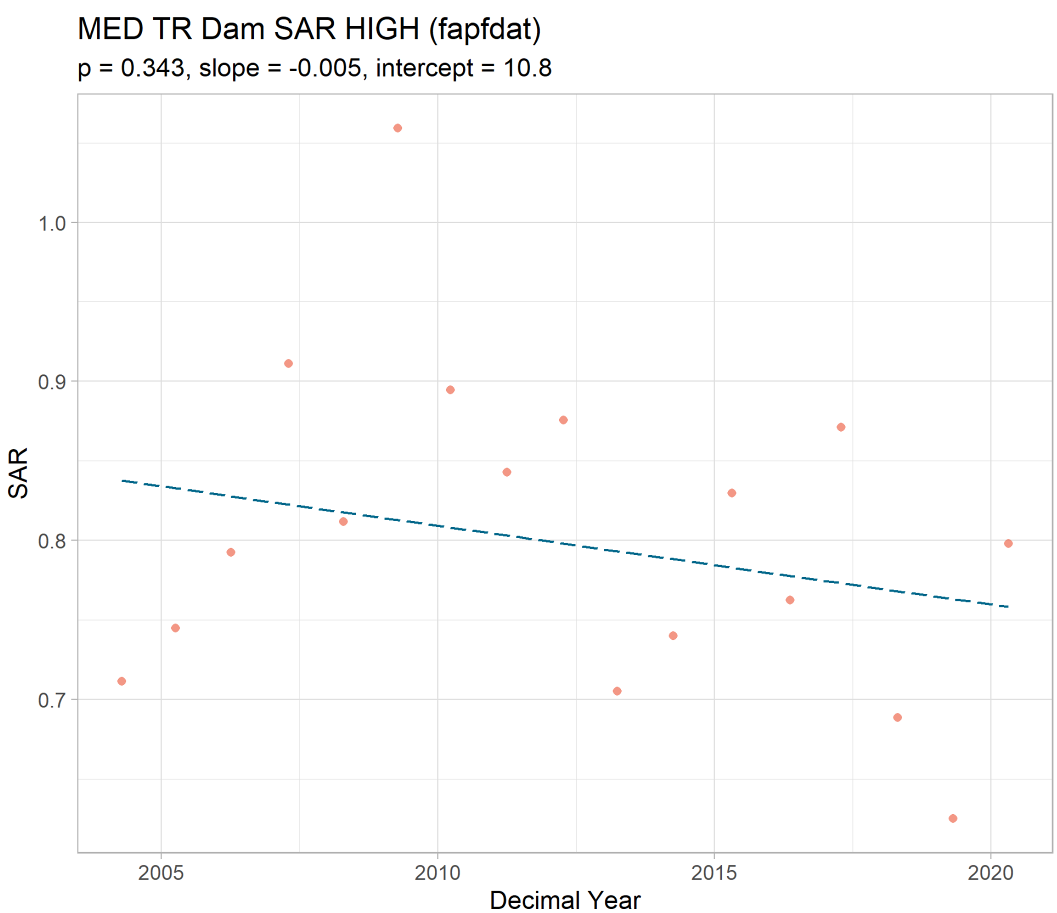
*Note: "HIGH" is spring season (high water) and "LOW" is late summer season (low water/baseflow)



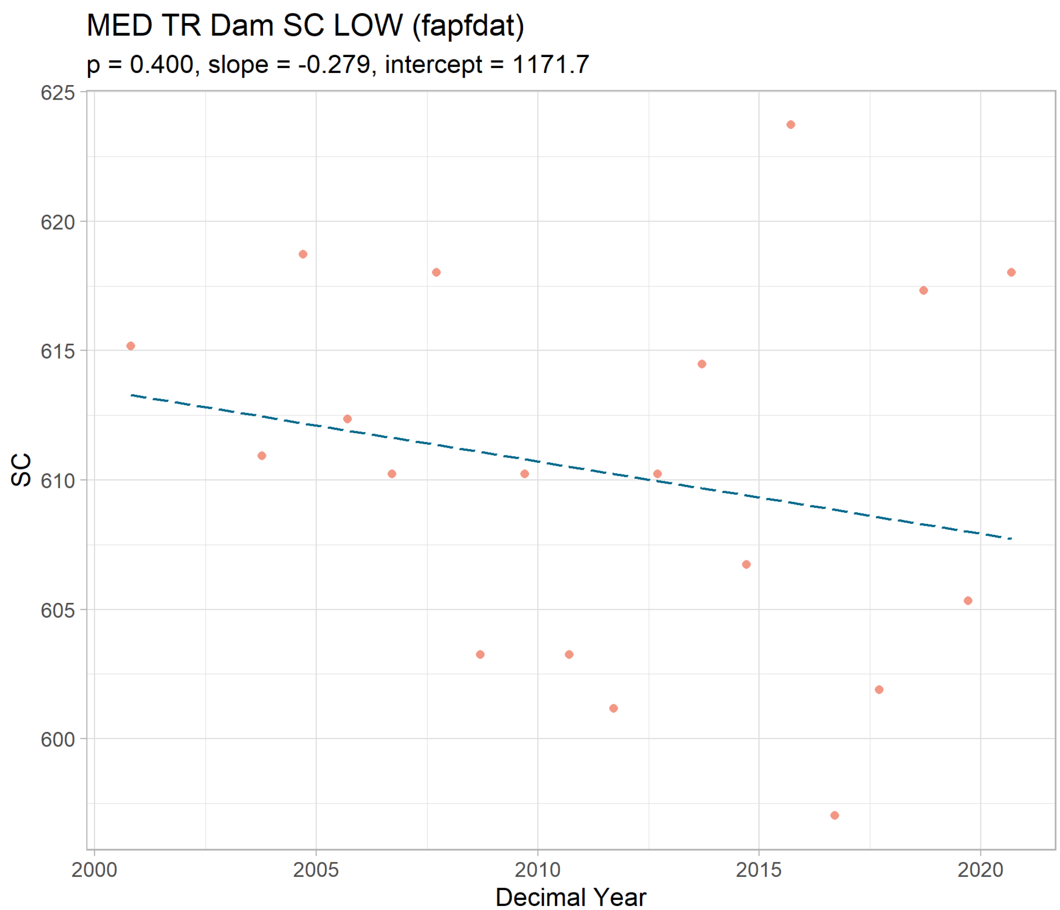


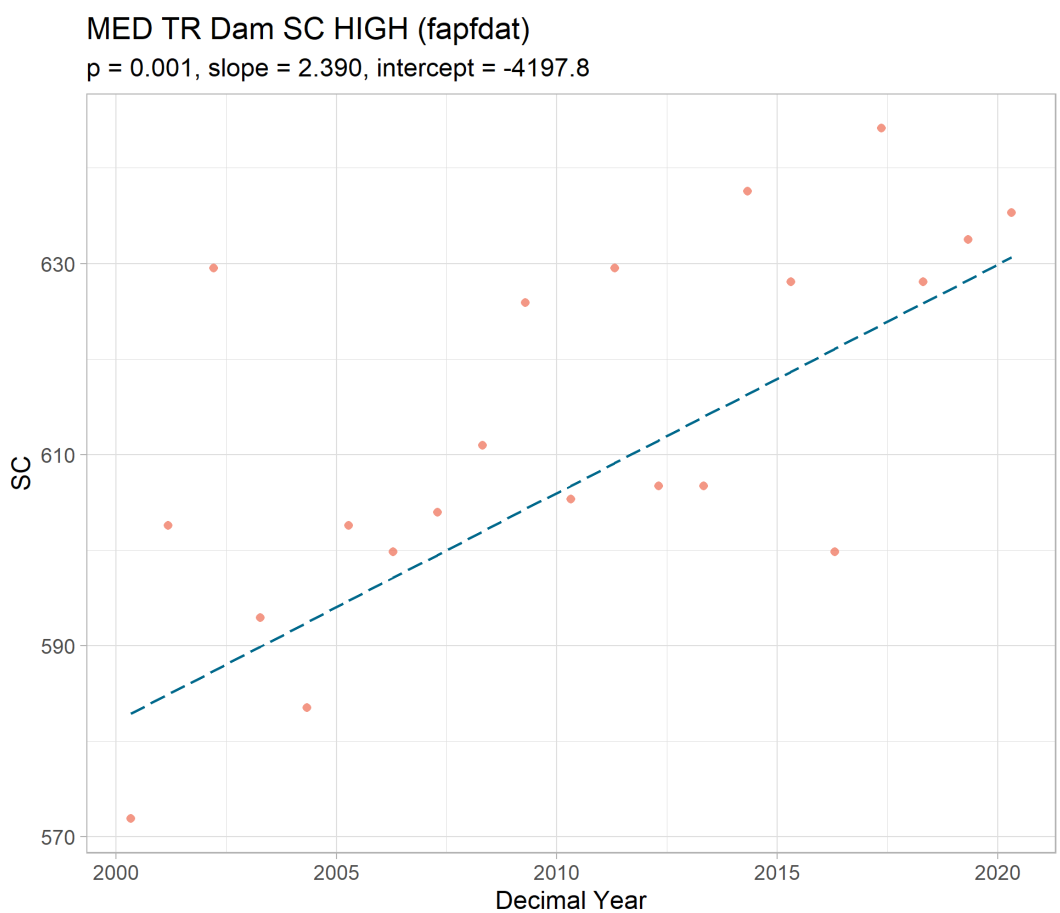
*Note: “HIGH” is spring season (high water) and “LOW” is late summer season (low water/baseflow)



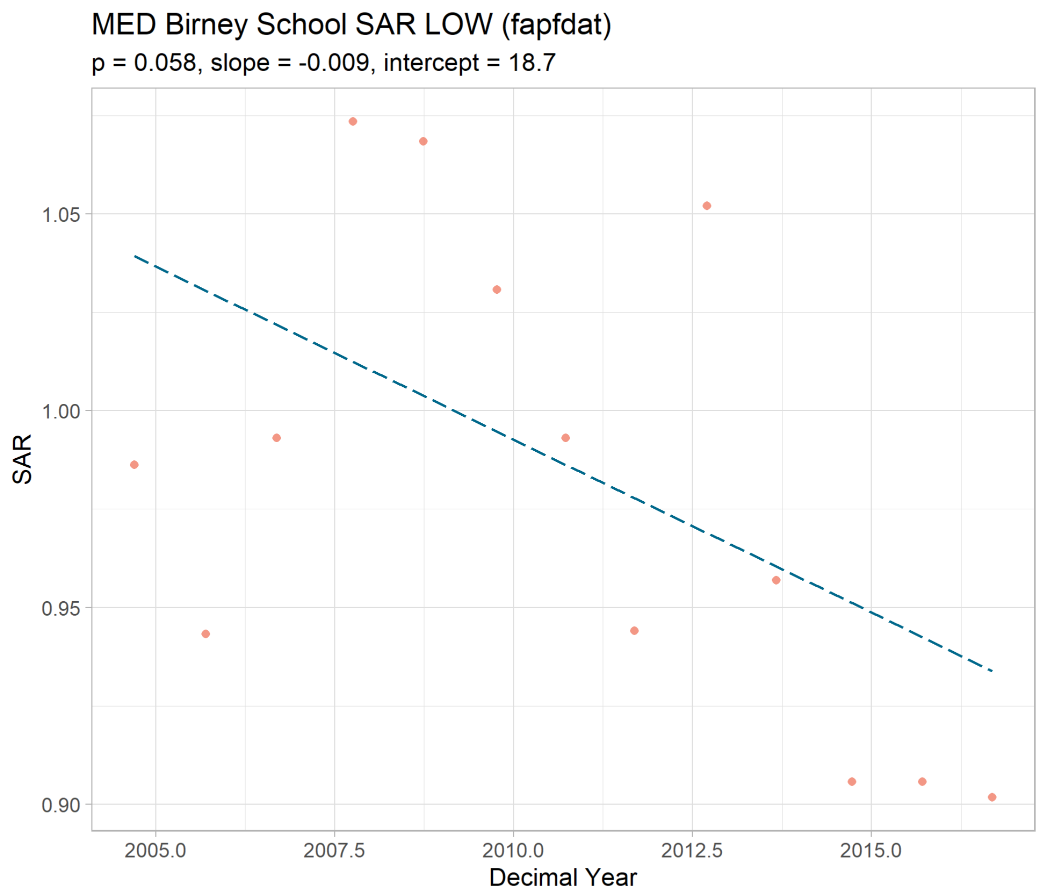


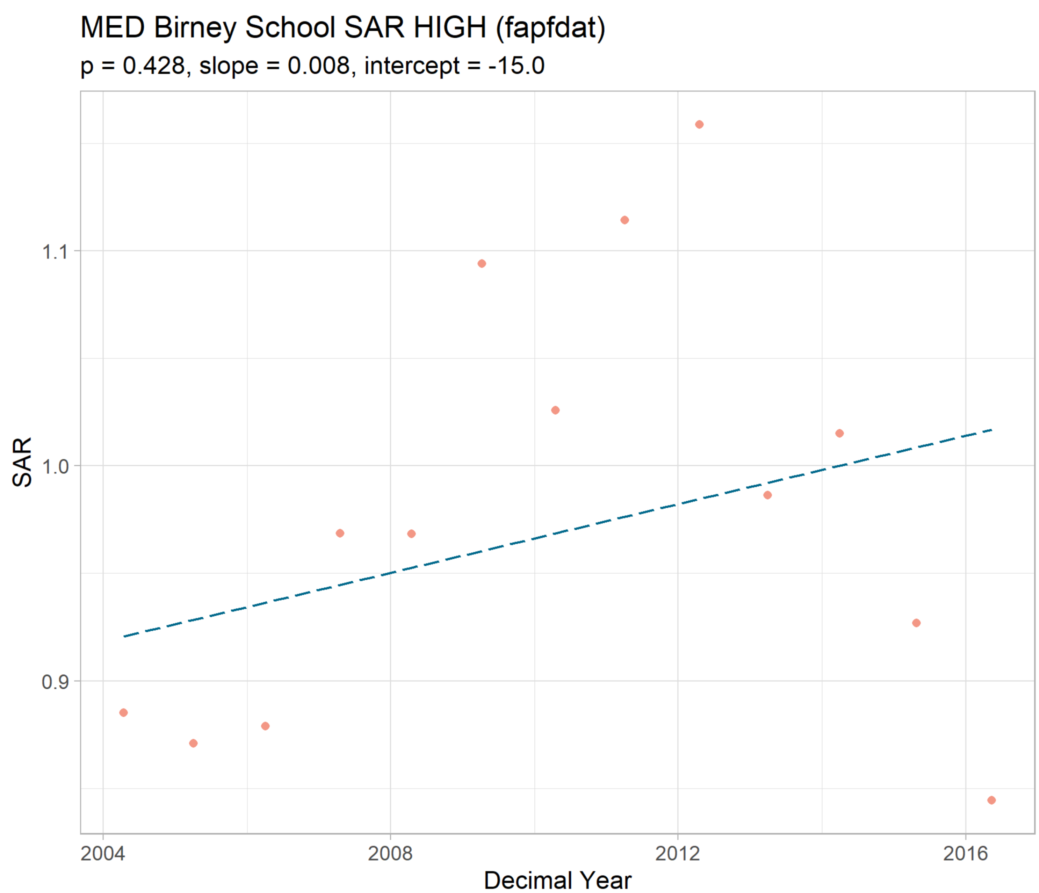
*Note: "HIGH" is spring season (high water) and "LOW" is late summer season (low water/baseflow)





*Note: "HIGH" is spring season (high water) and "LOW" is late summer season (low water/baseflow)

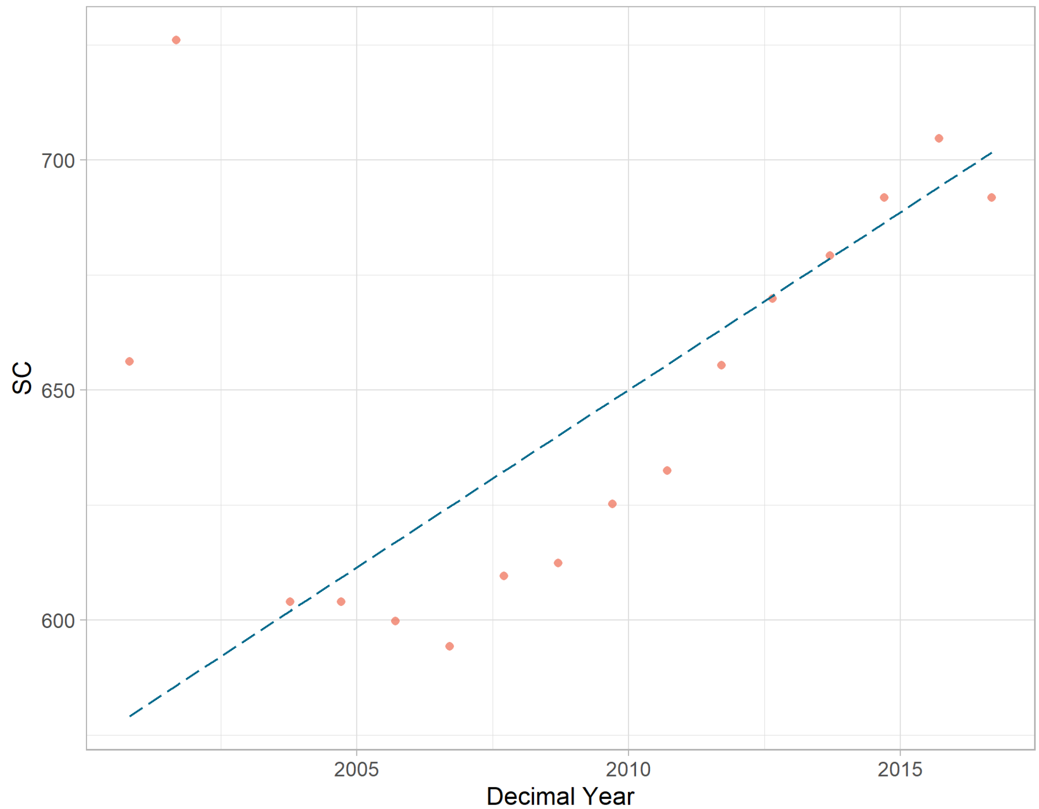




*Note: “HIGH” is spring season (high water) and “LOW” is late summer season (low water/baseflow)

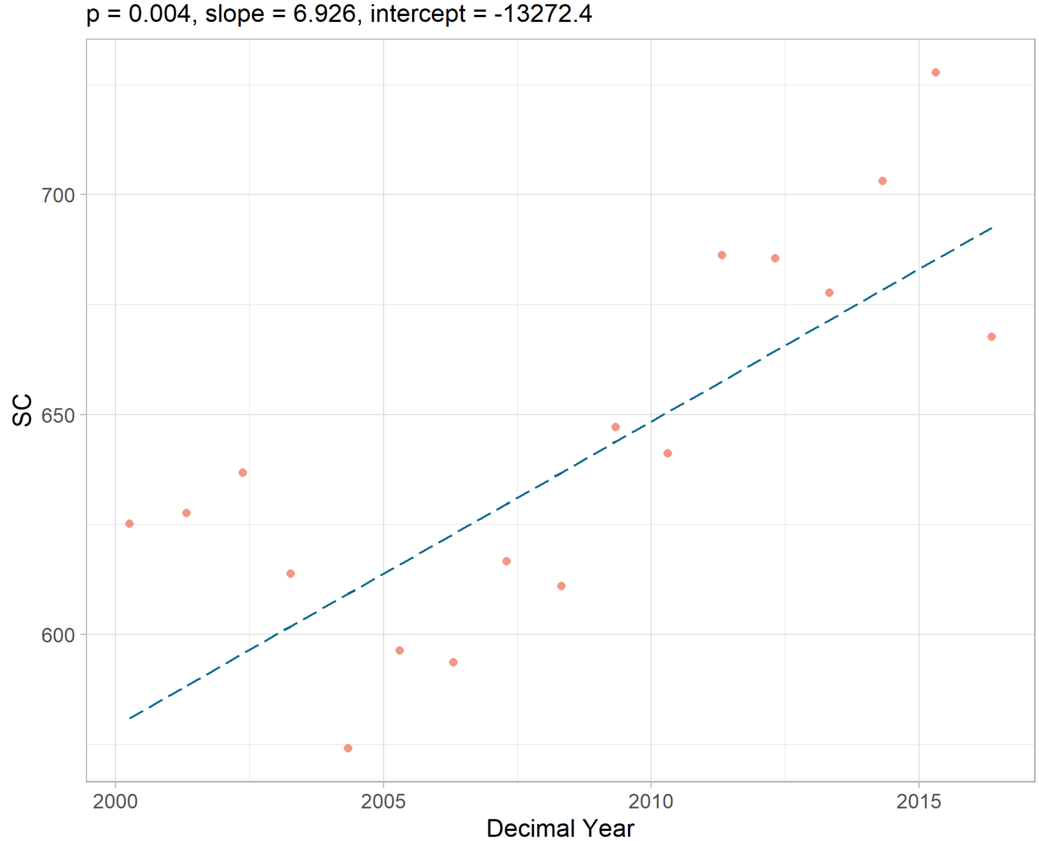
MED Birney School SC LOW (fapfdat)

p = 0.008, slope = 7.721, intercept = -14869.6



MED Birney School SC HIGH (fapfdat)

p = 0.004, slope = 6.926, intercept = -13272.4



*Note: “HIGH” is spring season (high water) and “LOW” is late summer season (low water/baseflow)