StalGrowth – A program to estimate speleothem growth rates and seasonal growth variations

Supplementary Material

Instructions StalGrowth

The StalGrowth program releases can be downloaded from GitHub, a repository hosting service: Https://github.com/RolfVieten/StalGrowth/releases/latest. The release has three assets: 1. StalGrowth-Binaries.zip; 2. Source code (zip); and 3. Source code (tar.gz) The user will be able to compile StalGrowth on their computer and the advanced user will be able to add and modify the source code while a normal user will be able to view and download the release for any Windows OS platform. This way the StalGrowth source code may be improved and expanded with new features.

Input Data Preparation and Upload

All input information to run StalGrowth is stored in one input file. The file can be created using for example Microsoft Excel © and saving it as a comma separated values file (.csv). The file has eleven columns which are **1st** the timestamp (Format mm/dd/yyyy hh:mm:ss . Please note this includes leading zeros. The program is somewhat sensitive to this parameter. **2nd** and **3rd** the drip interval and its error (in seconds), **4th** and **5th** the film thickness and its error (in meter), **6th** and **7th** the temperature and its error (in °C), **8th** and **9th** the pCO_2 concentration (in atm) and calcium concentration of the drip water and its error in the **10th** and **11th** column (in mol/m^3). Figure S1 shows the csv-input file. The data is transferred to StalGrowth via the command *File->Load CSV* and selecting the CSV file from the folder where it is saved. Automatically the data will be displayed in the graphical user interface (GUI) of StalGrowth.

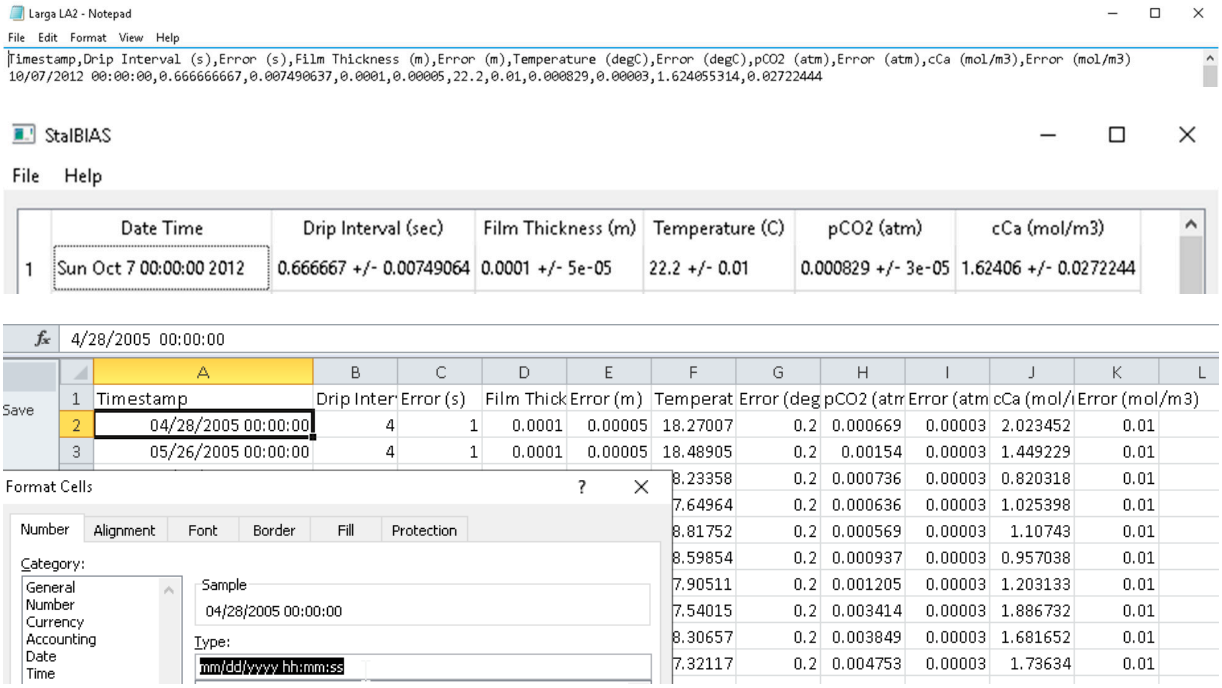


Figure S1: Top shows the CSV input file, shown is the data header (first row) and the first field observation data (second row) from Cueva Larga. Bottom shows the same data in StalGrowth GUI after it has been uploaded to StalGrowth.

Calculate and Graph

After the data has been uploaded to StalGrowth the *Calculate and Graph* function will calculate the stalagmite growth rate and graph the input parameters (cCa, pCO2 and T) in the top plot of the *Results Graph* window (Fig. S2) and in the lower plot StalGrowth shows the calculated growth rate in black, the apparent cCa in red and the measured cCa (real).

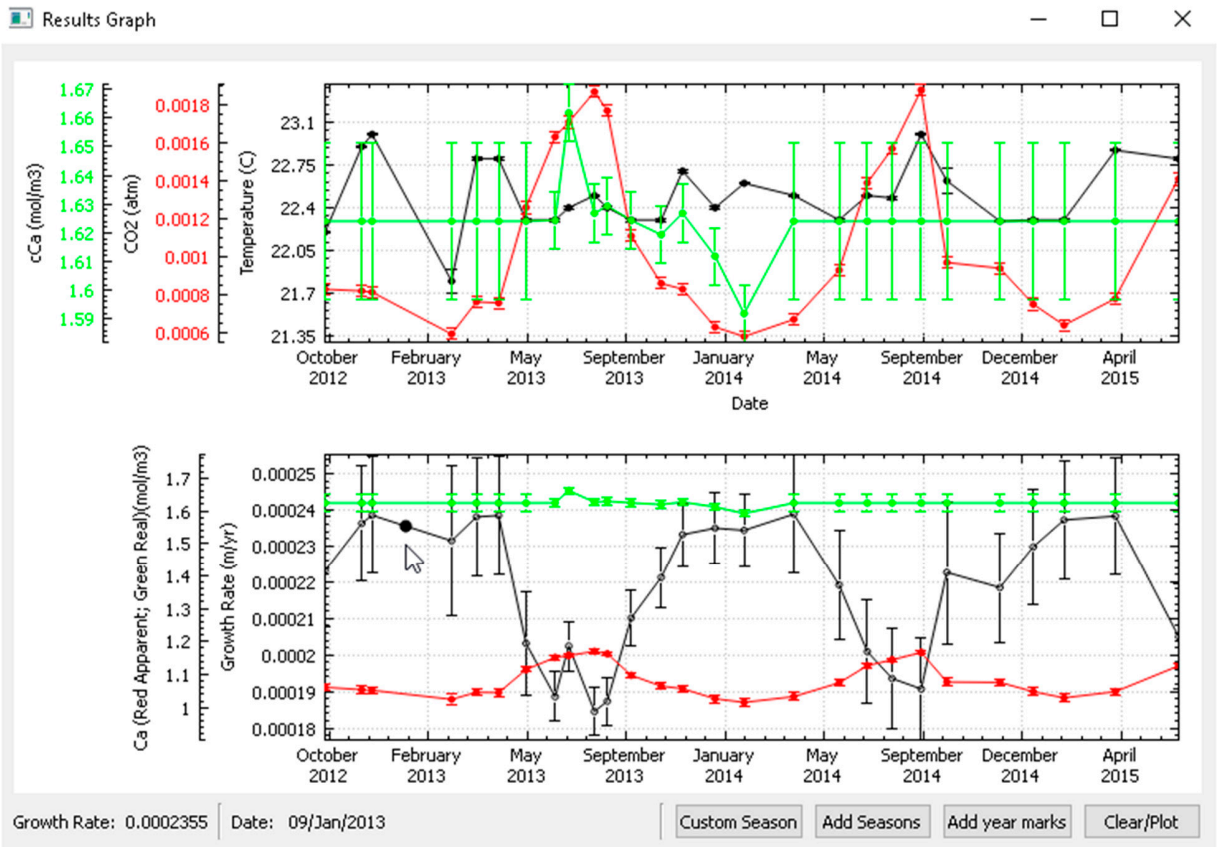
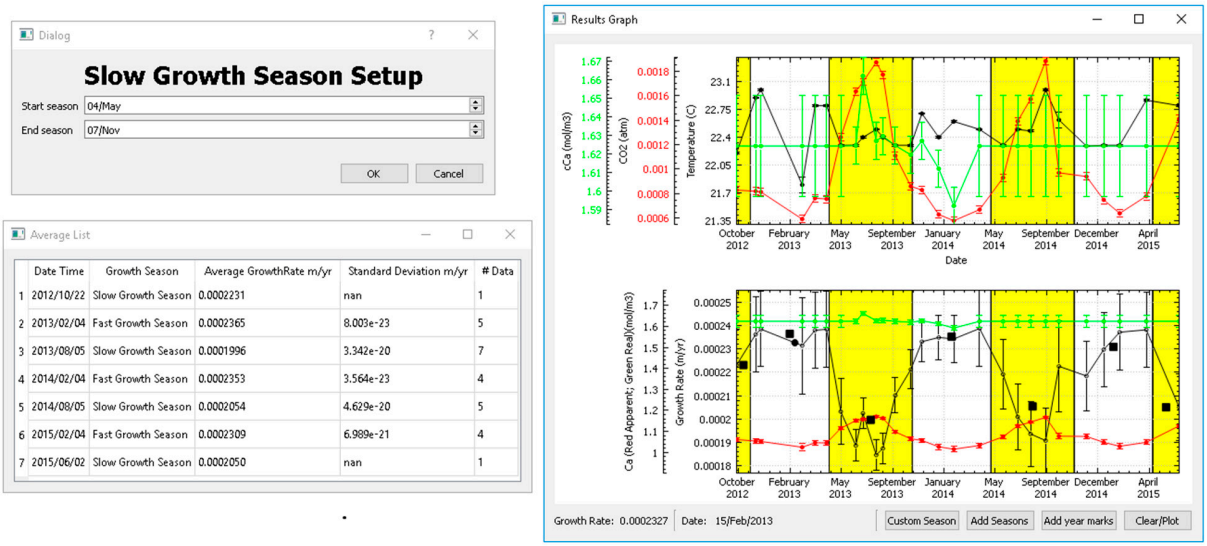


Fig. S2: Results Graph window: Top plot shows the input parameters; lower plot shows the calculated growth rate together with the apparent calcium concentration and the real (measured) calcium concentration. In the lower left corner, the information of the interactive date and growth rate reader is shown. The position of the growth rate reader is show by the black circle on top of the growth rate plot and the position is controlled with the position of the mouse's position (white arrow). In the right lower corner additional plotting options are available to mark the first of each year (*Add year marks*), to mark summer and winter seasons (*Add Seasons*) or to mark custom seasons (*Custom Seasons*). The option *Clear Plot* will set the plot back to its initial conditions.

The Results Graph window is the first step of data analysis using StalGrowth. The *Add Seasons* option will highlight the summer season in yellow. The summer season is defined by the equinoxes from 20th of March to 23rd of September. *Add Seasons* also opens the *Average List* window which shows the median date of each season and the average growth rate of each season and its standard deviation which were calculated using all data points belonging to each season. The number of data points per season is shown in the *# Data* column. The median date and average seasonal growth rate are illustrated in the *Results Graph* window by black squares inside each season. The results can be used to investigate differences among seasons of individual years.

The carbonate growth rates in the *Results Graph* window have to be inspected visually before quantifying the seasonal growth bias. The goal of the visual inspection is to verify the calculated growth rates for seasonality and judge whether or not the seasonality overlaps with the summer-winter season defined by the equinoxes. Most settings are expected to have seasonal variations in carbonate precipitation (James et

al., 2015). In the case that the growth rates appear constant over time or very without any relation to seasons the analysis via StalGrowth can be used as evidence that there is no bias in the speleothem record related to seasonal growth. In the case that the growth rates show seasonality but the seasonality deviates from the climate seasonality defined by the equinoxes, the user may adjust the start and end date using the *Custom Season* option. *Custom Season* opens the Dialog window entitled Slow Growth Season Setup, where the user has to specify the new start and end date of the Slow Growth Season. In the example (Fig. S3) the slow growth season was shifted by 45 days (from 4th of May to 7th of November), which overlaps very well with the times of lower growth rates.



	Date Time	Growth Season	Average GrowthRate m/yr	Standard Deviation m/yr	# Data
1	2012/10/22	Slow Growth Season	0.0002231	nan	1
2	2013/02/04	Fast Growth Season	0.0002365	8.003e-23	5
3	2013/08/05	Slow Growth Season	0.0001996	3.342e-20	7
4	2014/02/04	Fast Growth Season	0.0002353	3.564e-23	4
5	2014/08/05	Slow Growth Season	0.0002054	4.629e-20	5
6	2015/02/04	Fast Growth Season	0.0002309	6.989e-21	4
7	2015/06/02	Slow Growth Season	0.0002050	nan	1

Figure S3: showing the *Custom Season* option applied to the drip site data of site L2 in Cueva Larga from 2012 to 2015. The Results Graph window shows that the carbonate precipitation has seasonality. The seasonality is well described by lag 45 days (4th of May to 7th of November) behind the season defined by the equinoxes.

Comparisons between the input data plot (top right Fig. S3) with the results plot (bottom right Fig. S3) can help identify which parameter or which combination of parameters are responsible for the changes in growth rate. In the example shown in Fig. S3, the change in cave atmospheric pCO_2 shows a relation to the change in growth rate.

Statistics – Calculating the Seasonal Growth Bias

From the initial StalGrowth window select the Statistics option and the *Statistics & Biasing* window will open. Here StalGrowth calculates the seasonal growth bias. The window presents the calculated growth rates via the graphic and the data table. All data points can be included in selection as belonging to the slow or fast growing season using the *Auto Season* option. *Auto Season* opens the *Slow Growth Season Setup* window where the start and end of the slow growth season can be selected, similar to the *Custom Season* option in the Calculate and Graph section. If the user decides to use the equinoxes and the summer (winter) is the slow growth season, the 20th of March has to be chosen as the start (end) and the 23rd of September as the end (start) of the season. If the seasonality is best described by custom dates, these dates can be used here. After applying the *Auto Season* command the slow growth season is highlighted (Fig. S4) and data points belonging to the slow (fast) growth season are marked in red (blue).

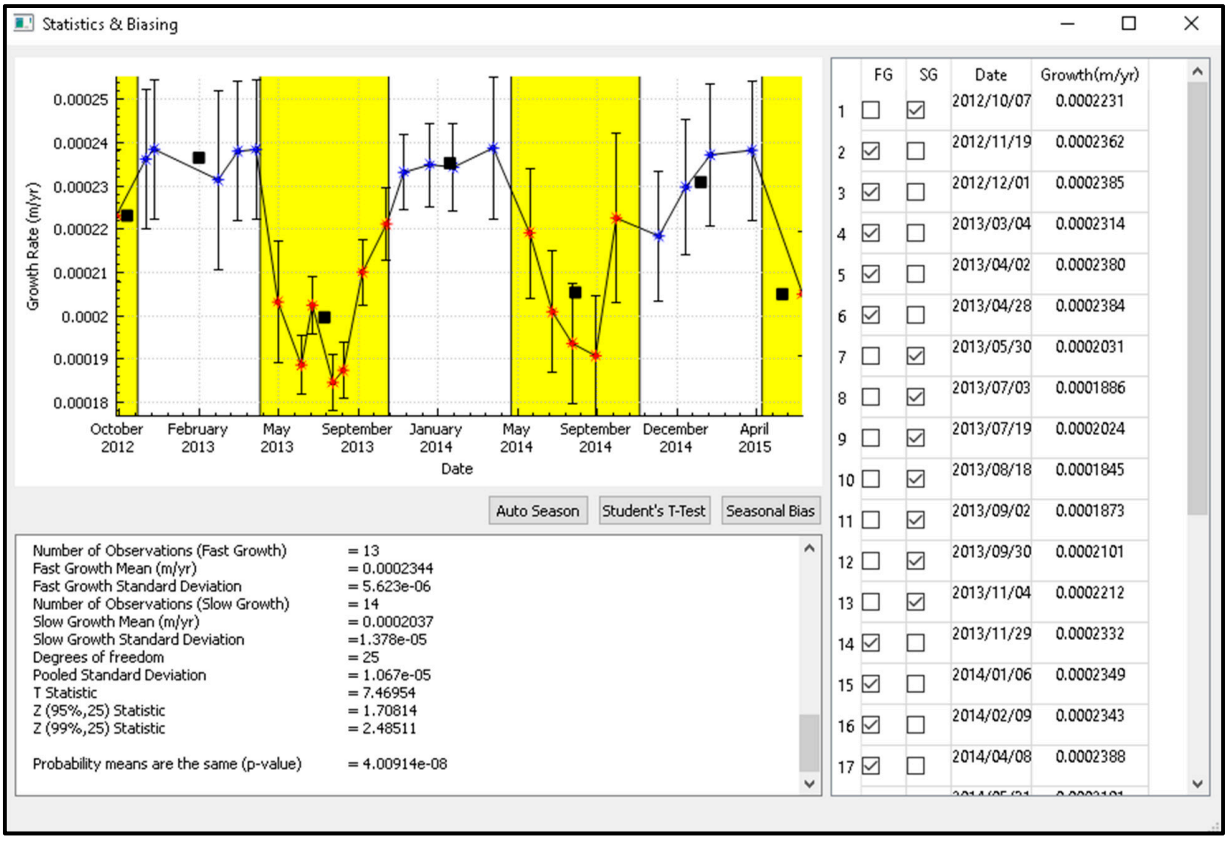


Fig. S4: Statistics window of drip site data L2 after applying Auto Season and using the custom dates adjusted to the seasonality of Cueva Larga (4th of May to 7th of November). Top plot shows the growth rates and seasons. Slow (fast) growth rate is highlighted in yellow (white) and data points are marked in red (blue). Text field on below the plot shows the result for the student's t-test and the data table on the right side shows the individual data point and if it belongs to the fast growth FG season (checkmark in FG column) or if it belongs to the slow growth SG season (checkmark in SG column).

After applying *Auto Season* the individual data points belonging to each season are automatically marked as belonging to the FG (fast growth season) or SG (slow growth season) in the data table (Fig. S4). Automatically the results of the student's t-test are displayed in the text field below the plot. The student's t-test calculates the probability that the means of the fast growth seasons and the slow growth seasons are the same. In the example in Fig S4 the probability is $4*10^{-8}$ that the season's mean growth rates are the same. This probability is smaller than 0.05 and we can reject the hypothesis that both means are the same and can conclude that there are seasonal differences in speleothem growth rate.

The data table is interactive and allows the user to change the classification as FG or SG season or to exclude data points (no selection of FG or SG). Data points might be excluded if there is evidence that they are outliers or if they fall into the transition period between the SG and FG season. Finally with by clicking the *Seasonal Bias* button StalGrowth calculates the fraction in percent which grows during the fast growth season. This information can then be used to interpret the speleothem proxy values in more detail by accounting for the seasonal bias resulting from different speleothem growth rates.