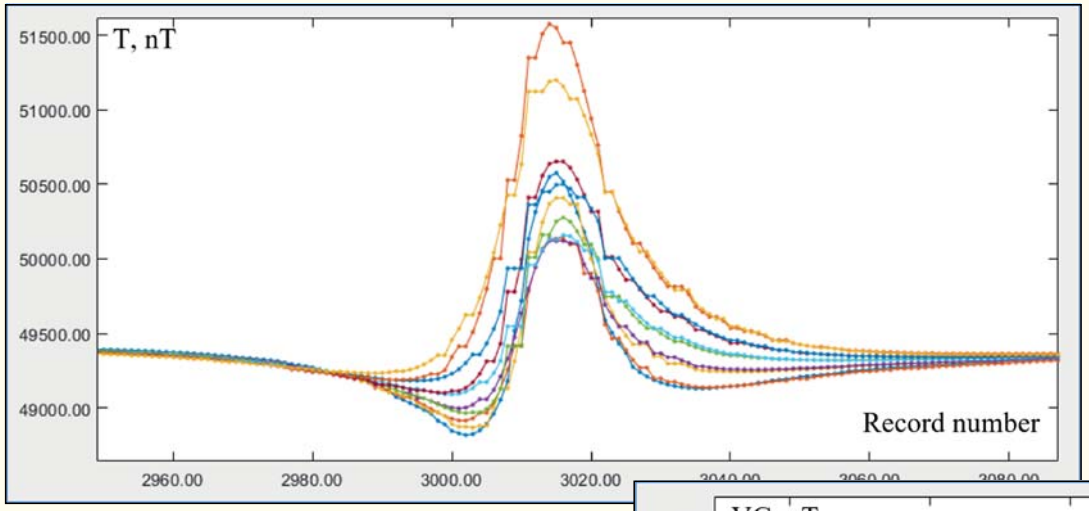
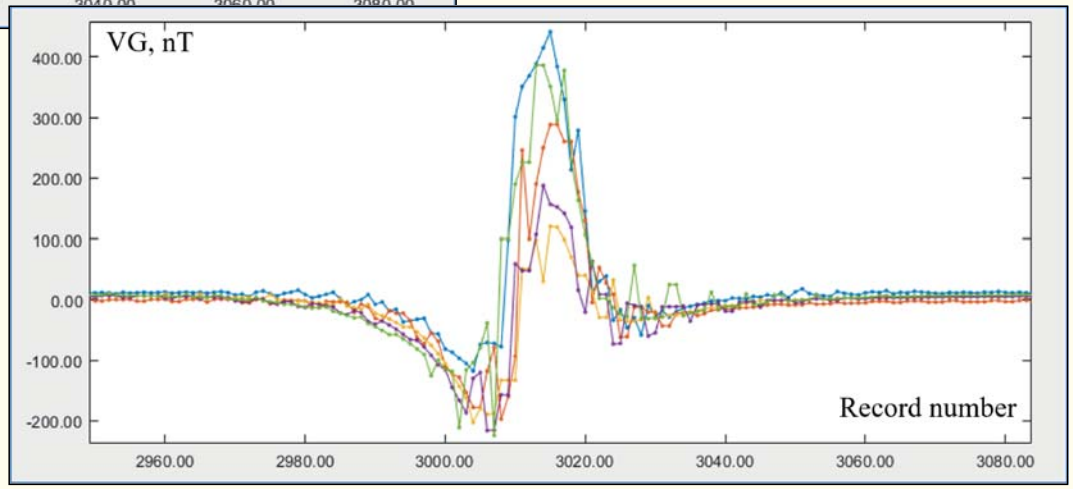
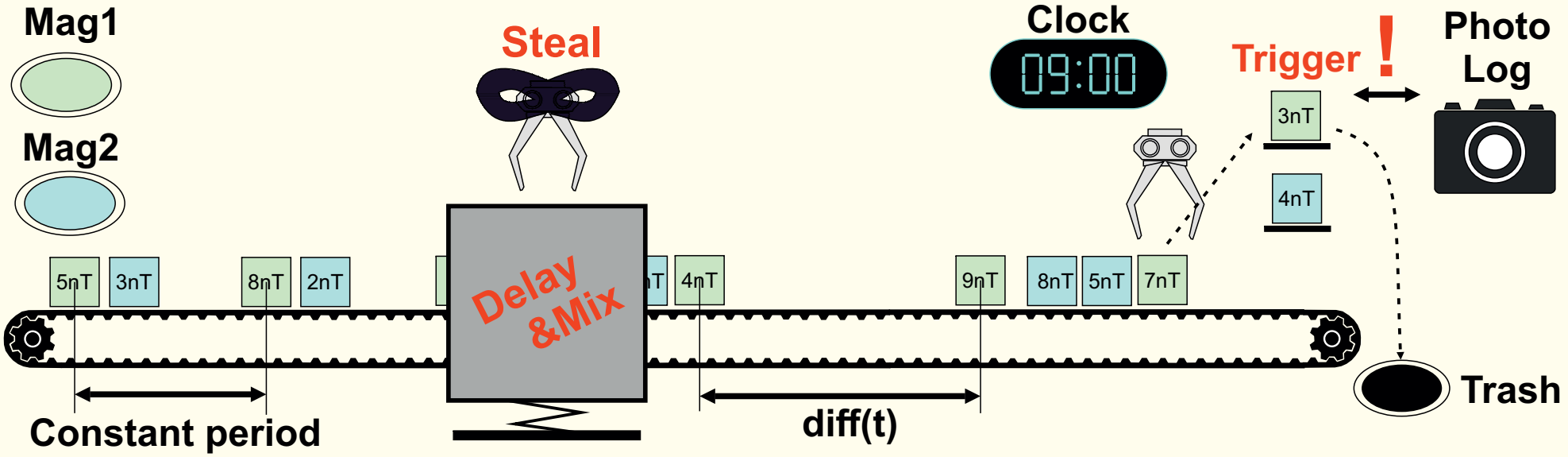
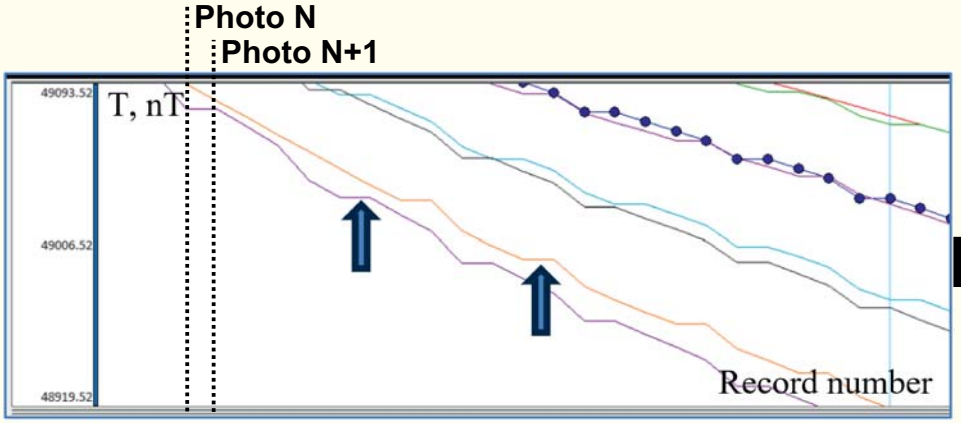
“Saw effect” the causes of the problem



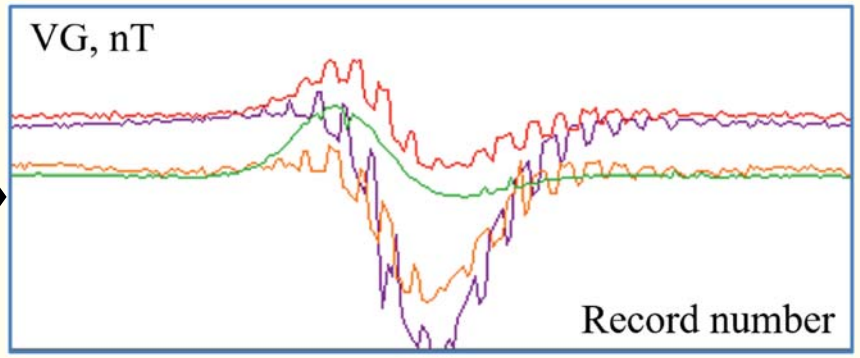


Synchronisation (time labeling) by QINSy with Mag-trigger (all mags are put into one Log-file)





"Missed and time-shifted" measurements



"Saw effect" for Vertical Gradient

Slide 1

1) Let us consider the Scanfish-QINSy system from a mechanical point of view, conceptualizing it as a conveyor belt. The ScanFish side is shown on the left while the QINSY side is shown on the right. It should be noted that only two magnetometers are shown in this slide, but there could be, for example, ten. This slide demonstrates the system operation during the "synchronisation" of the magnetometer measurements by QINSy, with all measurements being recorded into a single log file.

2) The "synchronisation" word in the slide title is not entirely accurate. If you look at the conveyor belt, you will notice that the "synchronisation process" simply involves "assigning" time-labels to the boxes by photographing them along with the "arrival time" shown on the clock to the right.

3) The "Boxes" represent Mag's digital messages. You can see the magnetic field value written on the side of each box.

4) The period of the magnetometer measurements is very stable, so the distance between boxes remains constant for each magnetometer on the right side.

5) The digital data channel can be represented by two devices: a "Delay and Mix" container and a "Steal" manipulator. The first device delays the boxes for different time (and sometimes the order of the boxes is altered as a result). The second device occasionally steals a random box. As a result, we obtain slightly "disordered" boxes on the right side, with some boxes missing.

6) The "data logging" process performed by QINSy can be represented by two shelves and a camera. The manipulator places the green boxes (measurements of the first magnetometer) on the top shelf and the blue boxes (measurements of the second magnetometer) on the bottom shelf. It then takes a photo including the clock (timestamp). BUT a photograph is only taken when the green box is placed on the shelf (the measurements of the first magnetometer serve as a trigger for the camera).

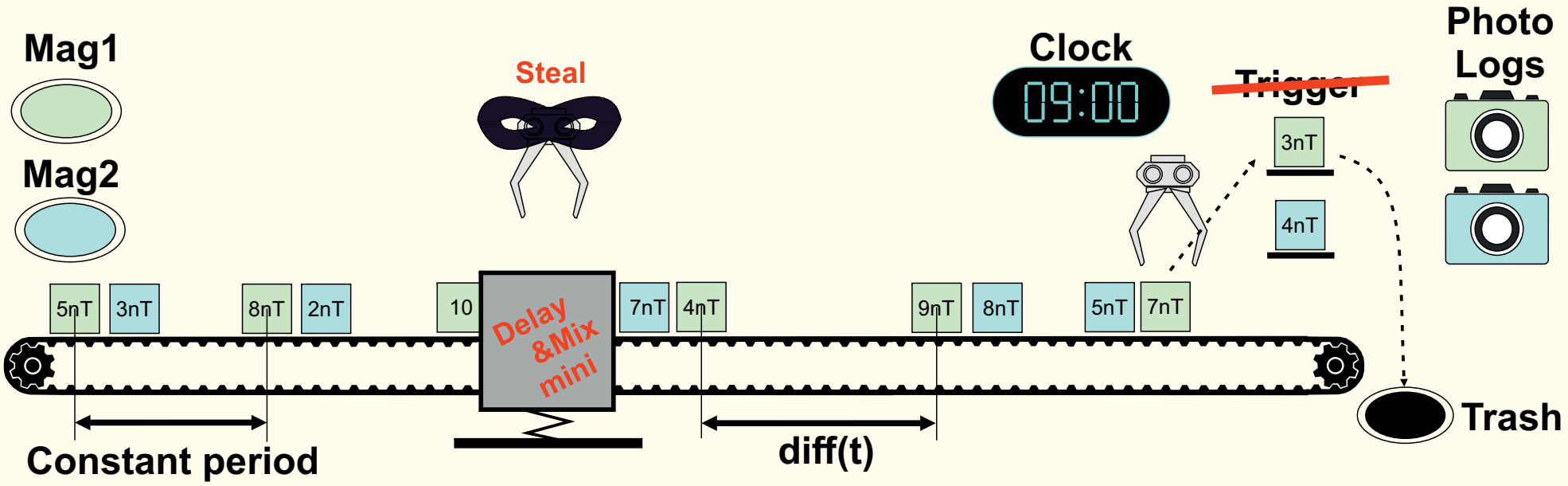
7) By analysing the camera operation along with the sequence of boxes on the conveyor, we can observe that the 5nT blue box will not be photographed. In contrast, the 8nT blue box will be photographed twice (along with the 9nT and 4nT green boxes).

8) If we were to plot graphs of the magnetic field using the values captured in the photographs, such "photos with boxes repeated" would result in horizontal lines on the magnetic field graph (as indicated by the blue arrows in the bottom left part of the slide).

9) When calculating the difference between measurements from two magnetometers (the vertical magnetic field gradient) using photographs, photos with a "repeating box" will result in subtracting measurements that are "time delayed". Such calculations will result in a visual "sawtooth effect" in areas with a high magnetic field gradient.

10) To summarize, the sawtooth effect is caused by the combined effect of the following factors: (1) delays in the digital data channel, (2) loss of measurements in the digital link, and (3) a recording system that uses a single magnetometer as a trigger.

Synchronisation (time labeling) with separate Log-files, equipment settings improvement and “algorithmic synchronisation” procedure



Improved Log & equipment settings

see Syncro_ScanFish_vol1.pdf

1)

2)

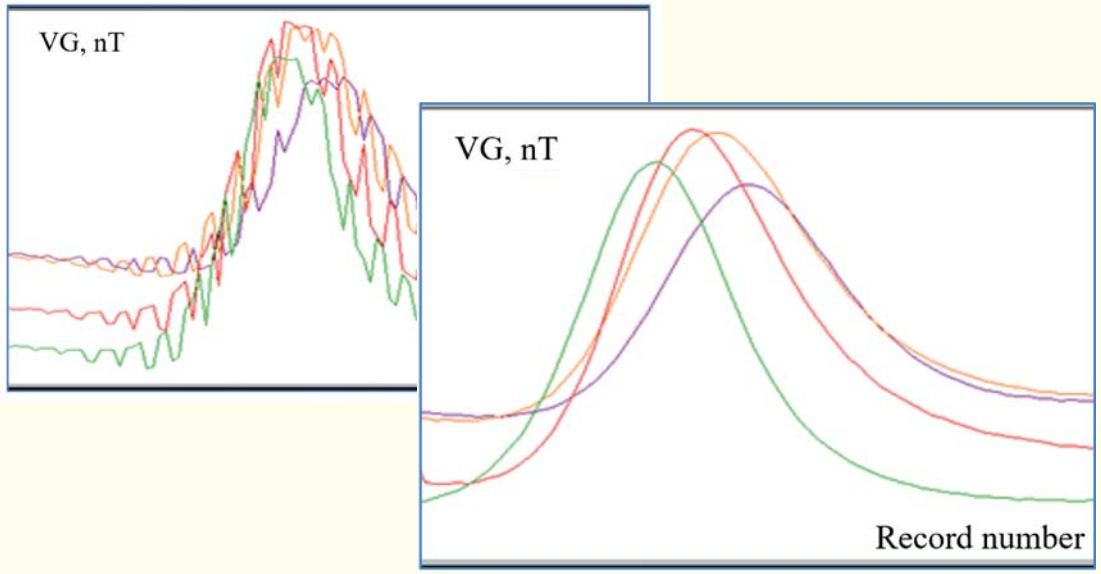
85% of solution

3) **“Algorithmic synchronisation”**

see Syncro_ScanFish_vol2.pdf

– detect gaps (“boxes stolen”);
– optimize **dt** to constant.

15% of solutions + control tool



“Saw effect” for Vertical Gradient

Slide 2

1) The slide demonstrates the improved Scanfish-QINSy system.

2) There are three causes of the sawtooth effect. Among them, the "magnetometer-trigger influence" is the easiest to remove. To do this, we record the digital messages (measurements) from each magnetometer into a separate log. The slide illustrates this procedure using two cameras: each camera will photograph its own shelf whenever a new box is placed on it. This way, we will except "skipping boxes during photography" and take a photograph of the "arrival time" for each box.

3) We can improve the digital data channel settings by "simplifying" the conveyor belt. This adjustment will minimize delays in the "Delay and Mix" device and reduce the number of measurements missed ("stolen"). Unfortunately, we cannot remove these effects completely.

4) The improvements described will solve the "saw effect" problem by 85%, but it will still be present in magnetic field recordings.

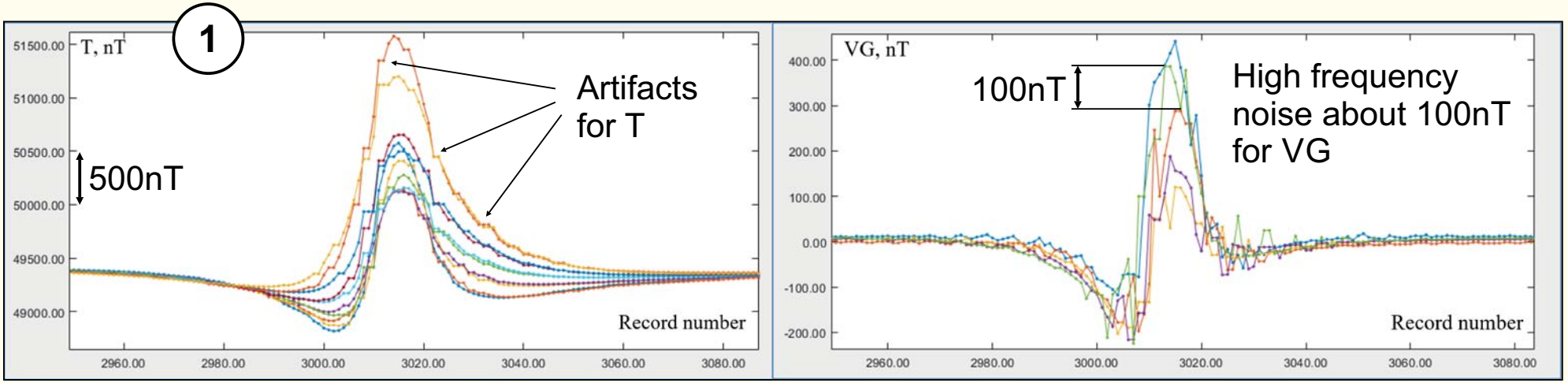
5) We can reduce a "disorder" of boxes on the conveyor and determine the position of "stolen" boxes using the mathematical processing procedure called "algorithmic synchronization". This will remove the "saw effect" more thoroughly and adjust the timestamps in the photos so that they almost coincide with the time the boxes were placed on the conveyor belt.

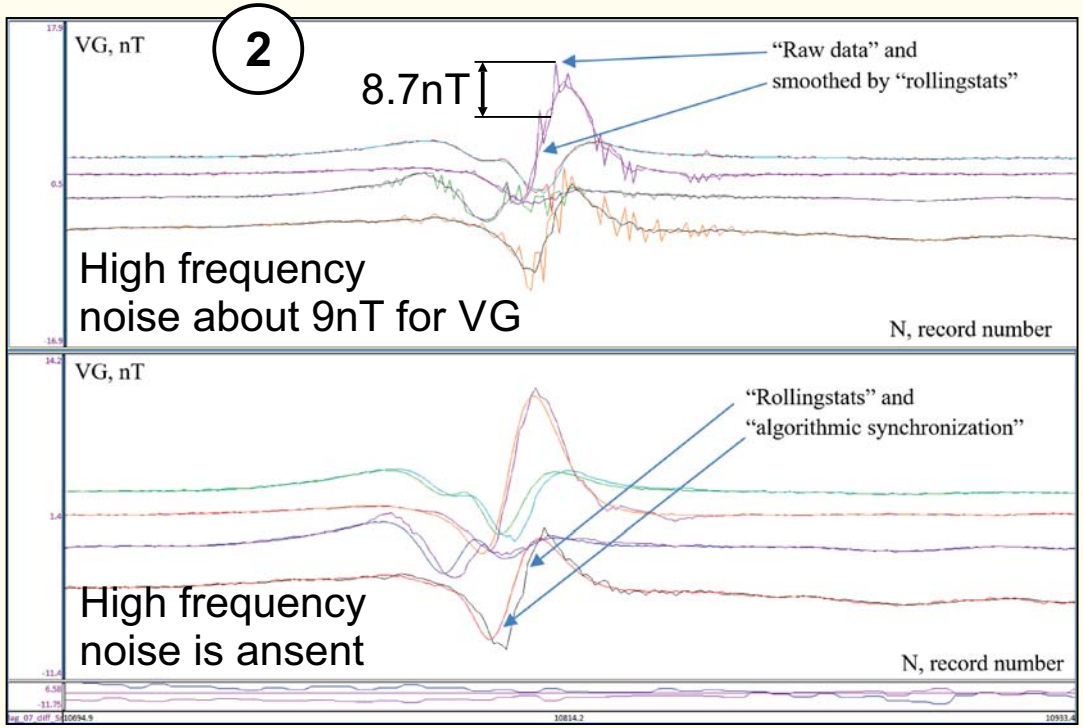
6) To summarize:

6.1) The sawtooth effect is a special case caused by the absence of timestamps in magnetometer measurements. The measurements are transmitted over a digital channel resulting in delays and data loss. QINSy assigns timestamps to the measurements based on the "measurement arrival" time (not the "measurement taking time"). If the timestamps are organized using a magnetometer-trigger, this introduces additional errors.

6.2) By bringing the values of the "measurement arrival time" closer to the "measurement taking time", we can reduce errors in the survey data (the saw effect is a consequence of such errors). To achieve this, the following actions are performed: (1) the use of the "magnetometer-trigger" is refused; (2) the data channel settings are optimized; and (3) additional mathematical processing ("algorithmic synchronization") is applied.

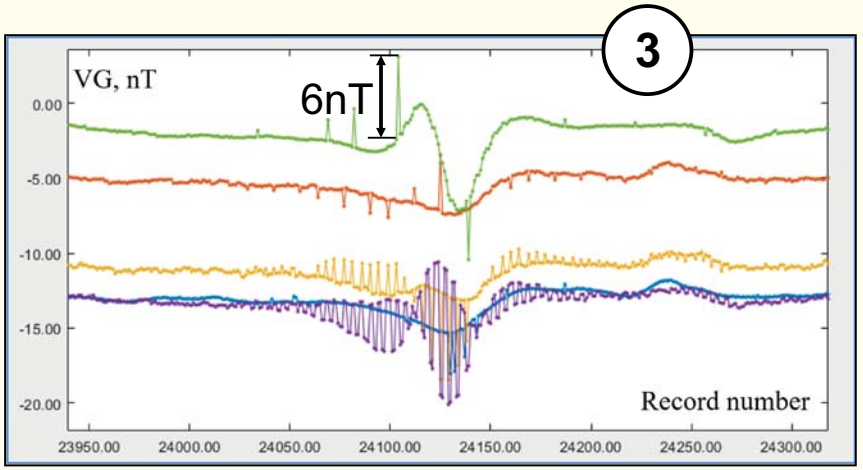
Why should timestamps correction be done?





"Rollingstats" and "algorithmic synchronization"

For a quality-surveyed magnetic field,
the "gradient" should be smooth.
If there are artifacts on the gradient,
there are errors in the original field.



VG inapplicable for "smoothing"

Slide 3

1) Why is it necessary to perform timestamp correction, or more precisely, a "careful" recalculation of all sensor measurements to a single series of timestamps? A particularly striking example of the need for this is the data obtained using a "magnetometer-trigger". There are visible artifacts in the magnetic field plots (see 1) that are associated with "missing a measurement" or "rephotographing a measurement", as it illustrated schematically on Slide 1.

2) These artifacts are barely visible to the untrained eye in the magnetic field plot. However, after subtracting the values measured by the two magnetometers and plotting the vertical gradient graphs, these artifacts become clearly visible and create a "saw effect" (resembling a meander or high-frequency noise). Moreover, the larger the amplitude of the anomaly and the high its gradient, the greater the amplitude of the artifacts. For example, in (1) the amplitude is approximately 100 nT, in (2) - 9 nT, in (3) - 6 nT.

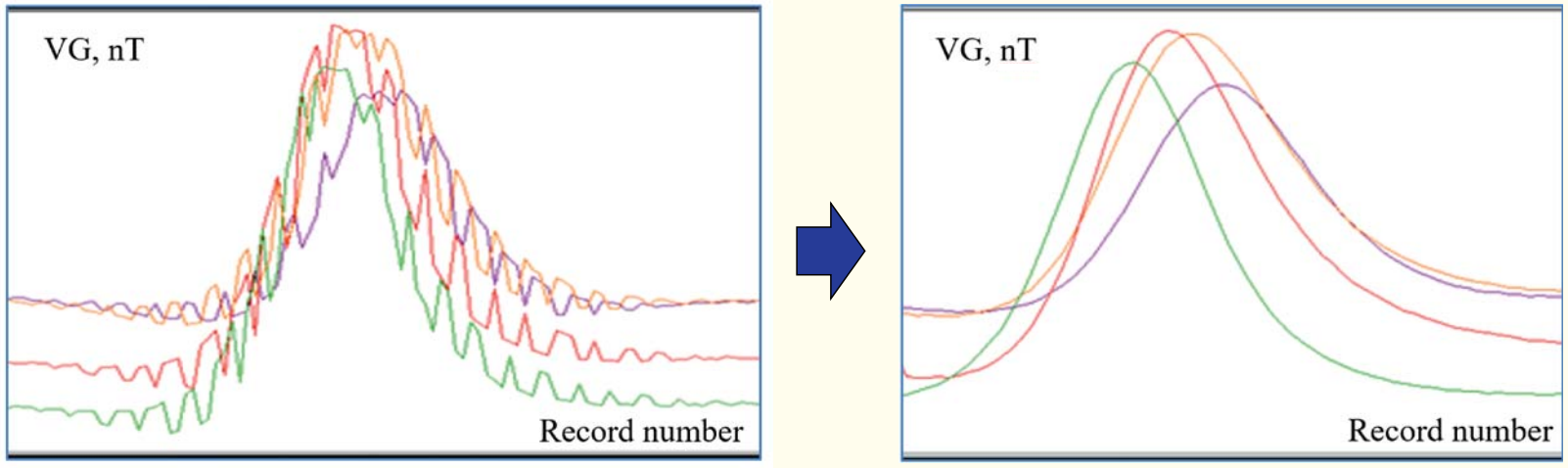
3) The gradient of a carefully measured magnetic field, by its physical nature, should be a smooth function. Consequently, "high-frequency noise" in the gradient directly indicates errors in the original magnetic field measurements. If artifacts with an amplitude of 100 nT are considered as the result of subtracting measurements of two identical and independent sensors, one must assume that each sensor's measurements contain noise of approximately 100/2 nT. This level of noise significantly exceeds the SoW requirements and, under a strict approach, the data should not be accepted by a Client.

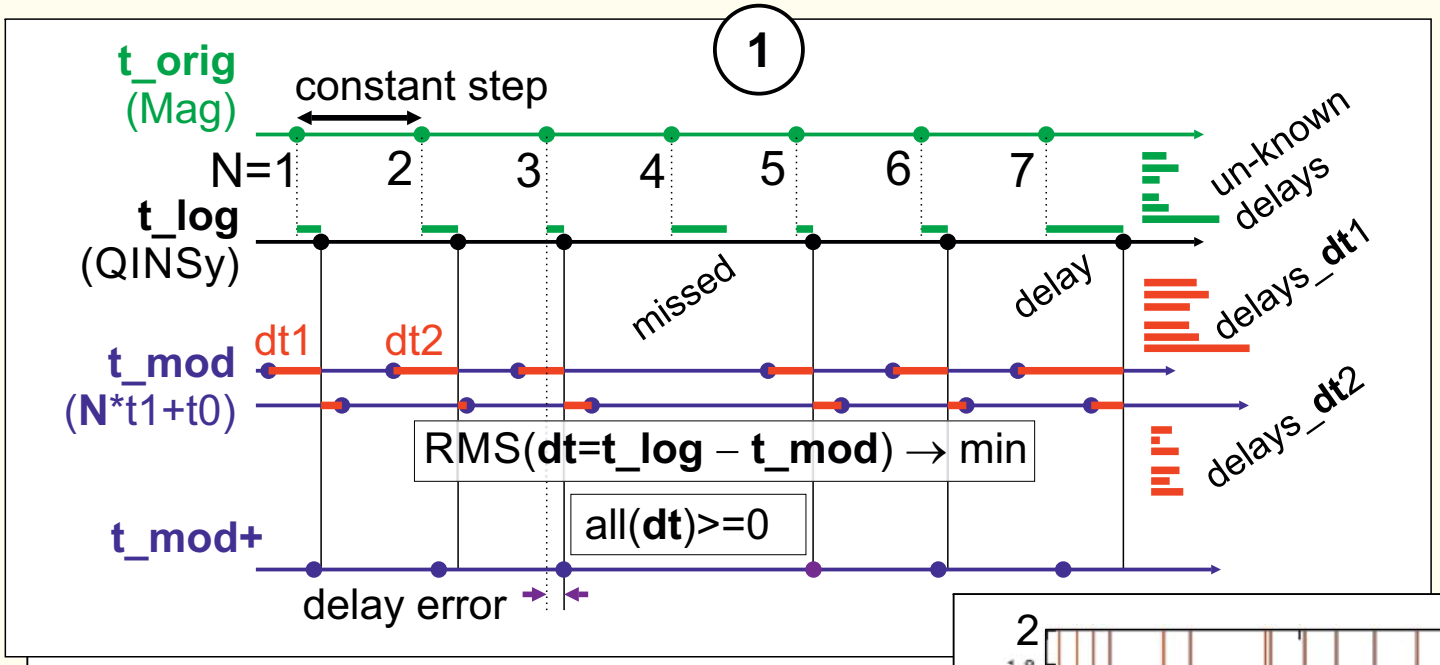
4) If the magnetic field measurements are subject to some form of filtering that removes "high-frequency noise" (as shown in 2), it simply means "high-frequency noise masking-smoothing". While the amplitude of the high-frequency noise is visually reduced, it continues to distort the shape of the measured magnetic field graphs. The (3) demonstrates a case where smoothing does not unambiguously produce a result close to the "un-noised field" (purple graph). Also, smoothing during processing does not negate the fact that the measured magnetic field contains high-frequency noise of approximately 50 nT in the measured magnetic field (hence, the data do not meet the SoW requirements).

5) The knowledge of the delay influence in the data channel allows us to demonstrate that the "saw effect" ("high-frequency noise" of 100nT) is not a consequence of the measurement error of the magnetic sensors, but rather it results from a "synchronization error". Organizing measurement recording without using the "magnetometer-trigger", as well as optimizing the settings of the data channel, can significantly reduce the visible part of the "saw effect" (to single "spikes"). However, the visually unexpressed part of this error will still affect (through the shift of timestamps) the magnetic field recordings.

6) The use of processing procedures known as "algorithmic synchronization" further reduces the impact of delays in the digital data channel, leaving only a small constant component: the "error of the time of fastest delivery of the digital message".

Algorithmic synchronisation: math and script commands





Math

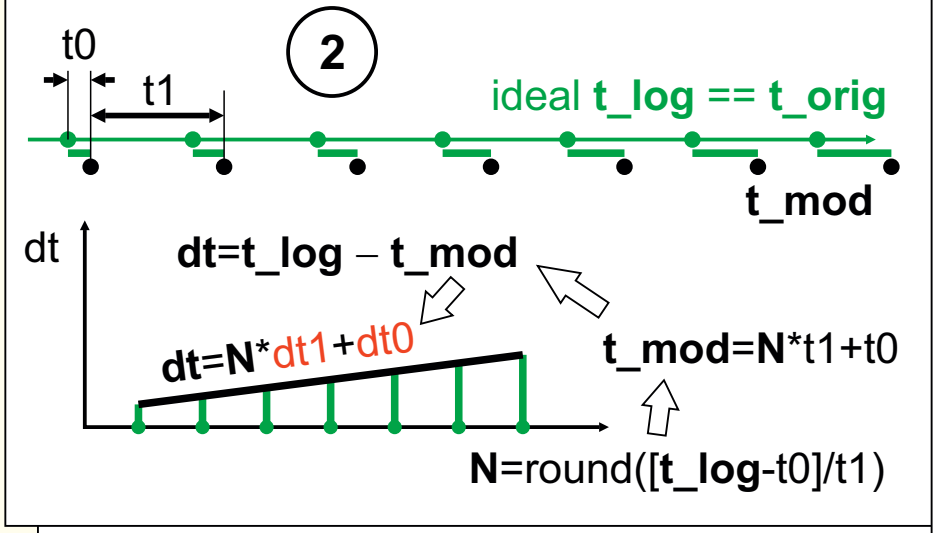
$$N=\text{round}([t\_log - t0]/t1)$$

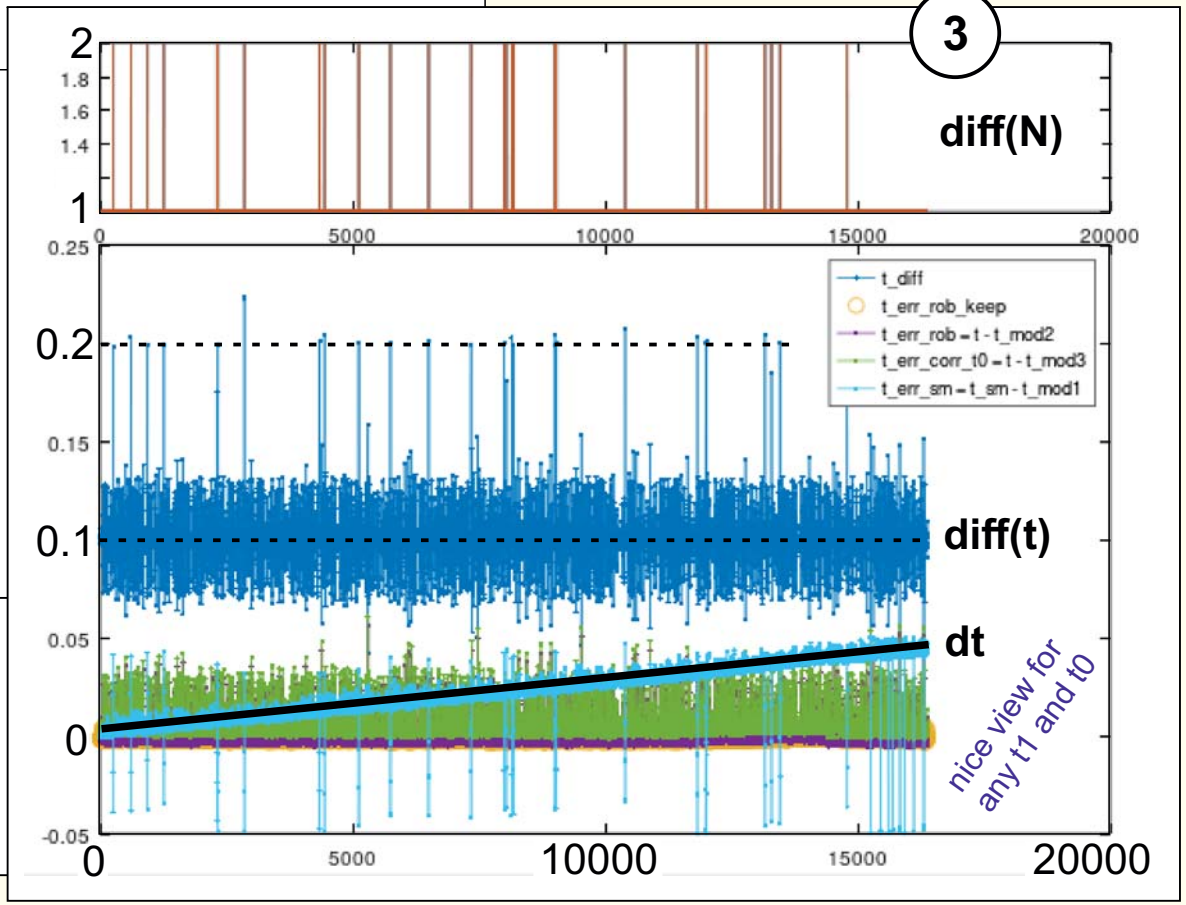
$$t\_mod = N*t1 + t0$$

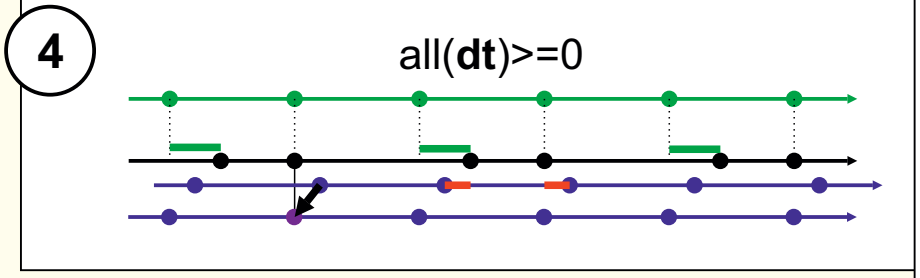
$$dt = t\_log - t\_mod$$

$$RMS(dt) \rightarrow \min$$

$$all(dt) >= 0$$







Slide 4

1) (1) shows the time of message transmission by the magnetometer (t_orig, green) and the time of their reception by QINSy (t_log, black). The green segments represent the unknown value of "delays in the data channel"; one measurement is "lost". The correction of timestamps is reduced to the task of finding the "optimal ensemble of delays", while simultaneously determining the exact value of the step between magnetometer measurements. This process can be schematically represented as the construction of a model time series of measurements (t_mod) with a uniform step, followed by its shift to find the optimal (in terms of RMS) ensemble of deviations between the timestamps of QINSy measurements and the timestamps of the model series (from delay_dt1 to delay_dt2). Additionally, a search for the measurement period, on which the model series of measurements is based, must also be performed.

2) In real calculations, no "period search from value to value" or "t_mod shift" is performed. (2) shows the "ideal" QINSy message reception time (t_log) coinciding with the magnetometer message transmission time (t_orig; green color) and the model series (t_mod) with a slightly larger period (t1) than the magnetometer measurement period. Let the maximum deviation (dt) not exceed half of the model period of measurements. Then, by dividing the logging time (t_log) by t1 and rounding the result, we calculate the "serial number of the measurement period" (N). If we plot the deviations dt and N on a graph, we will obtain a sloping line. By approximating it with a linear polynomial, we can "refine" the value of the period t1 so that the line becomes horizontal. At the same time, by approximating it using RMS, we also calculate the "optimal ensemble of deviations" (in terms of RMS).

3) For a more accurate calculation of N and identification of "lost measurements", it is desirable to reduce the influence of "random noise" present in t_log. Therefore, the estimation of the period t1 is performed using "smoothed t_log values" (also removing deviations at the asymptotes of the sample deviations). After that, the non-smoothed data are used in the calculations. At the same time, the N values are additionally corrected according to the following rule: if there is a "large negative deviation", it is likely that the N value, due to the large delay in data transmission, was calculated one unit larger than it should be (due to not meeting the condition "dt does not exceed half of the model measurement period").

4) The additional condition is written on the slide as all(dt)>=0. RMS calculations produce both positive and negative deviations. However, the measurement delay in the digital channel is always positive (namely, "a data message cannot be received by QINSy before it is sent by the magnetometer"). To fulfill this condition, we "shift the t_mod series" along the time axis so that all delays are positive (see t_mod+ in (1) and the bottom line in (4). Physically, the arithmetic mean in the RMS calculation can be viewed as an unknown "average delay time", relative to which the deviations can be either positive or negative. Since this time is unknown to us, we change the shift (t0) so that the deviations are greater than 0. After shifting, there remains an "uncompensated" time equal to the minimum transit time of the message from the magnetometer to QINSy over the entire measurement time; this is labeled as "delay error" in (1).

5) As a result of the calculations performed for the timestamps of a single magnetometer, we obtain: the exact period of magnetometer measurements t1, the shift t0, and the serial numbers of measurements N (factoring the missing measurements). This allows us to calculate the t_mod series, which is the best approximation to the original magnetometer transmission time t_orig.

Script commands

1

SUSet

Define initial settings

2

Load01

Load Mags logs

3

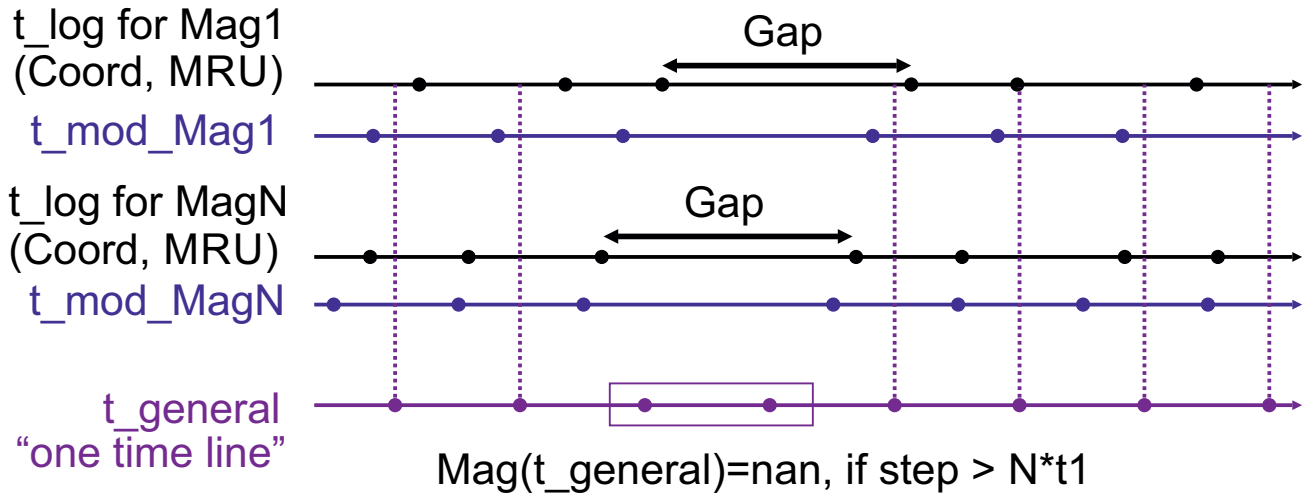
FixTime

Recover time for each Mag

4

Interp

Interpolation to one time line



Mag(t_general)=nan, if step > N*t1

5

Save01

Save data calculated relatively t_general

Slide 5

The script includes 5 main commands:

1) Reading the magnetic survey settings, which are defined directly in the script code (to avoid manual input each time).

2) Reading data from log-files of all magnetometers (each magnetometer is recorded into a separate file).

3) Correcting (restoring) timestamps for the message sequence of each magnetometer (a unique timestamp series is created for each magnetometer); the calculation methodology was explained on the previous slide.

4) Interpolating measurements to a common sequence of timestamps. When interpolating magnetometer data, their own series of timestamps are used; when interpolating magnetometer coordinates, the timestamps recorded by QINSy in the magnetometers log-files are used (since these are the timestamps for which the coordinates were calculated).

5) Saving the results of "recalculating the measurements of all sensors to a single series of timestamps" to a file.