

## System response modeling SkyTEM data in Aarhus Workbench

SkyTEM data in Aarhus Workbench is normally modeled using the system transfer function which included modeling of the transmitter waveform, the low-pass filter characteristics of the receiver coil and the electronics, and a possible calibration time-shift. With a recent development from 2017 however, it has become possible to model SkyTEM data with a system response, rather than modeling the different components of the system transfer function separately. The system response can either be calculated based on the individual system components or, as it is done for the SkyTEM system, it can be derived from measurements at high altitude. The latter option allows the system response to include both known and partly unknown effects.

The most important advantage of system response modeling is, that it makes it possible to perform on-time modeling. With on-time modeling, it is possible to model and use time gates during the ramp-down, which improves the near-surface resolution. Figure 1 shows a schematic drawing of the primary and secondary fields during and after the ramp-down. Normally it is only possible to use time gates after the ramp-down.

To use system response modeling during the ramp-down, two requirements must be fulfilled:

- The first requirement is that the primary field must have been removed from the measured  $db/dt$  responses. For SkyTEM data the primary field is removed with a combination of zero-positioning and the primary field compensation (PFC) method. With zero-positioning the receiver coil is placed so, that the flux of the primary field through the receiver is as close to zero as possible. This greatly reduces the primary field, but it does not remove it entirely, as even small changes to the geometry of the frame during flight will introduce some primary field flux through the receiver coil. The PFC method uses detailed information about the system geometry and transmitter current to estimate the primary field and subtract it from the measured signal for each raw data shot. When combined zero-positioning and the PFC method will in theory completely remove the primary field in measured data.
- The second requirement is that there can be no front gate involved. For SkyTEM data the high moment data is measured with a front gate, so system response modeling can only be done on the low moment. In practice that is not a limit however, as there already is an overlap between usable early high moment time gates and late low moment time gates. The important time gates are the early low moment time gates, and they are measured without a front gate. Figure 2 shows sounding curve examples for a few different SkyTEM systems. As the number of coil turns increase from 4 to 12, the length of the ramp-down increases, but so too does the number of extra early low moment time gates that potentially could be used with system response modeling.

System response modeling can also be conducted on older SkyTEM surveys that include PFC, if a high-altitude test exists from which SkyTEM Surveys can extract the system response.

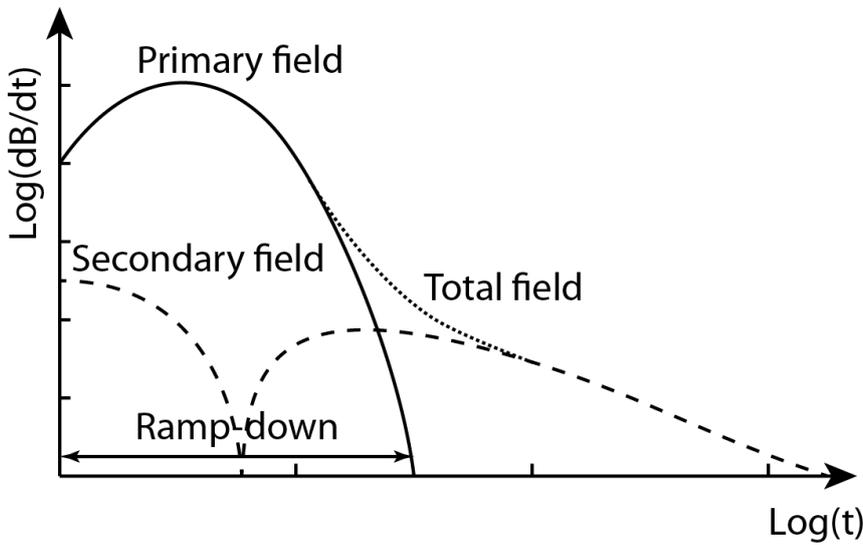


Figure 1: A schematic drawing of a measurement during and after ramp-down, where  $t = 0$  is defined as the start of the ramp-down. During ramp-down the primary field is generally orders of magnitude larger than the secondary field. Note also how the secondary field approach zero as it goes through a sign change during the ramp-down.

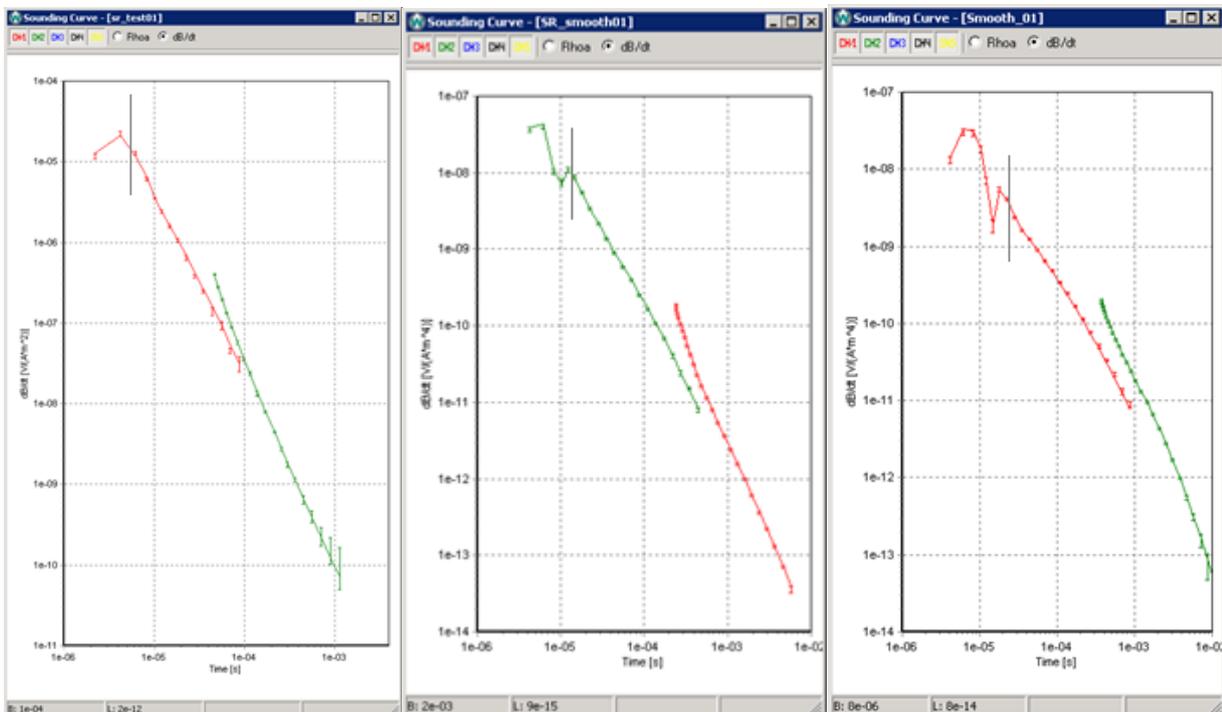


Figure 2: Three examples of a sounding curve with data and model fit for the SkyTEM304, SkyTEM308 and SkyTEM312 systems. As the number of coil turns increase from 4 to 12, the length of the ramp-down increase and the first usable gate, as indicated by the grey line, gets pushed back. This however also increase the number of extra time gates that potentially could be used with system response modeling.

## Getting ready for system response modeling

To do system response modeling in Aarhus Workbench, it is necessary to adjust the geometry file and to add a system response file.

### Adjustments to the geometry file

There are a couple of entries in the geometry file that will need to be added or adjusted as described below.

#### **Under [General]:**

*LoopType=73*

This is the same segmented loop as with LoopType = 72, but it triggers a change in how some of the mathematics are done for the inversions. The time transform will be done with the inverse Laplace transform instead of the Fourier transform. This is a required change for doing system response modeling.

#### **Under [Channel1] with the low moment entries:**

*SystemResponseConvolution=1*

This enables the system response modeling.

*RemoveInitialGates=1*

When using system response modeling, one should not default remove all the on-time gates in the ramp-down. Gates before the turn-off should still be default removed. The above value is an example and may not be the correct one.

*GateTimeShift=0*

Since the time shift effect is included in the system response, it should not be applied here as well.

*SignPattern=1 -1*

It is necessary to state the transmitter sign pattern as the system response file only describes a single system response and the number of repetitions to be modeled. The above values are an example and may not be the correct ones.

### The system response file

The system response file itself (\*.sr) is a text file with the same name as the geometry file. It is essentially an extension of the geometry file and it will be imported alongside the geometry file when that is imported and includes the line with SystemResponseConvolution=1.

Note that it is possible to use the update system setup option in Aarhus Workbench to reapply a geometry file that include a system response file. This can be done to already imported and processed data, so there no need to redo everything.

The system response file for SkyTEM Surveys is made up of a header followed by a system response. It is possible to include multiple such system response blocks in a single system response file. A part of system response file has been included below:

//sr2 file

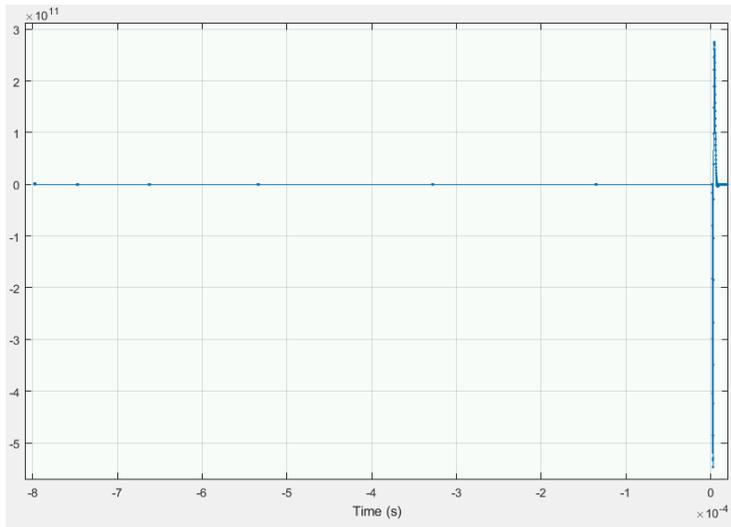
```

1 4 274 2014 12 10 13 02 35 600 2014 12 10 14 51 07 140
  2.0000000000000000e-006      0
  2.2000000000000000e-006 -5.947874386146842e+008
  2.4000000000000000e-006 -3.478788868250981e+009
  2.6000000000000000e-006 -8.902952303850727e+009
  2.8000000000000000e-006 -1.615605319584283e+010
  3.0000000000000000e-006 -2.425144842971714e+010
  3.2000000000000000e-006 -3.226548140478106e+010
  3.4000000000000000e-006 -3.947787182609752e+010
  3.6000000000000000e-006 -4.540535981728255e+010

  ...
  
```

The first line describes the number of the channel, the number of repetitions, the number of data points in the system response below, followed by the begin time (yyyy mm dd hh nn ss zzz) and the end time for where this system response is applicable. The system response consists of the number of data points rows with times and values. The system response will be very close to zero everywhere except around the central part. Figure 3 show a plot of a typical system response.

a)



b)

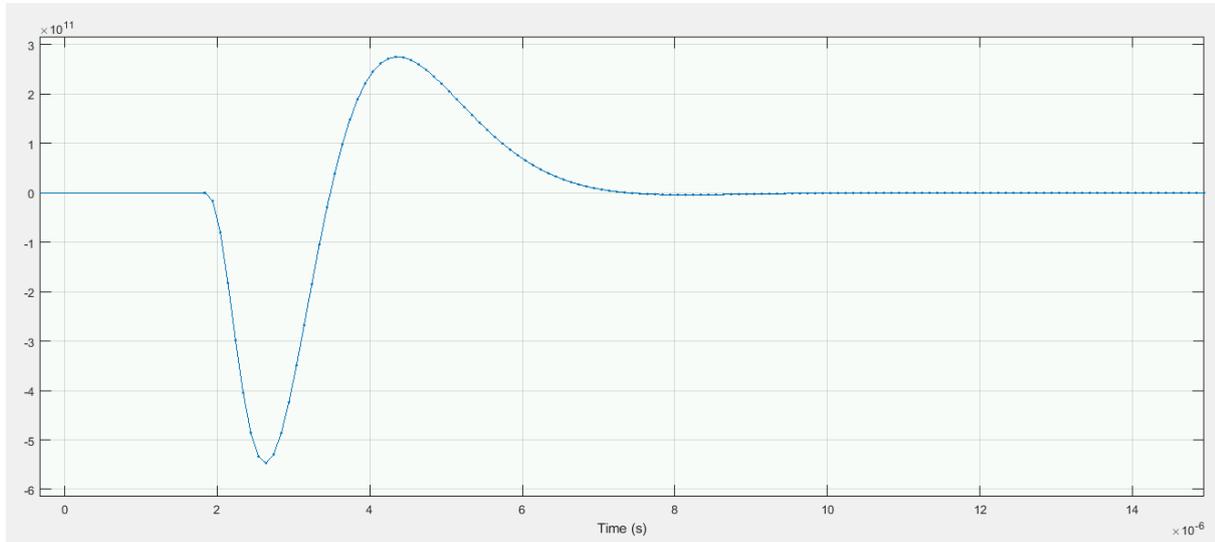


Figure 3: a) The full system response. b) The central part of the system response.

## Data processing on-time gates for system response modeling

The assigned data uncertainty (the error bars) on the different time gates are given as a standard deviation (STD) value. Each gate has a total STD in the inversion with contributions from the uniform STD that was set in the geometry file, usually 3%, the user STD one can set in the processing, and the STD from the stacking.

The removal of the primary field is not an exact process, so the STD on the on-time gates should in general be larger than on the off-time gates. The STD values are relative, so they also need to be adapted close to the sign change where a very low value otherwise will result in a very small STD, that will dominate the inversion. It is suggested to add 5-8% on all on-time gates and 10-50% on gates closer the sign change. Note however that the sign change shift slightly with different ground resistivities. Examples of this can be seen in figure 4.

Gates from before the begin of the ramp-down, should not be used.

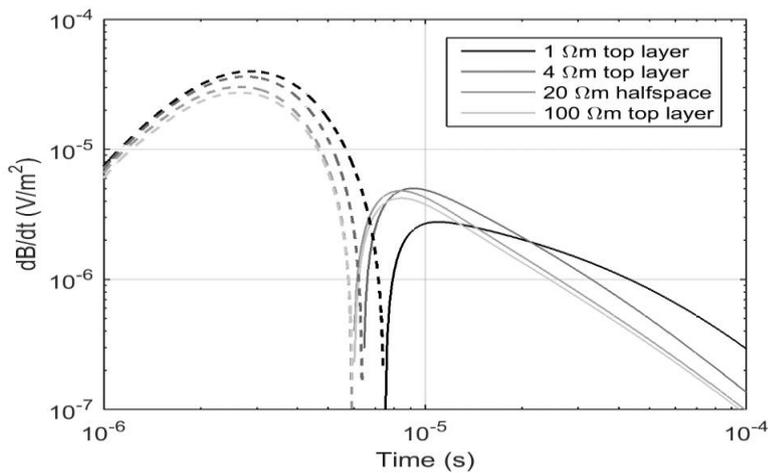


Figure 4: The impact on the measured response due to a 2 m layer on a 20 Ωm background where the top layer has a resistivity of 1 Ωm, 4 Ωm, 20 Ωm and 100 Ωm. Dashed lines are negative values and unbroken lines are positive values.

The best way to deal with this situation is to use the Data Dependent STD function or the easier System Response STD function in Aarhus Workbench. They are a both special cases of the user STD.

To use the data Dependent STD, first select the AEM node that holds the processing nodes, then click Data Dependent STD on the Airborne TEM ribbon. The channels are on the left with a list of gates. Select a gate and press Get to bring it over to the STD change matrix. Then set the User STD to be applied for the gate of that channel below a minimum signal level. It is possible to use a layered setup with multiple values for the same channel and gate combination, but at different minimum signal levels. An example of such a layered

setup can be seen in Figure 5. Add more rows and get more gates as needed and make sure to save the setup to a file so that it can be loaded again if needed. Use apply to write the changes to the database.

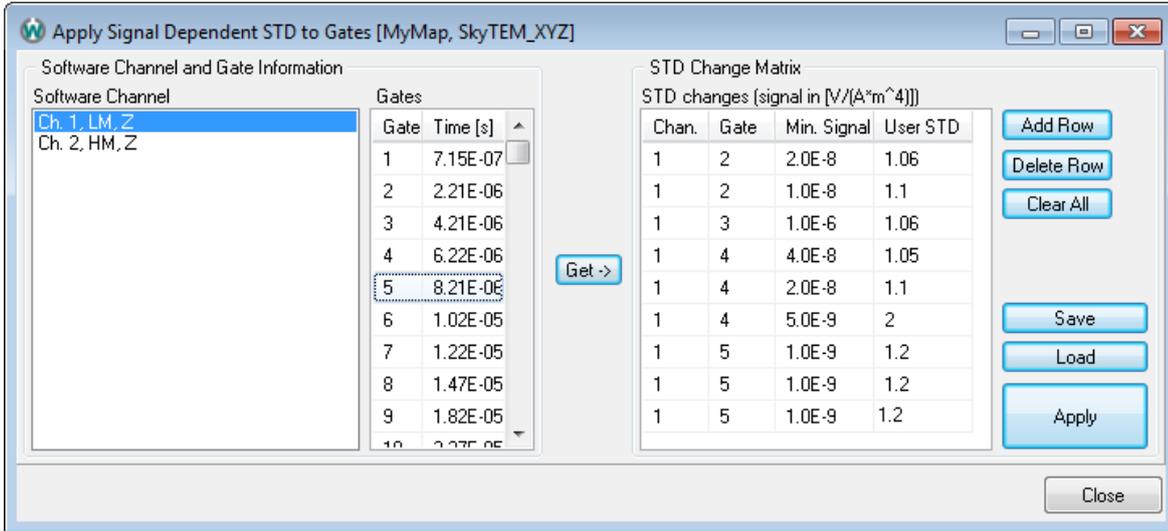


Figure 5: Example Data Dependent STD using a layered setup that tries to compensate for the shift of the sign change in time. Recall how one the user interface 6% is written as 1.06.

To instead use System Response STD, first select the AEM node that holds the processing nodes, then click System Response STD on the Airborne TEM ribbon. Unlike Data Dependent STD where specific gates are given a STD based on the signal level, this function will apply a STD to one, two or three gates symmetrically around the first sign change within a given gate interval. This allows the setup to account for the slight shifts to the sign change that occurs with different ground resistivities. First set the gate interval in which to look for the sign change. The list of the low moment gates is displayed on the left. Gates from before the begin of the ramp-down, should not be used in system response inversions, and can also cause problems here as they can introduce an extra earlier sign change. Then set how many gates around the sign changes should be changed and adjust the STD for each of these gates.

It will often not be necessary to otherwise adjust the processing, as the from time used for the sign and slope filters there, ensure that the earlier on-time gates don't affect the processing. If the later gates already have been processed, inversion can often be setup with a higher minimum number of gates requirement without needing to go through the manual processing again. This is not always the case however as the minimum number of gates is applied individually to each moment, so it depends on how the increased minimum number of gates affect the high moment. In many cases this will not be enough of an issue to warrant doing additional manual removal on the low moment.

When setting up a new processing, make sure not to mistake the unusual look of these early gates for couplings. An example of the unusual look of these early gates can be seen in Figure 6.

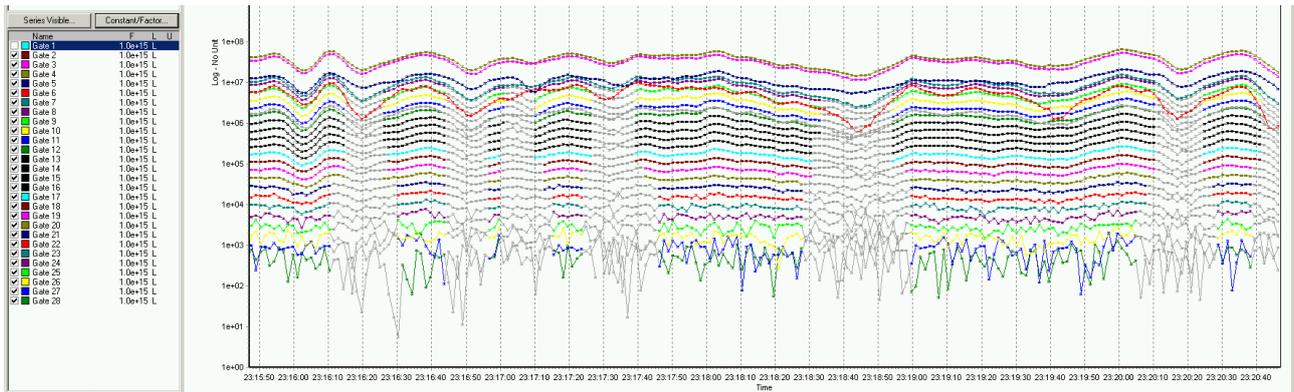


Figure 6: Example processing plot where the processing already was done when the earlier on-time gates was enabled. Those early gates should not be mistaken for couplings.

One last thing to keep in mind. As the calibration time shift here is included in the system response, the low moment time reference will be different with and without system response modeling.

## Inverting and evaluating inversion results with system response modeling

When inverting with system response modeling, the inversion must be done in linear rather than log data mode, to be able to handle the negative gates. This can be changed under advanced configuration during the inversion setup. The inversion setup should also be changed to reflect the expected increase in near-surface sensitivity. The first layer thickness should likely be lowered to 2-4 meters.

After the inversion it is recommended to use the quality control themes with the relative residual of the individual gates to check the data residual of the on-time gates to evaluate the inversion. It is possible to make map for each individual gate. An example of how to do that is shown in figure 7.

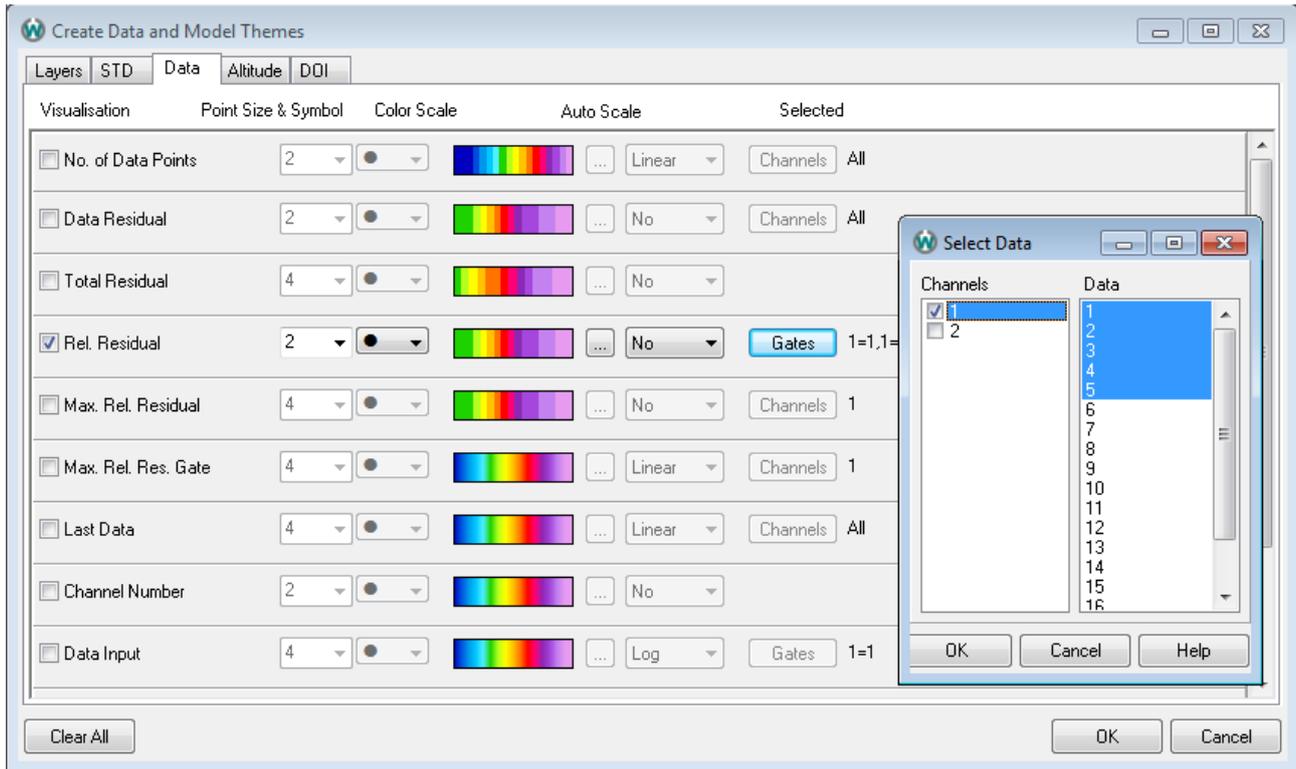


Figure 7: Example setup for making quality control themes for the relative residual of the on-time gates.