Documentation on Thaw Depth Calculation for Permafrost in WaSiM-ETH

When WaSiM-ETH is applied to permafrost regions it is now possible to consider the thickness of the active layer by using a simple thaw depth calculation approach.
Basically, the cells with permafrost must be provided in a new standard grid called ThawCoeffPermaFrost. Here, those cells must have a positive, non-zero α-value assigned.

The thaw depth will be calculated as follows:

$$d_{thaw} = \alpha \cdot \sqrt{n_{sf}}$$

where d_{thaw} thaw depth in m
α empiric coefficient (~0.02...0.05)
n_{sf} number of snow-free days (see below), depends on SWE_{min} and $n_{sc,min}$.

The number of snow-free days n_{sf} is calculated during the model run on a cell by cell basis. A timestep may be a fraction of a day, so n_{sf} is not an integer number. To account for short periods of snow fall during the snow free time, a period of up to $n_{sc,min}$ days will not be considered for refreezing but also not for thawing, so short periods of snow covered ground will simply stop the thaw depth increase. If, on the other hand, the number of consecutive days with a snow cover is longer than the number given in $n_{sc,min}$, then the soil is assumed to be frozen again and d_{thaw} and n_{sf} will both be reset to 0. This is the simple refreezing algorithm.

To avoid the impact of very short snow events and to account for spatial variance, the minimum snow water equivalent for an interval to be counted as snow covered may be specified. This parameter SWE_{min} must also be specified in the control file.

For analyzing the output, a number of grids and statistics file names must be provided in several sections of the control file.

Mandatory grids to switch on permafrost model:

- a standard grid (defined in section [standard_grids] with the identification ThawCoeffPermaFrost; missing values should NOT be filled for this grid
- a variable grid (defined in the section [variable_grids] with the identification PermafrostThawDepth; missing values should NOT be filled for this grid, the default value should be set to a thaw depth which is convenient for the model start, usually 0 if the model run starts immediately before the melting period, otherwise to some positive value when the soil is already thawed. Values must be given in meters. The readgrid parameter should be used for model runs with warm-start conditions (so a valid grid is present as initial state as result from an other model run)

Optional grids:
the following grids may be defined in the section [variable_grids]. If they are not declared, they are created internally, but there will be no possibility to write those grids to the harddisk.

- A grid containing the number (including fractions) of consecutive days with a snow cover of more than SWE_{min} days. The identification is: SnowCoverDaysGrid. The values of this grid are used in the thaw depth algorithm to determine if refreezing starts (it is known there as $n_{sc,min}$)
- A grid containing the number (including fractions) of consecutive days without a snow cover of more than SWE_{min} days. This grid is called: SnowFreeDaysGrid. This grid holds the cell values for n_{sf} as used by the thaw depth algorithm.

Both grids should be read in from disk for subsequent model runs, otherwise (cold start condotions)

they may be created with default values of 0. They should NOT be filled if there are missing values in some cells.

The parameters $n_{sc,min}$, SWE_{min} must be provided in the section [permafrost]. To have statistics of the average thaw depth for each subbasin, the name and statistics code for a statistics file must also be given in the same section.

Examples for changes to the control file ($grid and $suffix are defined usually somewhere above):

```
# set the name of the input grid with alpha-coefficients for
# permafrost thaw depth
$set $ThawCoeffPermaFrost =  $grid//.alpha

# set some variables for permafrost active layer model
$set $SnowFeeDaysGrid     = sfre//$grid//.//$suffix
$set $SnowCoverDaysGrid   = scov//$grid//.//$suffix
$set $ThawDepthGrid       = thdp//$grid//.//$suffix

# in section [standard_grids]
[standard_grids]
...
$inpath//$ThawCoeffPermaFrost ThawCoeffPermaFrost 0 # thaw coefficient
...

# in section [variable_grids]
[variable_grids]
...
$outpath//$SnowFeeDaysGrid SnowFreeDaysGrid    0 0 # snow-free days
$Writegrid
$readgrids
$outpath//$SnowCoverDaysGrid SnowCoverDaysGrid 0 0 # snow covered days
$Writegrid
$readgrids
$outpath//$ThawDepthGrid PermafrostThawDepth   0 0 # thaw depth
$Writegrid
$readgrids

# permafrost parameters
# note:
# - parameter alpha must be read in as a grid with valid cells marked by an
#   alpha value > 0 (all other cells must be nodata, NOT 0)
# - two grids are used within the mode: SnowCoverDaysGrid and SnowFreeDaysGrid.
#   If these grids should be initialized, they must be read in as variable grid
#   otherwise they will be generated internally (and cannot be written)
# - parameters are then: minimum number of days with snowcover, after which the
#   soild will fereeze (happens suddenly - this is NOT
#   a refreezing model, only a state change in order to initialize the next
#   thawing period
# - minimum SWE (snow water equivalent) to be counted as snow cover days
[permafrost]
1                # method: 1=simple Alpha*sqrt(snow-free-days)
15               # nsc min number of days with snow cover for refreezing
4                # maximum snow water equivalent for the interval to be counted
# as snow covered (then, the snow-cover-days grid will be incremented by the
# length of an interval)
$outpath//thaw//$grid//.//$code//$year $hour_mean # thaw dept statistics
```