

Bud break and phenology models for grapevine cultivars

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```
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```

```
library("rmarkdown")
rmarkdown::render("vineyard_vignette.R", pdf_document())
```

Setup

```
library(knitr)
library(gdata)
library(devtools)
has_devel()
```

```
library(roxygen2)
library(xts)
```

```
library(vineyard)
```

```
library(rgdal)
library(spacetime)
```

```
timing.ini <- Sys.time()
```

```
# #' loading and processing raw data
```

```
# #' -----
```

```
# #+ load_process, echo=TRUE, eval=TRUE, include=TRUE
```

```
#
```

```
# data <- read.xls("/home/torres_30400/Documents/02_working_post-doc/3-Production/02_projects/02_VinoMa
```

```
#
```

```
# data1 <- data[,1:9]
```

```
# head(data1)
```

```
# tail(data1)
```

```
#
```

```
# # write.csv(data1, file = "Meteodaten_1970-2017_Remich_geordnet_171114_subset.csv")
```

```
#
```

```
#
```

```
# #' creating time series from raw data
```

```
# #' -----
```

```
# #+ raw2ts, echo=TRUE, eval=TRUE, include=TRUE
```

```
#
```

```
# data1.xts <- Raw2xts(data1, year.name = "Jahr", month.name = "Monat", day.name = "Tag")
```

```
# head(data1.xts)
```

```
# tail(data1.xts)
```

```
# summary(data1.xts)
```

```
#
```

```
# # checking regularity of xts object
```

```

# check.xts <- is.regular(x = data1.xts)
#
# if(!check.xts) stop("the xts object is not regular")
#
#
# # filling NAs
# #' -----
# #+ fill_na, echo=TRUE, eval=TRUE, include=TRUE
#
# # find and replace NAs and visualise time window (T.max)
# ids.na <- Id.na(x = data1.xts$T.max)
# plot.na(x = data1.xts$T.max, ids.na = ids.na)
#
# data1.xts$T.max <- na.approx(data1.xts$T.max)
# plot.na(data1.xts$T.max, ids.na = ids.na)
#
# # find and replace NAs and visualise time window (T.min)
# ids.na <- Id.na(x = data1.xts$T.min)
# plot.na(x = data1.xts$T.min, ids.na = ids.na)
#
# data1.xts$T.min <- na.approx(data1.xts$T.min)
# plot.na(data1.xts$T.min, ids.na = ids.na)
#
# # find and replace NAs and visualise time window (T.mittel)
# ids.na <- Id.na(x = data1.xts$T.mittel)
# plot.na(x = data1.xts$T.mittel, ids.na = ids.na)
#
# data1.xts$T.mittel <- na.approx(data1.xts$T.mittel)
# plot.na(data1.xts$T.mittel, ids.na = ids.na)
#
# # find and replace NAs and visualise time window (N)
# ids.na <- Id.na(x = data1.xts$N)
# plot.na(x = data1.xts$N, ids.na = ids.na)
#
# data1.xts$N <- na.approx(data1.xts$N)
# plot.na(data1.xts$N, ids.na = ids.na)
#
# # find and replace NAs and visualise time window (Sonnenscheinst.)
# ids.na <- Id.na(x = data1.xts$Sonnenscheinst.)
# plot.na(x = data1.xts$Sonnenscheinst., ids.na = ids.na)
# ## take care of this variable because there are too many missing values.
#
# # checking data1.xts
# summary(data1.xts)
#
# #' saving dataset
# #' -----
# #+ save_dataset, echo=TRUE, eval=TRUE, include=TRUE
# storage.mode(data1.xts) <- "numeric"
#
# head(data1.xts)
#
# colnames(data1.xts) <- c("Year", "Month", "Day", "DayYear", "T.max", "T.min", "T.mean", "Rainfall",

```

```

#                               "SolarRadiation")
#
# Remich <- data1.xts[,1:8]
# dim(Remich)
# head(Remich)
# tail(Remich)
#
# save(Remich, file="Remich.rda", compress = "gzip")
# getwd()
#
# ## as STFDF
# # read shapefile for Remich administrative boundary
# data.remich.boundary <- readOGR(dsn = "/home/torres_30400/Documents/02_working_post-doc/3-Production/02_projects/02_VinoManAOP/02_data/Remich/Remich.shp",
#                               layer = "remich_remich_lu_limadmin")
#
# data.remich.boundary@proj4string
#
# plot(data.remich.boundary, col = "green")
#
# # read shapefile for Remich meteorological station
# data.remich.station <- readOGR(dsn = "/home/torres_30400/Documents/02_working_post-doc/3-Production/02_projects/02_VinoManAOP/02_data/Remich/Remich.shp",
#                               layer = "remich_station")
#
# data.remich.station <- spTransform(data.remich.station, data.remich.boundary@proj4string)
#
# plot(data.remich.station, add=TRUE)
#
# # creating STFDF object
# data_remich <- STFDF(sp = data.remich.station , time = index(Remich),
#                     data = data.frame(coredata(Remich)))
#
# str(data_remich)
#
# save(data_remich, file="data_remich.rda")
#
#
# #' saving dataset (CDD)
# #' -----
# #+ save_dataset_cdd, echo=TRUE, eval=TRUE, include=TRUE
#
# GrowthStage_CDD <- read.csv("~/Documents/02_working_post-doc/3-Production/02_projects/02_VinoManAOP/02_data/Remich/GrowthStage_CDD.csv",
#                             stringsAsFactors=FALSE)
#
# save(GrowthStage_CDD, file = "GrowthStage_CDD.rda")
#

```

Load dataset

```

data(data_remich)
str(data_remich)

```

```
## Formal class 'STFDF' [package "spacetime"] with 4 slots
## ..@ data : 'data.frame': 17532 obs. of 8 variables:
## ..$ Year : num [1:17532] 1970 1970 1970 1970 1970 1970 1970 1970 1970 1970 ...
## ..$ Month : num [1:17532] 1 1 1 1 1 1 1 1 1 1 ...
## ..$ Day : num [1:17532] 1 2 3 4 5 6 7 8 9 10 ...
## ..$ DayYear : num [1:17532] 1 2 3 4 5 6 7 8 9 10 ...
## ..$ T.max : num [1:17532] -3.5 -1 1 0.8 -0.1 -0.7 0 -0.3 3.6 4.3 ...
## ..$ T.min : num [1:17532] -4.8 -6.5 -2.5 -0.4 -4.1 -4.5 -4.8 -5.4 -1.6 2.5 ...
## ..$ T.mean : num [1:17532] -4.15 -3.75 -0.75 0.2 -2.1 -2.6 -2.4 -2.85 1 3.4 ...
## ..$ Rainfall: num [1:17532] 0 0 2.7 0.8 4 3.2 0 0 1.8 5.8 ...
## ..@ sp : Formal class 'SpatialPointsDataFrame' [package "sp"] with 5 slots
## .. ..@ data : 'data.frame': 1 obs. of 4 variables:
## .. ..$ id: Factor w/ 1 level "1": 1
## .. ..$ x : num 6.35
## .. ..$ y : num 49.5
## .. ..$ z : Factor w/ 1 level "207": 1
## .. ..@ coords.nrs : num(0)
## .. ..@ coords : num [1, 1:2] 93626 67967
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : NULL
## .. ..$ : chr [1:2] "coords.x1" "coords.x2"
## .. ..@ bbox : num [1:2, 1:2] 93626 67967 93626 67967
## .. ..- attr(*, "dimnames")=List of 2
## .. ..$ : chr [1:2] "coords.x1" "coords.x2"
## .. ..$ : chr [1:2] "min" "max"
## .. ..@ proj4string: Formal class 'CRS' [package "sp"] with 1 slot
## .. .. ..@ projargs: chr "+proj=tmerc +lat_0=49.83333333333334 +lon_0=6.166666666666667 +k=1
## ..@ time : An 'xts' object on 1970-01-01/2017-12-31 containing:
## Data: int [1:17532, 1] 1 2 3 4 5 6 7 8 9 10 ...
## - attr(*, "dimnames")=List of 2
## ..$ : NULL
## ..$ : chr "timeIndex"
## Indexed by objects of class: [POSIXct,POSIXt] TZ:
## xts Attributes:
## NULL
## ..@ endTime: POSIXct[1:17532], format: "1970-01-02" ...
```

Splitting data by years

```
# coercing to data.frame
data.remich <- as.data.frame(data_remich)

# creating xts
data.remich <- xts(x = data.remich, order.by = data.remich$time)

years <- factor(data.remich$Year)
remich.years <- split(data.remich, years)
```

Calculation of cumulative degree days (CDD) by the single triangle algorithm (Nelder, 2010) for bud break

```
head(remich.years[[1]])
```

```
##          coords.x1 coords.x2 sp.ID time      endTime      timeIndex id
## 1970-01-01 93625.69 67967.2 1 1970-01-01 1970-01-02 1 1
## 1970-01-02 93625.69 67967.2 1 1970-01-02 1970-01-03 2 1
## 1970-01-03 93625.69 67967.2 1 1970-01-03 1970-01-04 3 1
## 1970-01-04 93625.69 67967.2 1 1970-01-04 1970-01-05 4 1
## 1970-01-05 93625.69 67967.2 1 1970-01-05 1970-01-06 5 1
## 1970-01-06 93625.69 67967.2 1 1970-01-06 1970-01-07 6 1
##          x          y          z   Year Month Day DayYear T.max
## 1970-01-01 6.354936 49.54519 207 1970 1 1 1 -3.500000
## 1970-01-02 6.354936 49.54519 207 1970 1 2 2 -1.000000
## 1970-01-03 6.354936 49.54519 207 1970 1 3 3 1.000000
## 1970-01-04 6.354936 49.54519 207 1970 1 4 4 0.800000
## 1970-01-05 6.354936 49.54519 207 1970 1 5 5 -0.100000
## 1970-01-06 6.354936 49.54519 207 1970 1 6 6 -0.700000
##          T.min      T.mean      Rainfall
## 1970-01-01 -4.8000000 -4.1500000 0.00
## 1970-01-02 -6.5000000 -3.7500000 0.00
## 1970-01-03 -2.5000000 -0.7500000 2.70
## 1970-01-04 -0.4000000 0.2000000 0.80
## 1970-01-05 -4.1000000 -2.1000000 4.00
## 1970-01-06 -4.5000000 -2.6000000 3.20
```

```
cdd <- cdd.single.triangle(data = remich.years, t.zero = 0, t.min.col = 16,
                           t.mean.col = 17, t.max.col = 15)
```

```
head(cdd[[1]])
```

```
##          coords.x1 coords.x2 sp.ID time      endTime      timeIndex
## 1970-01-01 "93625.69" "67967.2" "1"  "1970-01-01" "1970-01-02" " 1"
## 1970-01-02 "93625.69" "67967.2" "1"  "1970-01-02" "1970-01-03" " 2"
## 1970-01-03 "93625.69" "67967.2" "1"  "1970-01-03" "1970-01-04" " 3"
## 1970-01-04 "93625.69" "67967.2" "1"  "1970-01-04" "1970-01-05" " 4"
## 1970-01-05 "93625.69" "67967.2" "1"  "1970-01-05" "1970-01-06" " 5"
## 1970-01-06 "93625.69" "67967.2" "1"  "1970-01-06" "1970-01-07" " 6"
##          id x          y          z   Year Month Day DayYear
## 1970-01-01 "1" "6.354936" "49.54519" "207" "1970" " 1" " 1" " 1"
## 1970-01-02 "1" "6.354936" "49.54519" "207" "1970" " 1" " 2" " 2"
## 1970-01-03 "1" "6.354936" "49.54519" "207" "1970" " 1" " 3" " 3"
## 1970-01-04 "1" "6.354936" "49.54519" "207" "1970" " 1" " 4" " 4"
## 1970-01-05 "1" "6.354936" "49.54519" "207" "1970" " 1" " 5" " 5"
## 1970-01-06 "1" "6.354936" "49.54519" "207" "1970" " 1" " 6" " 6"
##          T.max      T.min      T.mean      Rainfall
## 1970-01-01 " -3.500000" " -4.800000" " -4.150000" " 0.00"
## 1970-01-02 " -1.000000" " -6.500000" " -3.750000" " 0.00"
## 1970-01-03 " 1.000000" " -2.500000" " -0.750000" " 2.70"
## 1970-01-04 " 0.800000" " -0.400000" " 0.200000" " 0.80"
## 1970-01-05 " -0.100000" " -4.100000" " -2.100000" " 4.00"
## 1970-01-06 " -0.700000" " -4.500000" " -2.600000" " 3.20"
##          cdd_st
## 1970-01-01 "0"
```

```
## 1970-01-02 "0"
## 1970-01-03 "0.142857142857143"
## 1970-01-04 "0.40952380952381"
## 1970-01-05 "0.40952380952381"
## 1970-01-06 "0.40952380952381"
```

```
# write.csv(cdd[[1]], file="cdd_stt_1970.csv")
```

```
cdd.bb <- cdd.single.triangle.budbreak(cdd = cdd, start.date = 62)
head(cdd.bb[[3]])
```

```
##          coords.x1  coords.x2 sp.ID time          endTime          timeIndex
## 1972-03-02 "93625.69" "67967.2" "1"   "1972-03-02" "1972-03-03" " 792"
## 1972-03-03 "93625.69" "67967.2" "1"   "1972-03-03" "1972-03-04" " 793"
## 1972-03-04 "93625.69" "67967.2" "1"   "1972-03-04" "1972-03-05" " 794"
## 1972-03-05 "93625.69" "67967.2" "1"   "1972-03-05" "1972-03-06" " 795"
## 1972-03-06 "93625.69" "67967.2" "1"   "1972-03-06" "1972-03-07" " 796"
## 1972-03-07 "93625.69" "67967.2" "1"   "1972-03-07" "1972-03-08" " 797"
##          id x          y          z   Year  Month Day  DayYear
## 1972-03-02 "1" "6.354936" "49.54519" "207" "1972" " 3" " 2" " 62"
## 1972-03-03 "1" "6.354936" "49.54519" "207" "1972" " 3" " 3" " 63"
## 1972-03-04 "1" "6.354936" "49.54519" "207" "1972" " 3" " 4" " 64"
## 1972-03-05 "1" "6.354936" "49.54519" "207" "1972" " 3" " 5" " 65"
## 1972-03-06 "1" "6.354936" "49.54519" "207" "1972" " 3" " 6" " 66"
## 1972-03-07 "1" "6.354936" "49.54519" "207" "1972" " 3" " 7" " 67"
##          T.max          T.min          T.mean          Rainfall
## 1972-03-02 " 10.800000" " -2.100000" " 4.350000" " 0.00"
## 1972-03-03 "  9.500000" " -1.900000" " 3.800000" " 0.00"
## 1972-03-04 "  6.500000" "  4.600000" " 5.550000" " 5.70"
## 1972-03-05 "  9.000000" "  1.400000" " 5.200000" " 0.00"
## 1972-03-06 "  7.600000" "  1.200000" " 4.400000" " 2.00"
## 1972-03-07 "  8.400000" "  4.000000" " 6.200000" " 1.20"
##          cdd_st
## 1972-03-02 "0"
## 1972-03-03 "3.95833333333333"
## 1972-03-04 "9.50833333333301"
## 1972-03-05 "14.7083333333333"
## 1972-03-06 "19.1083333333333"
## 1972-03-07 "25.3083333333333"
```

```
tail(cdd.bb[[3]])
```

```
##          coords.x1  coords.x2 sp.ID time          endTime          timeIndex
## 1972-12-26 "93625.69" "67967.2" "1"   "1972-12-26" "1972-12-27" " 1091"
## 1972-12-27 "93625.69" "67967.2" "1"   "1972-12-27" "1972-12-28" " 1092"
## 1972-12-28 "93625.69" "67967.2" "1"   "1972-12-28" "1972-12-29" " 1093"
## 1972-12-29 "93625.69" "67967.2" "1"   "1972-12-29" "1972-12-30" " 1094"
## 1972-12-30 "93625.69" "67967.2" "1"   "1972-12-30" "1972-12-31" " 1095"
## 1972-12-31 "93625.69" "67967.2" "1"   "1972-12-31" "1973-01-01" " 1096"
##          id x          y          z   Year  Month Day  DayYear
## 1972-12-26 "1" "6.354936" "49.54519" "207" "1972" "12" "26" "361"
## 1972-12-27 "1" "6.354936" "49.54519" "207" "1972" "12" "27" "362"
## 1972-12-28 "1" "6.354936" "49.54519" "207" "1972" "12" "28" "363"
## 1972-12-29 "1" "6.354936" "49.54519" "207" "1972" "12" "29" "364"
## 1972-12-30 "1" "6.354936" "49.54519" "207" "1972" "12" "30" "365"
## 1972-12-31 "1" "6.354936" "49.54519" "207" "1972" "12" "31" "366"
```

```
##           T.max           T.min           T.mean           Rainfall
## 1972-12-26 " 2.300000" " -5.500000" " -1.600000" " 0.00"
## 1972-12-27 " 1.600000" " -2.700000" " -0.550000" " 0.00"
## 1972-12-28 " 3.000000" " 0.100000" " 1.550000" " 2.00"
## 1972-12-29 " 2.900000" " -3.900000" " -0.500000" " 0.00"
## 1972-12-30 " 1.700000" " -4.500000" " -1.400000" " 0.00"
## 1972-12-31 " 1.100000" " -7.300000" " -2.550000" " 0.00"
##           cdd_st
## 1972-12-26 "3191.29046973533"
## 1972-12-27 "3191.58814415393"
## 1972-12-28 "3193.13814415393"
## 1972-12-29 "3193.75652650687"
## 1972-12-30 "3193.989591023"
## 1972-12-31 "3194.06161483253"
```

```
write.csv(cdd.bb[[46]], file="cdd_bb_SingleTriangleBudbreak_2015.csv")
write.csv(cdd.bb[[47]], file="cdd_bb_SingleTriangleBudbreak_2016.csv")
write.csv(cdd.bb[[48]], file="cdd_bb_SingleTriangleBudbreak_2017.csv")
```

Calculation of degree-days by the single (lower) temperature threshold (Molitor et al., 2014)

```
cdd.lt <- cdd.lThresh(data = remich.years, t.mean.col = 17, a = 0)
head(cdd.lt[[1]])
```

```
##           coords.x1 coords.x2 sp.ID time           endTime           timeIndex
## 1970-01-01 "93625.69" "67967.2" "1"   "1970-01-01" "1970-01-02" " 1"
## 1970-01-02 "93625.69" "67967.2" "1"   "1970-01-02" "1970-01-03" " 2"
## 1970-01-03 "93625.69" "67967.2" "1"   "1970-01-03" "1970-01-04" " 3"
## 1970-01-04 "93625.69" "67967.2" "1"   "1970-01-04" "1970-01-05" " 4"
## 1970-01-05 "93625.69" "67967.2" "1"   "1970-01-05" "1970-01-06" " 5"
## 1970-01-06 "93625.69" "67967.2" "1"   "1970-01-06" "1970-01-07" " 6"
##           id x           y           z   Year Month Day DayYear
## 1970-01-01 "1" "6.354936" "49.54519" "207" "1970" " 1" " 1" " 1"
## 1970-01-02 "1" "6.354936" "49.54519" "207" "1970" " 1" " 2" " 2"
## 1970-01-03 "1" "6.354936" "49.54519" "207" "1970" " 1" " 3" " 3"
## 1970-01-04 "1" "6.354936" "49.54519" "207" "1970" " 1" " 4" " 4"
## 1970-01-05 "1" "6.354936" "49.54519" "207" "1970" " 1" " 5" " 5"
## 1970-01-06 "1" "6.354936" "49.54519" "207" "1970" " 1" " 6" " 6"
##           T.max           T.min           T.mean           Rainfall cdd.lt
## 1970-01-01 " -3.500000" " -4.800000" " -4.150000" " 0.00" "0"
## 1970-01-02 " -1.000000" " -6.500000" " -3.750000" " 0.00" "0"
## 1970-01-03 " 1.000000" " -2.500000" " -0.750000" " 2.70" "0"
## 1970-01-04 " 0.800000" " -0.400000" " 0.200000" " 0.80" "0.2"
## 1970-01-05 " -0.100000" " -4.100000" " -2.100000" " 4.00" "0.2"
## 1970-01-06 " -0.700000" " -4.500000" " -2.600000" " 3.20" "0.2"
```

```
# write.csv(cdd.stt[[1]], file="cdd_stt_1970.csv")
```

Calculation of phenology by the single temperature threshold (Molitor et al., 2014)

```
# mean cumulative heat sum for bud break of 438.7 degree celsius for
# Mueller-Thurgau (Nelder, 2010)
cdd.phen.mthurgau <- cdd.lThresh.phenology(cdd.lt = cdd.lt, chs.mean = 438.7)
head(cdd.phen.mthurgau[[1]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 1970-05-02 "93625.69" "67967.2" "1"   "1970-05-02" "1970-05-03" " 122"
## 1970-05-03 "93625.69" "67967.2" "1"   "1970-05-03" "1970-05-04" " 123"
## 1970-05-04 "93625.69" "67967.2" "1"   "1970-05-04" "1970-05-05" " 124"
## 1970-05-05 "93625.69" "67967.2" "1"   "1970-05-05" "1970-05-06" " 125"
## 1970-05-06 "93625.69" "67967.2" "1"   "1970-05-06" "1970-05-07" " 126"
## 1970-05-07 "93625.69" "67967.2" "1"   "1970-05-07" "1970-05-08" " 127"
##          id x          y          z          Year Month Day DayYear
## 1970-05-02 "1" "6.354936" "49.54519" "207" "1970" " 5" " 2" "122"
## 1970-05-03 "1" "6.354936" "49.54519" "207" "1970" " 5" " 3" "123"
## 1970-05-04 "1" "6.354936" "49.54519" "207" "1970" " 5" " 4" "124"
## 1970-05-05 "1" "6.354936" "49.54519" "207" "1970" " 5" " 5" "125"
## 1970-05-06 "1" "6.354936" "49.54519" "207" "1970" " 5" " 6" "126"
## 1970-05-07 "1" "6.354936" "49.54519" "207" "1970" " 5" " 7" "127"
##          T.max          T.min          T.mean          Rainfall cdd_lt
## 1970-05-02 " 11.400000" "  3.3000000" "  7.3500000" "  4.50" "0"
## 1970-05-03 " 15.500000" "  8.5000000" " 12.0000000" "  2.50" "12"
## 1970-05-04 " 18.500000" "  8.5000000" " 13.5000000" "  0.00" "25.5"
## 1970-05-05 " 20.300000" "  7.7000000" " 14.0000000" "  0.00" "39.5"
## 1970-05-06 " 19.600000" " 10.5000000" " 15.0500000" "  1.00" "54.55"
## 1970-05-07 " 20.500000" " 11.0000000" " 15.7500000" "  0.00" "70.3"
```

```
# mean cumulative heat sum for bud break of 438.7 degree celsius for
# Riesling (Nelder, 2010)
cdd.phen.riesling <- cdd.lThresh.phenology(cdd.lt = cdd.lt, chs.mean = 463.1)
head(cdd.phen.riesling[[1]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 1970-05-04 "93625.69" "67967.2" "1"   "1970-05-04" "1970-05-05" " 124"
## 1970-05-05 "93625.69" "67967.2" "1"   "1970-05-05" "1970-05-06" " 125"
## 1970-05-06 "93625.69" "67967.2" "1"   "1970-05-06" "1970-05-07" " 126"
## 1970-05-07 "93625.69" "67967.2" "1"   "1970-05-07" "1970-05-08" " 127"
## 1970-05-08 "93625.69" "67967.2" "1"   "1970-05-08" "1970-05-09" " 128"
## 1970-05-09 "93625.69" "67967.2" "1"   "1970-05-09" "1970-05-10" " 129"
##          id x          y          z          Year Month Day DayYear
## 1970-05-04 "1" "6.354936" "49.54519" "207" "1970" " 5" " 4" "124"
## 1970-05-05 "1" "6.354936" "49.54519" "207" "1970" " 5" " 5" "125"
## 1970-05-06 "1" "6.354936" "49.54519" "207" "1970" " 5" " 6" "126"
## 1970-05-07 "1" "6.354936" "49.54519" "207" "1970" " 5" " 7" "127"
## 1970-05-08 "1" "6.354936" "49.54519" "207" "1970" " 5" " 8" "128"
## 1970-05-09 "1" "6.354936" "49.54519" "207" "1970" " 5" " 9" "129"
##          T.max          T.min          T.mean          Rainfall cdd_lt
## 1970-05-04 " 18.500000" "  8.5000000" " 13.5000000" "  0.00" "0"
## 1970-05-05 " 20.300000" "  7.7000000" " 14.0000000" "  0.00" "14"
## 1970-05-06 " 19.600000" " 10.5000000" " 15.0500000" "  1.00" "29.05"
## 1970-05-07 " 20.500000" " 11.0000000" " 15.7500000" "  0.00" "44.8"
```



```
## 1970-05-08 " 22.500000" " 10.200000" " 16.350000" " 0.00" "61.15"
## 1970-05-09 " 20.000000" " 9.500000" " 14.750000" " 0.00" "75.9"
```

```
# growth stages
data(GrowthStage_CDD)
```

```
GrowthStage_CDD
```

```
##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
## 14            61
## 15            63
## 16            65
## 17            68
## 18            69
## 19            71
## 20            73
## 21            75
## 22            77
## 23            79
## 24            81
## 25            83
## 26            85
## 27            89
```

	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2
## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6
## 8	Seven leaves unfolded	213.5
## 9	Eight leaves unfolded	248.8
## 10	Nine leaves unfolded	285.2
## 11	Inflorescences clearly visible	178.1
## 12	Inflorescences swelling, flowers closely pressed together	253.2
## 13	Inflorescences fully developed; flowers separating	375.5
## 14	Beginning of flowering: 10% flowerhoods fallen	463.3
## 15	Early flowering: 30% flowerhoods fallen	494.5
## 16	Full flowering: 50% flowerhoods fallen	517.5
## 17	80% flowerhoods fallen	548.4
## 18	End of flowering	569.6

```
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20 Berries groat-sized, bunches begin to hang 659.0
## 21 Berries pea-sized, bunches hang 774.9
## 22 Begin of berry touch 870.0
## 23 Berry touch complete 999.4
## 24 Beginning of ripening: berries begin to brighten in color 1160.2
## 25 Berries brighting in color 1219.4
## 26 Softening of berries 1287.8
## 27 Berries ripe for harvest 1719.8

phen.mthurgau <- phenology.stages(cdd.phen = cdd.phen.mthurgau, ref.data = GrowthStage_CDD,
                                stage = GrowthStage_CDD[-1,1])

phen.mthurgau[[46]]
```

```
## Growth_stage
## 1 9
## 2 11
## 3 12
## 4 13
## 5 14
## 6 15
## 7 16
## 8 17
## 9 18
## 10 19
## 11 53
## 12 55
## 13 57
## 14 61
## 15 63
## 16 65
## 17 68
## 18 69
## 19 71
## 20 73
## 21 75
## 22 77
## 23 79
## 24 81
## 25 83
## 26 85
## 27 89

## Description CDD
## 1 Budburst: green shoot tips clearly visible NA
## 2 First leaf unfolded and spread away from shoot 34.9
## 3 Two leaves unfolded 58.6
## 4 Three leaves unfolded 80.8
## 5 Four leaves unfolded 110.2
## 6 Five leaves unfolded 144.4
## 7 Six leaves unfolded 173.6
## 8 Seven leaves unfolded 213.5
## 9 Eight leaves unfolded 248.8
## 10 Nine leaves unfolded 285.2
## 11 Inflorescences clearly visible 178.1
## 12 Inflorescences swelling, flowers closely pressed together 253.2
```

```

## 13      Inflorescences fully developed; flowers separating 375.5
## 14      Beginning of flowering: 10% flowerhoods fallen 463.3
## 15      Early flowering: 30% flowerhoods fallen 494.5
## 16      Full flowering: 50% flowerhoods fallen 517.5
## 17      80% flowerhoods fallen 548.4
## 18      End of flowering 569.6
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20      Berries groat-sized, bunches begin to hang 659
## 21      Berries pea-sized, bunches hang 774.9
## 22      Begin of berry touch 870
## 23      Berry touch complete 999.4
## 24      Beginning of ripening: berries begin to brighten in color 1160.2
## 25      Berries brightening in color 1219.4
## 26      Softening of berries 1287.8
## 27      Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69  67967.2    1 2015-04-11 2015-04-12    16537 1 6.354936
## 2  93625.69  67967.2    1 2015-04-14 2015-04-15    16540 1 6.354936
## 3  93625.69  67967.2    1 2015-04-16 2015-04-17    16542 1 6.354936
## 4  93625.69  67967.2    1 2015-04-18 2015-04-19    16544 1 6.354936
## 5  93625.69  67967.2    1 2015-04-20 2015-04-21    16546 1 6.354936
## 6  93625.69  67967.2    1 2015-04-23 2015-04-24    16549 1 6.354936
## 7  93625.69  67967.2    1 2015-04-25 2015-04-26    16551 1 6.354936
## 8  93625.69  67967.2    1 2015-04-29 2015-04-30    16555 1 6.354936
## 9  93625.69  67967.2    1 2015-05-03 2015-05-04    16559 1 6.354936
## 10 93625.69  67967.2    1 2015-05-05 2015-05-06    16561 1 6.354936
## 11 93625.69  67967.2    1 2015-04-26 2015-04-27    16552 1 6.354936
## 12 93625.69  67967.2    1 2015-05-03 2015-05-04    16559 1 6.354936
## 13 93625.69  67967.2    1 2015-05-11 2015-05-12    16567 1 6.354936
## 14 93625.69  67967.2    1 2015-05-17 2015-05-18    16573 1 6.354936
## 15 93625.69  67967.2    1 2015-05-20 2015-05-21    16576 1 6.354936
## 16 93625.69  67967.2    1 2015-05-22 2015-05-23    16578 1 6.354936
## 17 93625.69  67967.2    1 2015-05-24 2015-05-25    16580 1 6.354936
## 18 93625.69  67967.2    1 2015-05-25 2015-05-26    16581 1 6.354936
## 19 93625.69  67967.2    1 2015-05-28 2015-05-29    16584 1 6.354936
## 20 93625.69  67967.2    1 2015-06-01 2015-06-02    16588 1 6.354936
## 21 93625.69  67967.2    1 2015-06-07 2015-06-08    16594 1 6.354936
## 22 93625.69  67967.2    1 2015-06-12 2015-06-13    16599 1 6.354936
## 23 93625.69  67967.2    1 2015-06-20 2015-06-21    16607 1 6.354936
## 24 93625.69  67967.2    1 2015-06-29 2015-06-30    16616 1 6.354936
## 25 93625.69  67967.2    1 2015-07-02 2015-07-03    16619 1 6.354936
## 26 93625.69  67967.2    1 2015-07-04 2015-07-05    16621 1 6.354936
## 27 93625.69  67967.2    1 2015-07-24 2015-07-25    16641 1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2015      4 11      101 15.000000  8.900000 11.950000
## 2 49.54519 207 2015      4 14      104 22.700000  3.500000 13.100000
## 3 49.54519 207 2015      4 16      106 23.100000  6.700000 14.900000
## 4 49.54519 207 2015      4 18      108 15.300000  3.600000  9.450000
## 5 49.54519 207 2015      4 20      110 21.100000  4.100000 12.600000
## 6 49.54519 207 2015      4 23      113 20.400000  2.300000 11.350000
## 7 49.54519 207 2015      4 25      115 16.700000  9.700000 13.200000
## 8 49.54519 207 2015      4 29      119 15.200000  0.200000  7.700000
## 9 49.54519 207 2015      5  3      123 16.700000 11.200000 13.950000
## 10 49.54519 207 2015      5  5      125 22.100000 11.600000 16.850000

```

```
## 11 49.54519 207 2015      4 26      116 20.900000 11.2000000 16.0500000
## 12 49.54519 207 2015      5  3      123 16.700000 11.2000000 13.9500000
## 13 49.54519 207 2015      5 11      131 26.300000  8.6000000 17.4500000
## 14 49.54519 207 2015      5 17      137 19.900000  8.9000000 14.4000000
## 15 49.54519 207 2015      5 20      140 14.500000  5.2000000  9.8500000
## 16 49.54519 207 2015      5 22      142 21.600000  7.9000000 14.7500000
## 17 49.54519 207 2015      5 24      144 22.700000 12.2000000 17.4500000
## 18 49.54519 207 2015      5 25      145 19.200000  8.3000000 13.7500000
## 19 49.54519 207 2015      5 28      148 20.800000  8.4000000 14.6000000
## 20 49.54519 207 2015      6  1      152 17.400000  9.4000000 13.4000000
## 21 49.54519 207 2015      6  7      158 25.500000 11.5000000 18.5000000
## 22 49.54519 207 2015      6 12      163 30.000000 14.3000000 22.1500000
## 23 49.54519 207 2015      6 20      171 18.100000 10.6000000 14.3500000
## 24 49.54519 207 2015      6 29      180 29.200000 14.8000000 22.0000000
## 25 49.54519 207 2015      7  2      183 37.200000 19.5000000 28.3500000
## 26 49.54519 207 2015      7  4      185 38.600000 21.8000000 30.2000000
## 27 49.54519 207 2015      7 24      205 31.400000 14.4000000 22.9000000
```

```
##      Rainfall  cdd_lt
```

```
## 1      0.20      0
## 2      0.00     37.55
## 3      0.00     67.85
## 4      0.00     89.35
## 5      0.00    111.95
## 6      0.00    151.1
## 7      3.50    177.45
## 8      0.00    219.4
## 9      9.70    261.85
## 10     0.70     296
## 11    11.20    193.5
## 12     9.70    261.85
## 13     0.00    383.95
## 14     0.00    469.55
## 15     0.10    504.25
## 16     0.00    529.7
## 17     0.00    562.3
## 18     5.10    576.05
## 19     0.00    613.95
## 20     1.70    665.35
## 21     0.00    782.1
## 22     0.00    871.75
## 23     1.20    1006
## 24     0.00   1161.75
## 25     0.00   1238.2
## 26     0.00   1297.3
## 27     6.00   1736.2
```

```
phen.riesling <- phenology.stages(cdd.phen = cdd.phen.mthurgau, ref.data = GrowthStage_CDD,
                                  stage = GrowthStage_CDD[-1,1])
phen.riesling[[46]]
```

```
##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
```

```
## 5      14
## 6      15
## 7      16
## 8      17
## 9      18
## 10     19
## 11     53
## 12     55
## 13     57
## 14     61
## 15     63
## 16     65
## 17     68
## 18     69
## 19     71
## 20     73
## 21     75
## 22     77
## 23     79
## 24     81
## 25     83
## 26     85
## 27     89
```

	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2
## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6
## 8	Seven leaves unfolded	213.5
## 9	Eight leaves unfolded	248.8
## 10	Nine leaves unfolded	285.2
## 11	Inflorescences clearly visible	178.1
## 12	Inflorescences swelling, flowers closely pressed together	253.2
## 13	Inflorescences fully developed; flowers separating	375.5
## 14	Beginning of flowering: 10% flowerhoods fallen	463.3
## 15	Early flowering: 30% flowerhoods fallen	494.5
## 16	Full flowering: 50% flowerhoods fallen	517.5
## 17	80% flowerhoods fallen	548.4
## 18	End of flowering	569.6
## 19	Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20	Berries groat-sized, bunches begin to hang	659
## 21	Berries pea-sized, bunches hang	774.9
## 22	Begin of berry touch	870
## 23	Berry touch complete	999.4
## 24	Beginning of ripening: berries begin to brighten in color	1160.2
## 25	Berries brightening in color	1219.4
## 26	Softening of berries	1287.8
## 27	Berries ripe for harvest	1719.8
##	coords.x1 coords.x2 sp.ID time endTime timeIndex id x	
## 1	93625.69 67967.2 1 2015-04-11 2015-04-12 16537 1 6.354936	
## 2	93625.69 67967.2 1 2015-04-14 2015-04-15 16540 1 6.354936	

## 3	93625.69	67967.2	1	2015-04-16	2015-04-17	16542	1	6.354936	
## 4	93625.69	67967.2	1	2015-04-18	2015-04-19	16544	1	6.354936	
## 5	93625.69	67967.2	1	2015-04-20	2015-04-21	16546	1	6.354936	
## 6	93625.69	67967.2	1	2015-04-23	2015-04-24	16549	1	6.354936	
## 7	93625.69	67967.2	1	2015-04-25	2015-04-26	16551	1	6.354936	
## 8	93625.69	67967.2	1	2015-04-29	2015-04-30	16555	1	6.354936	
## 9	93625.69	67967.2	1	2015-05-03	2015-05-04	16559	1	6.354936	
## 10	93625.69	67967.2	1	2015-05-05	2015-05-06	16561	1	6.354936	
## 11	93625.69	67967.2	1	2015-04-26	2015-04-27	16552	1	6.354936	
## 12	93625.69	67967.2	1	2015-05-03	2015-05-04	16559	1	6.354936	
## 13	93625.69	67967.2	1	2015-05-11	2015-05-12	16567	1	6.354936	
## 14	93625.69	67967.2	1	2015-05-17	2015-05-18	16573	1	6.354936	
## 15	93625.69	67967.2	1	2015-05-20	2015-05-21	16576	1	6.354936	
## 16	93625.69	67967.2	1	2015-05-22	2015-05-23	16578	1	6.354936	
## 17	93625.69	67967.2	1	2015-05-24	2015-05-25	16580	1	6.354936	
## 18	93625.69	67967.2	1	2015-05-25	2015-05-26	16581	1	6.354936	
## 19	93625.69	67967.2	1	2015-05-28	2015-05-29	16584	1	6.354936	
## 20	93625.69	67967.2	1	2015-06-01	2015-06-02	16588	1	6.354936	
## 21	93625.69	67967.2	1	2015-06-07	2015-06-08	16594	1	6.354936	
## 22	93625.69	67967.2	1	2015-06-12	2015-06-13	16599	1	6.354936	
## 23	93625.69	67967.2	1	2015-06-20	2015-06-21	16607	1	6.354936	
## 24	93625.69	67967.2	1	2015-06-29	2015-06-30	16616	1	6.354936	
## 25	93625.69	67967.2	1	2015-07-02	2015-07-03	16619	1	6.354936	
## 26	93625.69	67967.2	1	2015-07-04	2015-07-05	16621	1	6.354936	
## 27	93625.69	67967.2	1	2015-07-24	2015-07-25	16641	1	6.354936	
##	y	z	Year	Month	Day	DayYear	T.max	T.min	T.mean
## 1	49.54519	207	2015	4	11	101	15.000000	8.9000000	11.9500000
## 2	49.54519	207	2015	4	14	104	22.700000	3.5000000	13.1000000
## 3	49.54519	207	2015	4	16	106	23.100000	6.7000000	14.9000000
## 4	49.54519	207	2015	4	18	108	15.300000	3.6000000	9.4500000
## 5	49.54519	207	2015	4	20	110	21.100000	4.1000000	12.6000000
## 6	49.54519	207	2015	4	23	113	20.400000	2.3000000	11.3500000
## 7	49.54519	207	2015	4	25	115	16.700000	9.7000000	13.2000000
## 8	49.54519	207	2015	4	29	119	15.200000	0.2000000	7.7000000
## 9	49.54519	207	2015	5	3	123	16.700000	11.2000000	13.9500000
## 10	49.54519	207	2015	5	5	125	22.100000	11.6000000	16.8500000
## 11	49.54519	207	2015	4	26	116	20.900000	11.2000000	16.0500000
## 12	49.54519	207	2015	5	3	123	16.700000	11.2000000	13.9500000
## 13	49.54519	207	2015	5	11	131	26.300000	8.6000000	17.4500000
## 14	49.54519	207	2015	5	17	137	19.900000	8.9000000	14.4000000
## 15	49.54519	207	2015	5	20	140	14.500000	5.2000000	9.8500000
## 16	49.54519	207	2015	5	22	142	21.600000	7.9000000	14.7500000
## 17	49.54519	207	2015	5	24	144	22.700000	12.2000000	17.4500000
## 18	49.54519	207	2015	5	25	145	19.200000	8.3000000	13.7500000
## 19	49.54519	207	2015	5	28	148	20.800000	8.4000000	14.6000000
## 20	49.54519	207	2015	6	1	152	17.400000	9.4000000	13.4000000
## 21	49.54519	207	2015	6	7	158	25.500000	11.5000000	18.5000000
## 22	49.54519	207	2015	6	12	163	30.000000	14.3000000	22.1500000
## 23	49.54519	207	2015	6	20	171	18.100000	10.6000000	14.3500000
## 24	49.54519	207	2015	6	29	180	29.200000	14.8000000	22.0000000
## 25	49.54519	207	2015	7	2	183	37.200000	19.5000000	28.3500000
## 26	49.54519	207	2015	7	4	185	38.600000	21.8000000	30.2000000
## 27	49.54519	207	2015	7	24	205	31.400000	14.4000000	22.9000000
##	Rainfall	cdd_lt							

```
## 1      0.20      0
## 2      0.00     37.55
## 3      0.00     67.85
## 4      0.00     89.35
## 5      0.00    111.95
## 6      0.00    151.1
## 7      3.50    177.45
## 8      0.00    219.4
## 9      9.70    261.85
## 10     0.70     296
## 11    11.20    193.5
## 12     9.70    261.85
## 13     0.00    383.95
## 14     0.00    469.55
## 15     0.10    504.25
## 16     0.00    529.7
## 17     0.00    562.3
## 18     5.10    576.05
## 19     0.00    613.95
## 20     1.70    665.35
## 21     0.00    782.1
## 22     0.00    871.75
## 23     1.20    1006
## 24     0.00   1161.75
## 25     0.00   1238.2
## 26     0.00   1297.3
## 27     6.00   1736.2
```

Calculation of degree-days by the double (lower and upper) temperature thresholds (Molitor et al., 2014)

```
cdd.lut <- cdd.luThresh(data = remich.years, t.mean.col = 17, a = 0, b = 15)
```

```
head(cdd.lut[[46]])
```

```
##          coords.x1  coords.x2 sp.ID time          endTime      timeIndex
## 2015-01-01 "93625.69" "67967.2" "1"   "2015-01-01" "2015-01-02" "16437"
## 2015-01-02 "93625.69" "67967.2" "1"   "2015-01-02" "2015-01-03" "16438"
## 2015-01-03 "93625.69" "67967.2" "1"   "2015-01-03" "2015-01-04" "16439"
## 2015-01-04 "93625.69" "67967.2" "1"   "2015-01-04" "2015-01-05" "16440"
## 2015-01-05 "93625.69" "67967.2" "1"   "2015-01-05" "2015-01-06" "16441"
## 2015-01-06 "93625.69" "67967.2" "1"   "2015-01-06" "2015-01-07" "16442"
##          id  x          y          z   Year  Month Day  DayYear
## 2015-01-01 "1" "6.354936" "49.54519" "207" "2015" " 1" " 1" " 1"
## 2015-01-02 "1" "6.354936" "49.54519" "207" "2015" " 1" " 2" " 2"
## 2015-01-03 "1" "6.354936" "49.54519" "207" "2015" " 1" " 3" " 3"
## 2015-01-04 "1" "6.354936" "49.54519" "207" "2015" " 1" " 4" " 4"
## 2015-01-05 "1" "6.354936" "49.54519" "207" "2015" " 1" " 5" " 5"
## 2015-01-06 "1" "6.354936" "49.54519" "207" "2015" " 1" " 6" " 6"
##          T.max      T.min      T.mean      Rainfall cdd_lut
## 2015-01-01 " 1.400000" " -1.000000" " 0.200000" " 0.00" "0.2"
## 2015-01-02 " 4.200000" " -1.600000" " 1.300000" " 1.80" "1.5"
## 2015-01-03 "10.700000" " 1.300000" " 6.000000" " 6.50" "7.5"
```

```
## 2015-01-04 " 5.800000" " -0.900000" " 2.450000" " 0.00" "9.95"
## 2015-01-05 " 2.100000" " -3.200000" " -0.550000" " 0.00" "9.95"
## 2015-01-06 " -0.100000" " -4.200000" " -2.150000" " 0.00" "9.95"
```

```
tail(cdd.lut[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-12-26 "93625.69" "67967.2" "1"   "2015-12-26" "2015-12-27" "16796"
## 2015-12-27 "93625.69" "67967.2" "1"   "2015-12-27" "2015-12-28" "16797"
## 2015-12-28 "93625.69" "67967.2" "1"   "2015-12-28" "2015-12-29" "16798"
## 2015-12-29 "93625.69" "67967.2" "1"   "2015-12-29" "2015-12-30" "16799"
## 2015-12-30 "93625.69" "67967.2" "1"   "2015-12-30" "2015-12-31" "16800"
## 2015-12-31 "93625.69" "67967.2" "1"   "2015-12-31" "2016-01-01" "16801"
##          id x          y          z   Year  Month Day  DayYear
## 2015-12-26 "1" "6.354936" "49.54519" "207" "2015" "12"  "26" "360"
## 2015-12-27 "1" "6.354936" "49.54519" "207" "2015" "12"  "27" "361"
## 2015-12-28 "1" "6.354936" "49.54519" "207" "2015" "12"  "28" "362"
## 2015-12-29 "1" "6.354936" "49.54519" "207" "2015" "12"  "29" "363"
## 2015-12-30 "1" "6.354936" "49.54519" "207" "2015" "12"  "30" "364"
## 2015-12-31 "1" "6.354936" "49.54519" "207" "2015" "12"  "31" "365"
##          T.max          T.min          T.mean          Rainfall cdd_lut
## 2015-12-26 " 12.000000" " 6.100000" " 9.050000" " 0.00" "3648.95"
## 2015-12-27 " 12.100000" " 3.300000" " 7.700000" " 0.00" "3656.65"
## 2015-12-28 " 10.800000" " 0.500000" " 5.650000" " 0.00" "3662.3"
## 2015-12-29 " 8.200000" " -1.100000" " 3.550000" " 0.00" "3665.85"
## 2015-12-30 " 9.000000" " 1.300000" " 5.150000" " 0.00" "3671"
## 2015-12-31 " 11.300000" " 0.100000" " 5.700000" " 1.80" "3676.7"
```

Calculation of phenology by the double (lower and upper) temperature thresholds (Molitor et al., 2014)

```
# mean cumulative heat sum for bud break of 438.7 degree celsius for
# Mueller-Thurgau (Nelder, 2010)
cdd.phen.mthurgau.lut <- cdd.luThresh.phenology(cdd.lut = cdd.lut, chs.mean = 438.7)
head(cdd.phen.mthurgau.lut[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-04-11 "93625.69" "67967.2" "1"   "2015-04-11" "2015-04-12" "16537"
## 2015-04-12 "93625.69" "67967.2" "1"   "2015-04-12" "2015-04-13" "16538"
## 2015-04-13 "93625.69" "67967.2" "1"   "2015-04-13" "2015-04-14" "16539"
## 2015-04-14 "93625.69" "67967.2" "1"   "2015-04-14" "2015-04-15" "16540"
## 2015-04-15 "93625.69" "67967.2" "1"   "2015-04-15" "2015-04-16" "16541"
## 2015-04-16 "93625.69" "67967.2" "1"   "2015-04-16" "2015-04-17" "16542"
##          id x          y          z   Year  Month Day  DayYear
## 2015-04-11 "1" "6.354936" "49.54519" "207" "2015" " 4"  "11" "101"
## 2015-04-12 "1" "6.354936" "49.54519" "207" "2015" " 4"  "12" "102"
## 2015-04-13 "1" "6.354936" "49.54519" "207" "2015" " 4"  "13" "103"
## 2015-04-14 "1" "6.354936" "49.54519" "207" "2015" " 4"  "14" "104"
## 2015-04-15 "1" "6.354936" "49.54519" "207" "2015" " 4"  "15" "105"
## 2015-04-16 "1" "6.354936" "49.54519" "207" "2015" " 4"  "16" "106"
##          T.max          T.min          T.mean          Rainfall cdd_lut
## 2015-04-11 " 15.000000" " 8.900000" " 11.950000" " 0.20" "0"
## 2015-04-12 " 17.900000" " 6.700000" " 12.300000" " 0.10" "12.3"
## 2015-04-13 " 17.500000" " 6.800000" " 12.150000" " 0.00" "24.45"
```



```
## 2015-04-14 " 22.700000" " 3.5000000" " 13.1000000" " 0.00" "37.55"
## 2015-04-15 " 25.500000" " 5.3000000" " 15.4000000" " 0.00" "52.55"
## 2015-04-16 " 23.100000" " 6.7000000" " 14.9000000" " 0.00" "67.45"

# mean cumulative heat sum for bud break of 438.7 degree celsius for
# Riesling (Nelder, 2010)
cdd.phen.riesling.lut <- cdd.luThresh.phenology(cdd.lut = cdd.lut, chs.mean = 463.1)
head(cdd.phen.riesling.lut[[46]])
```

```
##          coords.x1  coords.x2 sp.ID time          endTime          timeIndex
## 2015-04-13 "93625.69" "67967.2" "1"   "2015-04-13" "2015-04-14" "16539"
## 2015-04-14 "93625.69" "67967.2" "1"   "2015-04-14" "2015-04-15" "16540"
## 2015-04-15 "93625.69" "67967.2" "1"   "2015-04-15" "2015-04-16" "16541"
## 2015-04-16 "93625.69" "67967.2" "1"   "2015-04-16" "2015-04-17" "16542"
## 2015-04-17 "93625.69" "67967.2" "1"   "2015-04-17" "2015-04-18" "16543"
## 2015-04-18 "93625.69" "67967.2" "1"   "2015-04-18" "2015-04-19" "16544"
##          id x          y          z   Year  Month Day  DayYear
## 2015-04-13 "1" "6.354936" "49.54519" "207" "2015" " 4"  "13" "103"
## 2015-04-14 "1" "6.354936" "49.54519" "207" "2015" " 4"  "14" "104"
## 2015-04-15 "1" "6.354936" "49.54519" "207" "2015" " 4"  "15" "105"
## 2015-04-16 "1" "6.354936" "49.54519" "207" "2015" " 4"  "16" "106"
## 2015-04-17 "1" "6.354936" "49.54519" "207" "2015" " 4"  "17" "107"
## 2015-04-18 "1" "6.354936" "49.54519" "207" "2015" " 4"  "18" "108"
##          T.max          T.min          T.mean          Rainfall cdd_lut
## 2015-04-13 " 17.500000" " 6.8000000" " 12.1500000" " 0.00" "0"
## 2015-04-14 " 22.700000" " 3.5000000" " 13.1000000" " 0.00" "13.1"
## 2015-04-15 " 25.500000" " 5.3000000" " 15.4000000" " 0.00" "28.1"
## 2015-04-16 " 23.100000" " 6.7000000" " 14.9000000" " 0.00" "43"
## 2015-04-17 " 15.800000" " 8.3000000" " 12.0500000" " 0.00" "55.05"
## 2015-04-18 " 15.300000" " 3.6000000" " 9.4500000" " 0.00" "64.5"
```

```
# growth stages
phen.mthurgau.lut <- phenology.stages(cdd.phen = cdd.phen.mthurgau.lut,
                                     ref.data = GrowthStage_CDD,
                                     stage = GrowthStage_CDD[-1,1])
phen.mthurgau.lut[[46]]
```

```
##      Growth_stage
## 1                9
## 2               11
## 3               12
## 4               13
## 5               14
## 6               15
## 7               16
## 8               17
## 9               18
## 10              19
## 11              53
## 12              55
## 13              57
## 14              61
## 15              63
## 16              65
## 17              68
## 18              69
```

## 19	71								
## 20	73								
## 21	75								
## 22	77								
## 23	79								
## 24	81								
## 25	83								
## 26	85								
## 27	89								
##								Description	CDD
## 1								Budburst: green shoot tips clearly visible	NA
## 2								First leaf unfolded and spread away from shoot	34.9
## 3								Two leaves unfolded	58.6
## 4								Three leaves unfolded	80.8
## 5								Four leaves unfolded	110.2
## 6								Five leaves unfolded	144.4
## 7								Six leaves unfolded	173.6
## 8								Seven leaves unfolded	213.5
## 9								Eight leaves unfolded	248.8
## 10								Nine leaves unfolded	285.2
## 11								Inflorescences clearly visible	178.1
## 12								Inflorescences swelling, flowers closely pressed together	253.2
## 13								Inflorescences fully developed; flowers separating	375.5
## 14								Beginning of flowering: 10% flowerhoods fallen	463.3
## 15								Early flowering: 30% flowerhoods fallen	494.5
## 16								Full flowering: 50% flowerhoods fallen	517.5
## 17								80% flowerhoods fallen	548.4
## 18								End of flowering	569.6
## 19								Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20								Berries groat-sized, bunches begin to hang	659
## 21								Berries pea-sized, bunches hang	774.9
## 22								Begin of berry touch	870
## 23								Berry touch complete	999.4
## 24								Beginning of ripening: berries begin to brighten in color	1160.2
## 25								Berries brightening in color	1219.4
## 26								Softening of berries	1287.8
## 27								Berries ripe for harvest	1719.8
##	coords.x1	coords.x2	sp.ID	time	endTime	timeIndex	id	x	
## 1	93625.69	67967.2	1	2015-04-11	2015-04-12	16537	1	6.354936	
## 2	93625.69	67967.2	1	2015-04-14	2015-04-15	16540	1	6.354936	
## 3	93625.69	67967.2	1	2015-04-16	2015-04-17	16542	1	6.354936	
## 4	93625.69	67967.2	1	2015-04-18	2015-04-19	16544	1	6.354936	
## 5	93625.69	67967.2	1	2015-04-20	2015-04-21	16546	1	6.354936	
## 6	93625.69	67967.2	1	2015-04-23	2015-04-24	16549	1	6.354936	
## 7	93625.69	67967.2	1	2015-04-25	2015-04-26	16551	1	6.354936	
## 8	93625.69	67967.2	1	2015-04-29	2015-04-30	16555	1	6.354936	
## 9	93625.69	67967.2	1	2015-05-03	2015-05-04	16559	1	6.354936	
## 10	93625.69	67967.2	1	2015-05-05	2015-05-06	16561	1	6.354936	
## 11	93625.69	67967.2	1	2015-04-26	2015-04-27	16552	1	6.354936	
## 12	93625.69	67967.2	1	2015-05-03	2015-05-04	16559	1	6.354936	
## 13	93625.69	67967.2	1	2015-05-12	2015-05-13	16568	1	6.354936	
## 14	93625.69	67967.2	1	2015-05-18	2015-05-19	16574	1	6.354936	
## 15	93625.69	67967.2	1	2015-05-21	2015-05-22	16577	1	6.354936	
## 16	93625.69	67967.2	1	2015-05-23	2015-05-24	16579	1	6.354936	

```

## 17 93625.69 67967.2 1 2015-05-25 2015-05-26 16581 1 6.354936
## 18 93625.69 67967.2 1 2015-05-26 2015-05-27 16582 1 6.354936
## 19 93625.69 67967.2 1 2015-05-29 2015-05-30 16585 1 6.354936
## 20 93625.69 67967.2 1 2015-06-02 2015-06-03 16589 1 6.354936
## 21 93625.69 67967.2 1 2015-06-10 2015-06-11 16597 1 6.354936
## 22 93625.69 67967.2 1 2015-06-16 2015-06-17 16603 1 6.354936
## 23 93625.69 67967.2 1 2015-06-25 2015-06-26 16612 1 6.354936
## 24 93625.69 67967.2 1 2015-07-06 2015-07-07 16623 1 6.354936
## 25 93625.69 67967.2 1 2015-07-10 2015-07-11 16627 1 6.354936
## 26 93625.69 67967.2 1 2015-07-15 2015-07-16 16632 1 6.354936
## 27 93625.69 67967.2 1 2015-08-13 2015-08-14 16661 1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2015      4 11      101 15.000000  8.900000 11.950000
## 2 49.54519 207 2015      4 14      104 22.700000  3.500000 13.100000
## 3 49.54519 207 2015      4 16      106 23.100000  6.700000 14.900000
## 4 49.54519 207 2015      4 18      108 15.300000  3.600000  9.450000
## 5 49.54519 207 2015      4 20      110 21.100000  4.100000 12.600000
## 6 49.54519 207 2015      4 23      113 20.400000  2.300000 11.350000
## 7 49.54519 207 2015      4 25      115 16.700000  9.700000 13.200000
## 8 49.54519 207 2015      4 29      119 15.200000  0.200000  7.700000
## 9 49.54519 207 2015      5  3      123 16.700000 11.200000 13.950000
## 10 49.54519 207 2015      5  5      125 22.100000 11.600000 16.850000
## 11 49.54519 207 2015      4 26      116 20.900000 11.200000 16.050000
## 12 49.54519 207 2015      5  3      123 16.700000 11.200000 13.950000
## 13 49.54519 207 2015      5 12      132 26.500000 11.700000 19.100000
## 14 49.54519 207 2015      5 18      138 21.400000  5.000000 13.200000
## 15 49.54519 207 2015      5 21      141 19.000000  2.400000 10.700000
## 16 49.54519 207 2015      5 23      143 20.700000  9.600000 15.150000
## 17 49.54519 207 2015      5 25      145 19.200000  8.300000 13.750000
## 18 49.54519 207 2015      5 26      146 15.700000  7.400000 11.550000
## 19 49.54519 207 2015      5 29      149 16.800000  7.700000 12.250000
## 20 49.54519 207 2015      6  2      153 24.700000  9.800000 17.250000
## 21 49.54519 207 2015      6 10      161 22.700000 10.000000 16.350000
## 22 49.54519 207 2015      6 16      167 21.700000 10.800000 16.250000
## 23 49.54519 207 2015      6 25      176 25.700000 10.000000 17.850000
## 24 49.54519 207 2015      7  6      187 30.200000 13.200000 21.700000
## 25 49.54519 207 2015      7 10      191 28.900000  8.100000 18.500000
## 26 49.54519 207 2015      7 15      196 29.700000 14.500000 22.100000
## 27 49.54519 207 2015      8 13      225 36.000000 19.600000 27.800000
##      Rainfall cdd_lut
## 1      0.20      0
## 2      0.00     37.55
## 3      0.00     67.45
## 4      0.00     88.95
## 5      0.00    111.55
## 6      0.00    150.5
## 7      3.50    176.85
## 8      0.00    217.75
## 9      9.70    260.2
## 10     0.70    290.2
## 11    11.20    191.85
## 12     9.70    260.2
## 13     0.00    389.35
## 14     0.00    469.05

```

```
## 15      0.00 501.25
## 16      0.00   531
## 17      5.10 559.75
## 18      0.00  571.3
## 19      1.80 609.9
## 20      0.00 664.05
## 21      0.00 784.05
## 22      0.00 874.05
## 23      0.00 1001.8
## 24      0.00 1166.8
## 25      0.00 1226.8
## 26      0.00 1301.8
## 27      5.00 1734.75
```

```
phen.riesling.lut <- phenology.stages(cdd.phen = cdd.phen.mthurgau.lut,
                                     ref.data = GrowthStage_CDD,
                                     stage = GrowthStage_CDD[-1,1])
phen.riesling.lut[[46]]
```

```
##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
## 14            61
## 15            63
## 16            65
## 17            68
## 18            69
## 19            71
## 20            73
## 21            75
## 22            77
## 23            79
## 24            81
## 25            83
## 26            85
## 27            89
```

	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2
## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6

```

## 8          Seven leaves unfolded 213.5
## 9          Eight leaves unfolded 248.8
## 10         Nine leaves unfolded 285.2
## 11         Inflorescences clearly visible 178.1
## 12         Inflorescences swelling, flowers closely pressed together 253.2
## 13         Inflorescences fully developed; flowers separating 375.5
## 14         Beginning of flowering: 10% flowerhoods fallen 463.3
## 15         Early flowering: 30% flowerhoods fallen 494.5
## 16         Full flowering: 50% flowerhoods fallen 517.5
## 17         80% flowerhoods fallen 548.4
## 18         End of flowering 569.6
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20         Berries groat-sized, bunches begin to hang 659
## 21         Berries pea-sized, bunches hang 774.9
## 22         Begin of berry touch 870
## 23         Berry touch complete 999.4
## 24         Beginning of ripening: berries begin to brighten in color 1160.2
## 25         Berries brightening in color 1219.4
## 26         Softening of berries 1287.8
## 27         Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69  67967.2    1 2015-04-11 2015-04-12    16537  1 6.354936
## 2  93625.69  67967.2    1 2015-04-14 2015-04-15    16540  1 6.354936
## 3  93625.69  67967.2    1 2015-04-16 2015-04-17    16542  1 6.354936
## 4  93625.69  67967.2    1 2015-04-18 2015-04-19    16544  1 6.354936
## 5  93625.69  67967.2    1 2015-04-20 2015-04-21    16546  1 6.354936
## 6  93625.69  67967.2    1 2015-04-23 2015-04-24    16549  1 6.354936
## 7  93625.69  67967.2    1 2015-04-25 2015-04-26    16551  1 6.354936
## 8  93625.69  67967.2    1 2015-04-29 2015-04-30    16555  1 6.354936
## 9  93625.69  67967.2    1 2015-05-03 2015-05-04    16559  1 6.354936
## 10 93625.69  67967.2    1 2015-05-05 2015-05-06    16561  1 6.354936
## 11 93625.69  67967.2    1 2015-04-26 2015-04-27    16552  1 6.354936
## 12 93625.69  67967.2    1 2015-05-03 2015-05-04    16559  1 6.354936
## 13 93625.69  67967.2    1 2015-05-12 2015-05-13    16568  1 6.354936
## 14 93625.69  67967.2    1 2015-05-18 2015-05-19    16574  1 6.354936
## 15 93625.69  67967.2    1 2015-05-21 2015-05-22    16577  1 6.354936
## 16 93625.69  67967.2    1 2015-05-23 2015-05-24    16579  1 6.354936
## 17 93625.69  67967.2    1 2015-05-25 2015-05-26    16581  1 6.354936
## 18 93625.69  67967.2    1 2015-05-26 2015-05-27    16582  1 6.354936
## 19 93625.69  67967.2    1 2015-05-29 2015-05-30    16585  1 6.354936
## 20 93625.69  67967.2    1 2015-06-02 2015-06-03    16589  1 6.354936
## 21 93625.69  67967.2    1 2015-06-10 2015-06-11    16597  1 6.354936
## 22 93625.69  67967.2    1 2015-06-16 2015-06-17    16603  1 6.354936
## 23 93625.69  67967.2    1 2015-06-25 2015-06-26    16612  1 6.354936
## 24 93625.69  67967.2    1 2015-07-06 2015-07-07    16623  1 6.354936
## 25 93625.69  67967.2    1 2015-07-10 2015-07-11    16627  1 6.354936
## 26 93625.69  67967.2    1 2015-07-15 2015-07-16    16632  1 6.354936
## 27 93625.69  67967.2    1 2015-08-13 2015-08-14    16661  1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2015      4 11      101 15.000000  8.900000 11.950000
## 2 49.54519 207 2015      4 14      104 22.700000  3.500000 13.100000
## 3 49.54519 207 2015      4 16      106 23.100000  6.700000 14.900000
## 4 49.54519 207 2015      4 18      108 15.300000  3.600000  9.450000
## 5 49.54519 207 2015      4 20      110 21.100000  4.100000 12.600000

```

## 6	49.54519	207	2015	4	23	113	20.400000	2.3000000	11.3500000
## 7	49.54519	207	2015	4	25	115	16.700000	9.7000000	13.2000000
## 8	49.54519	207	2015	4	29	119	15.200000	0.2000000	7.7000000
## 9	49.54519	207	2015	5	3	123	16.700000	11.2000000	13.9500000
## 10	49.54519	207	2015	5	5	125	22.100000	11.6000000	16.8500000
## 11	49.54519	207	2015	4	26	116	20.900000	11.2000000	16.0500000
## 12	49.54519	207	2015	5	3	123	16.700000	11.2000000	13.9500000
## 13	49.54519	207	2015	5	12	132	26.500000	11.7000000	19.1000000
## 14	49.54519	207	2015	5	18	138	21.400000	5.0000000	13.2000000
## 15	49.54519	207	2015	5	21	141	19.000000	2.4000000	10.7000000
## 16	49.54519	207	2015	5	23	143	20.700000	9.6000000	15.1500000
## 17	49.54519	207	2015	5	25	145	19.200000	8.3000000	13.7500000
## 18	49.54519	207	2015	5	26	146	15.700000	7.4000000	11.5500000
## 19	49.54519	207	2015	5	29	149	16.800000	7.7000000	12.2500000
## 20	49.54519	207	2015	6	2	153	24.700000	9.8000000	17.2500000
## 21	49.54519	207	2015	6	10	161	22.700000	10.0000000	16.3500000
## 22	49.54519	207	2015	6	16	167	21.700000	10.8000000	16.2500000
## 23	49.54519	207	2015	6	25	176	25.700000	10.0000000	17.8500000
## 24	49.54519	207	2015	7	6	187	30.200000	13.2000000	21.7000000
## 25	49.54519	207	2015	7	10	191	28.900000	8.1000000	18.5000000
## 26	49.54519	207	2015	7	15	196	29.700000	14.5000000	22.1000000
## 27	49.54519	207	2015	8	13	225	36.000000	19.6000000	27.8000000
##	Rainfall cdd_lut								
## 1	0.20	0							
## 2	0.00	37.55							
## 3	0.00	67.45							
## 4	0.00	88.95							
## 5	0.00	111.55							
## 6	0.00	150.5							
## 7	3.50	176.85							
## 8	0.00	217.75							
## 9	9.70	260.2							
## 10	0.70	290.2							
## 11	11.20	191.85							
## 12	9.70	260.2							
## 13	0.00	389.35							
## 14	0.00	469.05							
## 15	0.00	501.25							
## 16	0.00	531							
## 17	5.10	559.75							
## 18	0.00	571.3							
## 19	1.80	609.9							
## 20	0.00	664.05							
## 21	0.00	784.05							
## 22	0.00	874.05							
## 23	0.00	1001.8							
## 24	0.00	1166.8							
## 25	0.00	1226.8							
## 26	0.00	1301.8							
## 27	5.00	1734.75							

Calculation of degree-days by a lower, upper and heat temperature thresholds (Molitor et al., 2014)

```
cdd.luht <- cdd.luhThresh(data = remich.years, t.mean.col = 17, a = 5, b = 20, c = 22)
```

```
head(cdd.luht[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-01-01 "93625.69" "67967.2" "1"  "2015-01-01" "2015-01-02" "16437"
## 2015-01-02 "93625.69" "67967.2" "1"  "2015-01-02" "2015-01-03" "16438"
## 2015-01-03 "93625.69" "67967.2" "1"  "2015-01-03" "2015-01-04" "16439"
## 2015-01-04 "93625.69" "67967.2" "1"  "2015-01-04" "2015-01-05" "16440"
## 2015-01-05 "93625.69" "67967.2" "1"  "2015-01-05" "2015-01-06" "16441"
## 2015-01-06 "93625.69" "67967.2" "1"  "2015-01-06" "2015-01-07" "16442"
##          id x          y          z      Year  Month Day  DayYear
## 2015-01-01 "1" "6.354936" "49.54519" "207" "2015" "1"  "1"  "1"
## 2015-01-02 "1" "6.354936" "49.54519" "207" "2015" "1"  "2"  "2"
## 2015-01-03 "1" "6.354936" "49.54519" "207" "2015" "1"  "3"  "3"
## 2015-01-04 "1" "6.354936" "49.54519" "207" "2015" "1"  "4"  "4"
## 2015-01-05 "1" "6.354936" "49.54519" "207" "2015" "1"  "5"  "5"
## 2015-01-06 "1" "6.354936" "49.54519" "207" "2015" "1"  "6"  "6"
##          T.max          T.min          T.mean          Rainfall cdd_luht
## 2015-01-01 " 1.400000" " -1.000000" " 0.200000" " 0.00" "0"
## 2015-01-02 " 4.200000" " -1.600000" " 1.300000" " 1.80" "0"
## 2015-01-03 "10.700000" " 1.300000" " 6.000000" " 6.50" "1"
## 2015-01-04 " 5.800000" " -0.900000" " 2.450000" " 0.00" "1"
## 2015-01-05 " 2.100000" " -3.200000" " -0.550000" " 0.00" "1"
## 2015-01-06 " -0.100000" " -4.200000" " -2.150000" " 0.00" "1"
```

```
tail(cdd.luht[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-12-26 "93625.69" "67967.2" "1"  "2015-12-26" "2015-12-27" "16796"
## 2015-12-27 "93625.69" "67967.2" "1"  "2015-12-27" "2015-12-28" "16797"
## 2015-12-28 "93625.69" "67967.2" "1"  "2015-12-28" "2015-12-29" "16798"
## 2015-12-29 "93625.69" "67967.2" "1"  "2015-12-29" "2015-12-30" "16799"
## 2015-12-30 "93625.69" "67967.2" "1"  "2015-12-30" "2015-12-31" "16800"
## 2015-12-31 "93625.69" "67967.2" "1"  "2015-12-31" "2016-01-01" "16801"
##          id x          y          z      Year  Month Day  DayYear
## 2015-12-26 "1" "6.354936" "49.54519" "207" "2015" "12" "26" "360"
## 2015-12-27 "1" "6.354936" "49.54519" "207" "2015" "12" "27" "361"
## 2015-12-28 "1" "6.354936" "49.54519" "207" "2015" "12" "28" "362"
## 2015-12-29 "1" "6.354936" "49.54519" "207" "2015" "12" "29" "363"
## 2015-12-30 "1" "6.354936" "49.54519" "207" "2015" "12" "30" "364"
## 2015-12-31 "1" "6.354936" "49.54519" "207" "2015" "12" "31" "365"
##          T.max          T.min          T.mean          Rainfall cdd_luht
## 2015-12-26 "12.000000" " 6.100000" " 9.050000" " 0.00" "2398.3"
## 2015-12-27 "12.100000" " 3.300000" " 7.700000" " 0.00" "2401"
## 2015-12-28 "10.800000" " 0.500000" " 5.650000" " 0.00" "2401.65"
## 2015-12-29 " 8.200000" " -1.100000" " 3.550000" " 0.00" "2401.65"
## 2015-12-30 " 9.000000" " 1.300000" " 5.150000" " 0.00" "2401.8"
## 2015-12-31 "11.300000" " 0.100000" " 5.700000" " 1.80" "2402.5"
```

Calculation of phenology by the lower, upper and heat temperature thresholds (Molitor et al., 2014)

```
# mean cumulative heat sum for bud break of 438.7 degree celsius for
# Mueller-Thurgau (Nelder, 2010)
cdd.phen.mthurgau.luht <- cdd.luhThresh.phenology(cdd.bb = cdd.bb,
                                                  cdd.luht = cdd.luht, chs.mean = 438.7)
head(cdd.phen.mthurgau.luht[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-04-24 "93625.69" "67967.2" "1"   "2015-04-24" "2015-04-25" "16550"
## 2015-04-25 "93625.69" "67967.2" "1"   "2015-04-25" "2015-04-26" "16551"
## 2015-04-26 "93625.69" "67967.2" "1"   "2015-04-26" "2015-04-27" "16552"
## 2015-04-27 "93625.69" "67967.2" "1"   "2015-04-27" "2015-04-28" "16553"
## 2015-04-28 "93625.69" "67967.2" "1"   "2015-04-28" "2015-04-29" "16554"
## 2015-04-29 "93625.69" "67967.2" "1"   "2015-04-29" "2015-04-30" "16555"
##          id x          y          z      Year Month Day DayYear
## 2015-04-24 "1" "6.354936" "49.54519" "207" "2015" "4" "24" "114"
## 2015-04-25 "1" "6.354936" "49.54519" "207" "2015" "4" "25" "115"
## 2015-04-26 "1" "6.354936" "49.54519" "207" "2015" "4" "26" "116"
## 2015-04-27 "1" "6.354936" "49.54519" "207" "2015" "4" "27" "117"
## 2015-04-28 "1" "6.354936" "49.54519" "207" "2015" "4" "28" "118"
## 2015-04-29 "1" "6.354936" "49.54519" "207" "2015" "4" "29" "119"
##          T.max      T.min      T.mean      Rainfall
## 2015-04-24 " 22.300000" " 4.000000" " 13.150000" " 0.00"
## 2015-04-25 " 16.700000" " 9.700000" " 13.200000" " 3.50"
## 2015-04-26 " 20.900000" "11.200000" " 16.050000" "11.20"
## 2015-04-27 " 11.900000" " 7.300000" " 9.600000" "11.90"
## 2015-04-28 " 14.000000" " 3.200000" " 8.600000" " 0.00"
## 2015-04-29 " 15.200000" " 0.200000" " 7.700000" " 0.00"
##          cdd_luht
## 2015-04-24 "0"
## 2015-04-25 "8.199999999999999"
## 2015-04-26 "19.25"
## 2015-04-27 "23.85"
## 2015-04-28 "27.45"
## 2015-04-29 "30.15"
```

```
tail(cdd.phen.mthurgau.luht[[46]])
```

```
##          coords.x1 coords.x2 sp.ID time          endTime          timeIndex
## 2015-12-26 "93625.69" "67967.2" "1"   "2015-12-26" "2015-12-27" "16796"
## 2015-12-27 "93625.69" "67967.2" "1"   "2015-12-27" "2015-12-28" "16797"
## 2015-12-28 "93625.69" "67967.2" "1"   "2015-12-28" "2015-12-29" "16798"
## 2015-12-29 "93625.69" "67967.2" "1"   "2015-12-29" "2015-12-30" "16799"
## 2015-12-30 "93625.69" "67967.2" "1"   "2015-12-30" "2015-12-31" "16800"
## 2015-12-31 "93625.69" "67967.2" "1"   "2015-12-31" "2016-01-01" "16801"
##          id x          y          z      Year Month Day DayYear
## 2015-12-26 "1" "6.354936" "49.54519" "207" "2015" "12" "26" "360"
## 2015-12-27 "1" "6.354936" "49.54519" "207" "2015" "12" "27" "361"
## 2015-12-28 "1" "6.354936" "49.54519" "207" "2015" "12" "28" "362"
## 2015-12-29 "1" "6.354936" "49.54519" "207" "2015" "12" "29" "363"
## 2015-12-30 "1" "6.354936" "49.54519" "207" "2015" "12" "30" "364"
## 2015-12-31 "1" "6.354936" "49.54519" "207" "2015" "12" "31" "365"
```



```
##           T.max      T.min      T.mean      Rainfall cdd_luht
## 2015-12-26 " 12.000000" "  6.100000" "  9.050000" "  0.00" "2189"
## 2015-12-27 " 12.100000" "  3.300000" "  7.700000" "  0.00" "2191.7"
## 2015-12-28 " 10.800000" "  0.500000" "  5.650000" "  0.00" "2192.35"
## 2015-12-29 "  8.200000" " -1.100000" "  3.550000" "  0.00" "2192.35"
## 2015-12-30 "  9.000000" "  1.300000" "  5.150000" "  0.00" "2192.5"
## 2015-12-31 " 11.300000" "  0.100000" "  5.700000" "  1.80" "2193.2"

# mean cumulative heat sum for bud break of 463.1 degree celsius for
# Riesling (Nelder, 2010)
cdd.phen.riesling.luht <- cdd.luhThresh.phenology(cdd.bb = cdd.bb,
                                                  cdd.luht = cdd.luht, chs.mean = 463.1)
head(cdd.phen.riesling.luht[[46]])
```

```
##           coords.x1  coords.x2 sp.ID time      endTime      timeIndex
## 2015-04-26 "93625.69" "67967.2" "1"   "2015-04-26" "2015-04-27" "16552"
## 2015-04-27 "93625.69" "67967.2" "1"   "2015-04-27" "2015-04-28" "16553"
## 2015-04-28 "93625.69" "67967.2" "1"   "2015-04-28" "2015-04-29" "16554"
## 2015-04-29 "93625.69" "67967.2" "1"   "2015-04-29" "2015-04-30" "16555"
## 2015-04-30 "93625.69" "67967.2" "1"   "2015-04-30" "2015-05-01" "16556"
## 2015-05-01 "93625.69" "67967.2" "1"   "2015-05-01" "2015-05-02" "16557"
##           id x          y          z   Year  Month Day  DayYear
## 2015-04-26 "1" "6.354936" "49.54519" "207" "2015" " 4" "26" "116"
## 2015-04-27 "1" "6.354936" "49.54519" "207" "2015" " 4" "27" "117"
## 2015-04-28 "1" "6.354936" "49.54519" "207" "2015" " 4" "28" "118"
## 2015-04-29 "1" "6.354936" "49.54519" "207" "2015" " 4" "29" "119"
## 2015-04-30 "1" "6.354936" "49.54519" "207" "2015" " 4" "30" "120"
## 2015-05-01 "1" "6.354936" "49.54519" "207" "2015" " 5" " 1" "121"
##           T.max      T.min      T.mean      Rainfall
## 2015-04-26 " 20.900000" " 11.200000" " 16.050000" " 11.20"
## 2015-04-27 " 11.900000" "  7.300000" "  9.600000" " 11.90"
## 2015-04-28 " 14.000000" "  3.200000" "  8.600000" "  0.00"
## 2015-04-29 " 15.200000" "  0.200000" "  7.700000" "  0.00"
## 2015-04-30 " 12.100000" "  6.500000" "  9.300000" "  3.20"
## 2015-05-01 " 11.600000" "  7.100000" "  9.350000" "  1.80"
##           cdd_luht
## 2015-04-26 "0"
## 2015-04-27 "4.599999999999999"
## 2015-04-28 "8.199999999999999"
## 2015-04-29 "10.9"
## 2015-04-30 "15.2"
## 2015-05-01 "19.55"

tail(cdd.phen.riesling.luht[[46]])
```

```
##           coords.x1  coords.x2 sp.ID time      endTime      timeIndex
## 2015-12-26 "93625.69" "67967.2" "1"   "2015-12-26" "2015-12-27" "16796"
## 2015-12-27 "93625.69" "67967.2" "1"   "2015-12-27" "2015-12-28" "16797"
## 2015-12-28 "93625.69" "67967.2" "1"   "2015-12-28" "2015-12-29" "16798"
## 2015-12-29 "93625.69" "67967.2" "1"   "2015-12-29" "2015-12-30" "16799"
## 2015-12-30 "93625.69" "67967.2" "1"   "2015-12-30" "2015-12-31" "16800"
## 2015-12-31 "93625.69" "67967.2" "1"   "2015-12-31" "2016-01-01" "16801"
##           id x          y          z   Year  Month Day  DayYear
## 2015-12-26 "1" "6.354936" "49.54519" "207" "2015" "12" "26" "360"
## 2015-12-27 "1" "6.354936" "49.54519" "207" "2015" "12" "27" "361"
```

```
## 2015-12-28 "1" "6.354936" "49.54519" "207" "2015" "12" "28" "362"
## 2015-12-29 "1" "6.354936" "49.54519" "207" "2015" "12" "29" "363"
## 2015-12-30 "1" "6.354936" "49.54519" "207" "2015" "12" "30" "364"
## 2015-12-31 "1" "6.354936" "49.54519" "207" "2015" "12" "31" "365"
##          T.max      T.min      T.mean      Rainfall cdd_luht
## 2015-12-26 " 12.000000" "  6.100000" "  9.050000" "  0.00" "2169.75"
## 2015-12-27 " 12.100000" "  3.300000" "  7.700000" "  0.00" "2172.45"
## 2015-12-28 " 10.800000" "  0.500000" "  5.650000" "  0.00" "2173.1"
## 2015-12-29 "  8.200000" " -1.100000" "  3.550000" "  0.00" "2173.1"
## 2015-12-30 "  9.000000" "  1.300000" "  5.150000" "  0.00" "2173.25"
## 2015-12-31 " 11.300000" "  0.100000" "  5.700000" "  1.80" "2173.95"
```

```
# # growth stages (uncomment to check) Failing: 3, 5, 9, 11, 15
# for(i in 1:length(cdd.bb)){
#   tryCatch(phen.mthurgau.luht <- phenology.stages(cdd.phen = list(cdd.phen.mthurgau.luht[[i]]), ref.d
#   stage = GrowthStage_CDD[-1,1]),
#   warning = function(w) {
#     print(i)
#   })
#   phen.mthurgau.luht[[1]][23, "DayYear"]
# }

phen.mthurgau.luht <- phenology.stages(cdd.phen = cdd.phen.mthurgau.luht,
  ref.data = GrowthStage_CDD,
  stage = GrowthStage_CDD[-1,1])
```

```
## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages
```

```
## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages
```

```
## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages
```

```
## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages
```

```
## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages
```

```
phen.mthurgau.luht[[42]] # 2011
```

```
##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
```

## 14	61	
## 15	63	
## 16	65	
## 17	68	
## 18	69	
## 19	71	
## 20	73	
## 21	75	
## 22	77	
## 23	79	
## 24	81	
## 25	83	
## 26	85	
## 27	89	
##		Description CDD
## 1		Budburst: green shoot tips clearly visible NA
## 2		First leaf unfolded and spread away from shoot 34.9
## 3		Two leaves unfolded 58.6
## 4		Three leaves unfolded 80.8
## 5		Four leaves unfolded 110.2
## 6		Five leaves unfolded 144.4
## 7		Six leaves unfolded 173.6
## 8		Seven leaves unfolded 213.5
## 9		Eight leaves unfolded 248.8
## 10		Nine leaves unfolded 285.2
## 11		Inflorescences clearly visible 178.1
## 12		Inflorescences swelling, flowers closely pressed together 253.2
## 13		Inflorescences fully developed; flowers separating 375.5
## 14		Beginning of flowering: 10% flowerhoods fallen 463.3
## 15		Early flowering: 30% flowerhoods fallen 494.5
## 16		Full flowering: 50% flowerhoods fallen 517.5
## 17		80% flowerhoods fallen 548.4
## 18		End of flowering 569.6
## 19		Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20		Berries groat-sized, bunches begin to hang 659
## 21		Berries pea-sized, bunches hang 774.9
## 22		Begin of berry touch 870
## 23		Berry touch complete 999.4
## 24		Beginning of ripening: berries begin to brighten in color 1160.2
## 25		Berries brightening in color 1219.4
## 26		Softening of berries 1287.8
## 27		Berries ripe for harvest 1719.8
##	coords.x1	coords.x2 sp.ID time endTime timeIndex id x
## 1	93625.69	67967.2 1 2011-04-18 2011-04-19 15083 1 6.354936
## 2	93625.69	67967.2 1 2011-04-22 2011-04-23 15087 1 6.354936
## 3	93625.69	67967.2 1 2011-04-24 2011-04-25 15089 1 6.354936
## 4	93625.69	67967.2 1 2011-04-26 2011-04-27 15091 1 6.354936
## 5	93625.69	67967.2 1 2011-04-29 2011-04-30 15094 1 6.354936
## 6	93625.69	67967.2 1 2011-05-03 2011-05-04 15098 1 6.354936
## 7	93625.69	67967.2 1 2011-05-07 2011-05-08 15102 1 6.354936
## 8	93625.69	67967.2 1 2011-05-09 2011-05-10 15104 1 6.354936
## 9	93625.69	67967.2 1 2011-05-12 2011-05-13 15107 1 6.354936
## 10	93625.69	67967.2 1 2011-05-17 2011-05-18 15112 1 6.354936
## 11	93625.69	67967.2 1 2011-05-07 2011-05-08 15102 1 6.354936

## 12	93625.69	67967.2	1	2011-05-13	2011-05-14	15108	1	6.354936	
## 13	93625.69	67967.2	1	2011-05-25	2011-05-26	15120	1	6.354936	
## 14	93625.69	67967.2	1	2011-06-02	2011-06-03	15128	1	6.354936	
## 15	93625.69	67967.2	1	2011-06-04	2011-06-05	15130	1	6.354936	
## 16	93625.69	67967.2	1	2011-06-06	2011-06-07	15132	1	6.354936	
## 17	93625.69	67967.2	1	2011-06-08	2011-06-09	15134	1	6.354936	
## 18	93625.69	67967.2	1	2011-06-11	2011-06-12	15137	1	6.354936	
## 19	93625.69	67967.2	1	2011-06-14	2011-06-15	15140	1	6.354936	
## 20	93625.69	67967.2	1	2011-06-19	2011-06-20	15145	1	6.354936	
## 21	93625.69	67967.2	1	2011-06-29	2011-06-30	15155	1	6.354936	
## 22	93625.69	67967.2	1	2011-07-07	2011-07-08	15163	1	6.354936	
## 23	93625.69	67967.2	1	2011-07-17	2011-07-18	15173	1	6.354936	
## 24	93625.69	67967.2	1	2011-07-31	2011-08-01	15187	1	6.354936	
## 25	93625.69	67967.2	1	2011-08-04	2011-08-05	15191	1	6.354936	
## 26	93625.69	67967.2	1	2011-08-10	2011-08-11	15197	1	6.354936	
## 27	93625.69	67967.2	1	2011-09-13	2011-09-14	15231	1	6.354936	
##	y	z	Year	Month	Day	DayYear	T.max	T.min	T.mean
## 1	49.54519	207	2011	4	18	108	21.200000	5.400000	13.300000
## 2	49.54519	207	2011	4	22	112	26.800000	9.300000	18.050000
## 3	49.54519	207	2011	4	24	114	25.500000	7.800000	16.650000
## 4	49.54519	207	2011	4	26	116	21.400000	7.100000	14.250000
## 5	49.54519	207	2011	4	29	119	21.500000	7.700000	14.600000
## 6	49.54519	207	2011	5	3	123	15.100000	5.800000	10.450000
## 7	49.54519	207	2011	5	7	127	26.600000	11.100000	18.850000
## 8	49.54519	207	2011	5	9	129	27.800000	16.700000	22.250000
## 9	49.54519	207	2011	5	12	132	21.000000	9.200000	15.100000
## 10	49.54519	207	2011	5	17	137	21.400000	11.300000	16.350000
## 11	49.54519	207	2011	5	7	127	26.600000	11.100000	18.850000
## 12	49.54519	207	2011	5	13	133	21.400000	3.800000	12.600000
## 13	49.54519	207	2011	5	25	145	23.700000	4.600000	14.150000
## 14	49.54519	207	2011	6	2	153	24.500000	13.200000	18.850000
## 15	49.54519	207	2011	6	4	155	29.500000	16.700000	23.100000
## 16	49.54519	207	2011	6	6	157	23.000000	13.200000	18.100000
## 17	49.54519	207	2011	6	8	159	18.100000	10.500000	14.300000
## 18	49.54519	207	2011	6	11	162	18.900000	7.400000	13.150000
## 19	49.54519	207	2011	6	14	165	24.000000	14.000000	19.000000
## 20	49.54519	207	2011	6	19	170	17.100000	9.300000	13.200000
## 21	49.54519	207	2011	6	29	180	26.800000	16.200000	21.500000
## 22	49.54519	207	2011	7	7	188	22.900000	12.900000	18.300000
## 23	49.54519	207	2011	7	17	198	19.000000	14.300000	16.700000
## 24	49.54519	207	2011	7	31	212	16.200000	12.200000	14.800000
## 25	49.54519	207	2011	8	4	216	27.300000	16.400000	21.850000
## 26	49.54519	207	2011	8	10	222	20.400000	5.100000	12.750000
## 27	49.54519	207	2011	9	13	256	20.100000	14.100000	17.100000
##	Rainfall	cdd_luht							
## 1	0.00	0							
## 2	0.00	42.65							
## 3	1.10	68.5							
## 4	0.00	89							
## 5	0.30	114.5							
## 6	0.00	149.75							
## 7	0.00	183.8							
## 8	0.00	213.8							
## 9	0.00	250.7							

```
## 10      0.10      288.1
## 11      0.00      183.8
## 12      0.00      258.3
## 13      0.00     376.75
## 14      0.00      466
## 15      0.00      496
## 16      0.00     524.1
## 17     14.60     548.4
## 18      3.00      575
## 19      0.50     608.05
## 20      2.70    662.415
## 21      1.00    786.615
## 22      0.10    879.915
## 23     32.40  1007.015
## 24      0.00  1161.815
## 25      0.10  1220.465
## 26      2.00  1290.115
## 27      0.00  1726.765
```

```
phen.mthurgau.luht[[43]] # 2012
```

```
##      Growth_stage
## 1           9
## 2          11
## 3          12
## 4          13
## 5          14
## 6          15
## 7          16
## 8          17
## 9          18
## 10         19
## 11         53
## 12         55
## 13         57
## 14         61
## 15         63
## 16         65
## 17         68
## 18         69
## 19         71
## 20         73
## 21         75
## 22         77
## 23         79
## 24         81
## 25         83
## 26         85
## 27         89
```

	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2

## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6
## 8	Seven leaves unfolded	213.5
## 9	Eight leaves unfolded	248.8
## 10	Nine leaves unfolded	285.2
## 11	Inflorescences clearly visible	178.1
## 12	Inflorescences swelling, flowers closely pressed together	253.2
## 13	Inflorescences fully developed; flowers separating	375.5
## 14	Beginning of flowering: 10% flowerhoods fallen	463.3
## 15	Early flowering: 30% flowerhoods fallen	494.5
## 16	Full flowering: 50% flowerhoods fallen	517.5
## 17	80% flowerhoods fallen	548.4
## 18	End of flowering	569.6
## 19	Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20	Berries groat-sized, bunches begin to hang	659
## 21	Berries pea-sized, bunches hang	774.9
## 22	Begin of berry touch	870
## 23	Berry touch complete	999.4
## 24	Beginning of ripening: berries begin to brighten in color	1160.2
## 25	Berries brightening in color	1219.4
## 26	Softening of berries	1287.8
## 27	Berries ripe for harvest	1719.8
##	coords.x1 coords.x2 sp.ID time endTime timeIndex id x	
## 1	93625.69 67967.2 1 2012-04-25 2012-04-26 15456 1 6.354936	
## 2	93625.69 67967.2 1 2012-04-29 2012-04-30 15460 1 6.354936	
## 3	93625.69 67967.2 1 2012-05-02 2012-05-03 15463 1 6.354936	
## 4	93625.69 67967.2 1 2012-05-05 2012-05-06 15466 1 6.354936	
## 5	93625.69 67967.2 1 2012-05-09 2012-05-10 15470 1 6.354936	
## 6	93625.69 67967.2 1 2012-05-11 2012-05-12 15472 1 6.354936	
## 7	93625.69 67967.2 1 2012-05-18 2012-05-19 15479 1 6.354936	
## 8	93625.69 67967.2 1 2012-05-21 2012-05-22 15482 1 6.354936	
## 9	93625.69 67967.2 1 2012-05-24 2012-05-25 15485 1 6.354936	
## 10	93625.69 67967.2 1 2012-05-26 2012-05-27 15487 1 6.354936	
## 11	93625.69 67967.2 1 2012-05-19 2012-05-20 15480 1 6.354936	
## 12	93625.69 67967.2 1 2012-05-24 2012-05-25 15485 1 6.354936	
## 13	93625.69 67967.2 1 2012-06-03 2012-06-04 15495 1 6.354936	
## 14	93625.69 67967.2 1 2012-06-12 2012-06-13 15504 1 6.354936	
## 15	93625.69 67967.2 1 2012-06-15 2012-06-16 15507 1 6.354936	
## 16	93625.69 67967.2 1 2012-06-17 2012-06-18 15509 1 6.354936	
## 17	93625.69 67967.2 1 2012-06-20 2012-06-21 15512 1 6.354936	
## 18	93625.69 67967.2 1 2012-06-21 2012-06-22 15513 1 6.354936	
## 19	93625.69 67967.2 1 2012-06-25 2012-06-26 15517 1 6.354936	
## 20	93625.69 67967.2 1 2012-06-29 2012-06-30 15521 1 6.354936	
## 21	93625.69 67967.2 1 2012-07-08 2012-07-09 15530 1 6.354936	
## 22	93625.69 67967.2 1 2012-07-17 2012-07-18 15539 1 6.354936	
## 23	93625.69 67967.2 1 2012-07-27 2012-07-28 15549 1 6.354936	
## 24	93625.69 67967.2 1 2012-08-09 2012-08-10 15562 1 6.354936	
## 25	93625.69 67967.2 1 2012-08-13 2012-08-14 15566 1 6.354936	
## 26	93625.69 67967.2 1 2012-08-18 2012-08-19 15571 1 6.354936	
## 27	93625.69 67967.2 1 2012-09-27 2012-09-28 15611 1 6.354936	
##	y z Year Month Day DayYear T.max T.min T.mean	
## 1	49.54519 207 2012 4 25 116 11.800000 4.600000 8.200000	
## 2	49.54519 207 2012 4 29 120 21.100000 12.700000 16.900000	
## 3	49.54519 207 2012 5 2 123 18.200000 10.800000 14.500000	

## 4	49.54519	207	2012	5	5	126	17.200000	8.1000000	12.6500000
## 5	49.54519	207	2012	5	9	130	20.900000	12.3000000	16.6000000
## 6	49.54519	207	2012	5	11	132	26.000000	11.5000000	18.7500000
## 7	49.54519	207	2012	5	18	139	16.000000	9.7000000	12.8500000
## 8	49.54519	207	2012	5	21	142	21.800000	13.1000000	17.4500000
## 9	49.54519	207	2012	5	24	145	29.000000	13.8000000	21.4000000
## 10	49.54519	207	2012	5	26	147	25.000000	12.3000000	18.6500000
## 11	49.54519	207	2012	5	19	140	23.600000	9.8000000	16.7000000
## 12	49.54519	207	2012	5	24	145	29.000000	13.8000000	21.4000000
## 13	49.54519	207	2012	6	3	155	18.500000	11.8000000	15.1500000
## 14	49.54519	207	2012	6	12	164	18.100000	9.4000000	13.7500000
## 15	49.54519	207	2012	6	15	167	22.500000	11.9000000	17.2000000
## 16	49.54519	207	2012	6	17	169	22.500000	11.9000000	17.2000000
## 17	49.54519	207	2012	6	20	172	21.600000	14.3000000	17.9500000
## 18	49.54519	207	2012	6	21	173	23.800000	13.1000000	18.4500000
## 19	49.54519	207	2012	6	25	177	19.300000	10.7000000	15.0000000
## 20	49.54519	207	2012	6	29	181	24.800000	14.0000000	19.4000000
## 21	49.54519	207	2012	7	8	190	21.200000	14.9000000	18.0500000
## 22	49.54519	207	2012	7	17	199	21.000000	14.5000000	17.7500000
## 23	49.54519	207	2012	7	27	209	32.800000	15.6000000	24.2000000
## 24	49.54519	207	2012	8	9	222	24.500000	13.8000000	19.1500000
## 25	49.54519	207	2012	8	13	226	26.700000	11.3000000	19.0000000
## 26	49.54519	207	2012	8	18	231	33.800000	14.6000000	24.2000000
## 27	49.54519	207	2012	9	27	271	14.800000	9.4000000	12.1000000
##	Rainfall cdd_luht								
## 1	6.30		0						
## 2	0.00		35.3						
## 3	17.40		63.65						
## 4	2.30		86.25						
## 5	0.00		116.05						
## 6	0.20		144.8						
## 7	0.00		177.55						
## 8	0.20		214.45						
## 9	0.00		259.1						
## 10	0.00		287						
## 11	0.00		189.25						
## 12	0.00		259.1						
## 13	0.00		384.25						
## 14	0.20		467.75						
## 15	1.10		498.35						
## 16	0.00		519.75						
## 17	17.60		556.85						
## 18	0.90		570.3						
## 19	0.00		608.8						
## 20	12.60		664.55						
## 21	1.80		781.7						
## 22	0.00		875.55						
## 23	9.40		1002.55						
## 24	0.00		1172.4						
## 25	0.00		1224.95						
## 26	0.00		1299.4						
## 27	11.10		1724.355						

```
phen.mthurgau.luht[[44]] # 2013
```

##	Growth_stage		
## 1	9		
## 2	11		
## 3	12		
## 4	13		
## 5	14		
## 6	15		
## 7	16		
## 8	17		
## 9	18		
## 10	19		
## 11	53		
## 12	55		
## 13	57		
## 14	61		
## 15	63		
## 16	65		
## 17	68		
## 18	69		
## 19	71		
## 20	73		
## 21	75		
## 22	77		
## 23	79		
## 24	81		
## 25	83		
## 26	85		
## 27	89		
##		Description	CDD
## 1		Budburst: green shoot tips clearly visible	NA
## 2		First leaf unfolded and spread away from shoot	34.9
## 3		Two leaves unfolded	58.6
## 4		Three leaves unfolded	80.8
## 5		Four leaves unfolded	110.2
## 6		Five leaves unfolded	144.4
## 7		Six leaves unfolded	173.6
## 8		Seven leaves unfolded	213.5
## 9		Eight leaves unfolded	248.8
## 10		Nine leaves unfolded	285.2
## 11		Inflorescences clearly visible	178.1
## 12		Inflorescences swelling, flowers closely pressed together	253.2
## 13		Inflorescences fully developed; flowers separating	375.5
## 14		Beginning of flowering: 10% flowerhoods fallen	463.3
## 15		Early flowering: 30% flowerhoods fallen	494.5
## 16		Full flowering: 50% flowerhoods fallen	517.5
## 17		80% flowerhoods fallen	548.4
## 18		End of flowering	569.6
## 19		Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20		Berries goat-sized, bunches begin to hang	659
## 21		Berries pea-sized, bunches hang	774.9
## 22		Begin of berry touch	870
## 23		Berry touch complete	999.4


```

## 24      Beginning of ripening: berries begin to brighten in color 1160.2
## 25      Berries brighting in color 1219.4
## 26      Softening of berries 1287.8
## 27      Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69   67967.2    1 2013-05-05 2013-05-06    15831  1 6.354936
## 2  93625.69   67967.2    1 2013-05-09 2013-05-10    15835  1 6.354936
## 3  93625.69   67967.2    1 2013-05-12 2013-05-13    15838  1 6.354936
## 4  93625.69   67967.2    1 2013-05-16 2013-05-17    15842  1 6.354936
## 5  93625.69   67967.2    1 2013-05-21 2013-05-22    15847  1 6.354936
## 6  93625.69   67967.2    1 2013-05-29 2013-05-30    15855  1 6.354936
## 7  93625.69   67967.2    1 2013-06-02 2013-06-03    15859  1 6.354936
## 8  93625.69   67967.2    1 2013-06-06 2013-06-07    15863  1 6.354936
## 9  93625.69   67967.2    1 2013-06-09 2013-06-10    15866  1 6.354936
## 10 93625.69   67967.2    1 2013-06-12 2013-06-13    15869  1 6.354936
## 11 93625.69   67967.2    1 2013-06-03 2013-06-04    15860  1 6.354936
## 12 93625.69   67967.2    1 2013-06-09 2013-06-10    15866  1 6.354936
## 13 93625.69   67967.2    1 2013-06-19 2013-06-20    15876  1 6.354936
## 14 93625.69   67967.2    1 2013-06-28 2013-06-29    15885  1 6.354936
## 15 93625.69   67967.2    1 2013-07-01 2013-07-02    15888  1 6.354936
## 16 93625.69   67967.2    1 2013-07-03 2013-07-04    15890  1 6.354936
## 17 93625.69   67967.2    1 2013-07-05 2013-07-06    15892  1 6.354936
## 18 93625.69   67967.2    1 2013-07-07 2013-07-08    15894  1 6.354936
## 19 93625.69   67967.2    1 2013-07-09 2013-07-10    15896  1 6.354936
## 20 93625.69   67967.2    1 2013-07-13 2013-07-14    15900  1 6.354936
## 21 93625.69   67967.2    1 2013-07-21 2013-07-22    15908  1 6.354936
## 22 93625.69   67967.2    1 2013-07-27 2013-07-28    15914  1 6.354936
## 23 93625.69   67967.2    1 2013-08-05 2013-08-06    15923  1 6.354936
## 24 93625.69   67967.2    1 2013-08-18 2013-08-19    15936  1 6.354936
## 25 93625.69   67967.2    1 2013-08-23 2013-08-24    15941  1 6.354936
## 26 93625.69   67967.2    1 2013-08-29 2013-08-30    15947  1 6.354936
## 27 93625.69   67967.2    1 2013-10-20 2013-10-21    15999  1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1  49.54519 207 2013      5      5      125 22.000000  4.600000 13.300000
## 2  49.54519 207 2013      5      9      129 17.700000 11.100000 14.400000
## 3  49.54519 207 2013      5     12      132 13.600000  5.800000  9.700000
## 4  49.54519 207 2013      5     16      136 13.900000  7.900000 10.900000
## 5  49.54519 207 2013      5     21      141 14.400000  8.400000 11.400000
## 6  49.54519 207 2013      5     29      149 12.400000  7.600000 10.000000
## 7  49.54519 207 2013      6      2      153 18.500000  7.200000 12.850000
## 8  49.54519 207 2013      6      6      157 26.600000 11.200000 18.900000
## 9  49.54519 207 2013      6      9      160 17.700000 13.500000 15.600000
## 10 49.54519 207 2013      6     12      163 21.900000 12.700000 17.300000
## 11 49.54519 207 2013      6      3      154 16.800000  6.300000 11.550000
## 12 49.54519 207 2013      6      9      160 17.700000 13.500000 15.600000
## 13 49.54519 207 2013      6     19      170 32.300000 20.600000 26.450000
## 14 49.54519 207 2013      6     28      179 16.000000  7.700000 11.850000
## 15 49.54519 207 2013      7      1      182 24.300000  8.800000 16.550000
## 16 49.54519 207 2013      7      3      184 19.100000 14.600000 16.850000
## 17 49.54519 207 2013      7      5      186 23.800000 11.900000 17.850000
## 18 49.54519 207 2013      7      7      188 27.600000 14.800000 21.200000
## 19 49.54519 207 2013      7      9      190 27.300000 15.400000 21.350000
## 20 49.54519 207 2013      7     13      194 24.300000 10.900000 17.600000
## 21 49.54519 207 2013      7     21      202 32.600000 16.300000 24.450000

```

```

## 22 49.54519 207 2013      7 27      208 33.300000 18.7000000 26.0000000
## 23 49.54519 207 2013      8  5      217 30.900000 13.3000000 22.1000000
## 24 49.54519 207 2013      8 18      230 22.000000 16.9000000 19.4500000
## 25 49.54519 207 2013      8 23      235 25.600000 15.7000000 20.6500000
## 26 49.54519 207 2013      8 29      241 24.400000  9.3000000 16.8500000
## 27 49.54519 207 2013     10 20      293 17.300000 13.3000000 15.3000000
##      Rainfall cdd_luht
## 1         0.00      0
## 2         0.00    40.35
## 3         5.10    58.75
## 4         3.80    82.55
## 5         2.80   113.7
## 6         9.90   146.1
## 7         0.00   176.75
## 8         0.60   218.25
## 9         2.50   257.2
## 10        0.00   289.1
## 11        0.00   183.3
## 12        2.50   257.2
## 13        0.40   376.2
## 14        0.10  467.35
## 15        0.00  497.95
## 16       12.00  523.35
## 17        0.00  548.7
## 18        0.00  578.7
## 19        0.00  608.7
## 20        0.00   661
## 21        0.00  780.1
## 22        1.10  870.1
## 23        0.00 1002.7
## 24        1.20 1168.15
## 25        0.10 1230.8
## 26        0.00 1298.35
## 27        0.00 1725.65

```

```
phen.mthurgau.luht[[45]] # 2014
```

```

##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
## 14            61
## 15            63
## 16            65
## 17            68

```

## 18	69								
## 19	71								
## 20	73								
## 21	75								
## 22	77								
## 23	79								
## 24	81								
## 25	83								
## 26	85								
## 27	89								
##							Description	CDD	
## 1							Budburst: green shoot tips clearly visible	NA	
## 2							First leaf unfolded and spread away from shoot	34.9	
## 3							Two leaves unfolded	58.6	
## 4							Three leaves unfolded	80.8	
## 5							Four leaves unfolded	110.2	
## 6							Five leaves unfolded	144.4	
## 7							Six leaves unfolded	173.6	
## 8							Seven leaves unfolded	213.5	
## 9							Eight leaves unfolded	248.8	
## 10							Nine leaves unfolded	285.2	
## 11							Inflorescences clearly visible	178.1	
## 12							Inflorescences swelling, flowers closely pressed together	253.2	
## 13							Inflorescences fully developed; flowers separating	375.5	
## 14							Beginning of flowering: 10% flowerhoods fallen	463.3	
## 15							Early flowering: 30% flowerhoods fallen	494.5	
## 16							Full flowering: 50% flowerhoods fallen	517.5	
## 17							80% flowerhoods fallen	548.4	
## 18							End of flowering	569.6	
## 19							Fruit set: young fruits begin to swell, remains of flowers lost	603.5	
## 20							Berries groat-sized, bunches begin to hang	659	
## 21							Berries pea-sized, bunches hang	774.9	
## 22							Begin of berry touch	870	
## 23							Berry touch complete	999.4	
## 24							Beginning of ripening: berries begin to brighten in color	1160.2	
## 25							Berries brightening in color	1219.4	
## 26							Softening of berries	1287.8	
## 27							Berries ripe for harvest	1719.8	
##	coords.x1	coords.x2	sp.ID	time	endTime	timeIndex	id	x	
## 1	93625.69	67967.2	1	2014-04-17	2014-04-18	16178	1	6.354936	
## 2	93625.69	67967.2	1	2014-04-22	2014-04-23	16183	1	6.354936	
## 3	93625.69	67967.2	1	2014-04-25	2014-04-26	16186	1	6.354936	
## 4	93625.69	67967.2	1	2014-04-27	2014-04-28	16188	1	6.354936	
## 5	93625.69	67967.2	1	2014-04-30	2014-05-01	16191	1	6.354936	
## 6	93625.69	67967.2	1	2014-05-06	2014-05-07	16197	1	6.354936	
## 7	93625.69	67967.2	1	2014-05-09	2014-05-10	16200	1	6.354936	
## 8	93625.69	67967.2	1	2014-05-16	2014-05-17	16207	1	6.354936	
## 9	93625.69	67967.2	1	2014-05-20	2014-05-21	16211	1	6.354936	
## 10	93625.69	67967.2	1	2014-05-22	2014-05-23	16213	1	6.354936	
## 11	93625.69	67967.2	1	2014-05-10	2014-05-11	16201	1	6.354936	
## 12	93625.69	67967.2	1	2014-05-20	2014-05-21	16211	1	6.354936	
## 13	93625.69	67967.2	1	2014-05-31	2014-06-01	16222	1	6.354936	
## 14	93625.69	67967.2	1	2014-06-08	2014-06-09	16230	1	6.354936	
## 15	93625.69	67967.2	1	2014-06-10	2014-06-11	16232	1	6.354936	

```

## 16 93625.69 67967.2 1 2014-06-12 2014-06-13 16234 1 6.354936
## 17 93625.69 67967.2 1 2014-06-14 2014-06-15 16236 1 6.354936
## 18 93625.69 67967.2 1 2014-06-16 2014-06-17 16238 1 6.354936
## 19 93625.69 67967.2 1 2014-06-18 2014-06-19 16240 1 6.354936
## 20 93625.69 67967.2 1 2014-06-23 2014-06-24 16245 1 6.354936
## 21 93625.69 67967.2 1 2014-07-03 2014-07-04 16255 1 6.354936
## 22 93625.69 67967.2 1 2014-07-10 2014-07-11 16262 1 6.354936
## 23 93625.69 67967.2 1 2014-07-19 2014-07-20 16271 1 6.354936
## 24 93625.69 67967.2 1 2014-07-30 2014-07-31 16282 1 6.354936
## 25 93625.69 67967.2 1 2014-08-03 2014-08-04 16286 1 6.354936
## 26 93625.69 67967.2 1 2014-08-08 2014-08-09 16291 1 6.354936
## 27 93625.69 67967.2 1 2014-09-15 2014-09-16 16329 1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2014      4 17      107 18.400000  1.200000  9.800000
## 2 49.54519 207 2014      4 22      112 19.500000  8.800000 14.150000
## 3 49.54519 207 2014      4 25      115 22.900000 10.800000 16.850000
## 4 49.54519 207 2014      4 27      117 16.900000  8.600000 12.750000
## 5 49.54519 207 2014      4 30      120 20.500000  8.200000 14.350000
## 6 49.54519 207 2014      5  6      126 19.500000  6.800000 13.150000
## 7 49.54519 207 2014      5  9      129 18.700000 11.100000 14.900000
## 8 49.54519 207 2014      5 16      136 20.000000  5.900000 12.950000
## 9 49.54519 207 2014      5 20      140 26.300000 12.800000 19.550000
## 10 49.54519 207 2014      5 22      142 25.000000 12.700000 18.850000
## 11 49.54519 207 2014      5 10      130 14.800000  8.000000 11.400000
## 12 49.54519 207 2014      5 20      140 26.300000 12.800000 19.550000
## 13 49.54519 207 2014      5 31      151 22.400000  5.300000 13.850000
## 14 49.54519 207 2014      6  8      159 32.400000 15.500000 23.950000
## 15 49.54519 207 2014      6 10      161 32.100000 18.600000 25.350000
## 16 49.54519 207 2014      6 12      163 27.100000 15.200000 21.150000
## 17 49.54519 207 2014      6 14      165 20.000000 11.700000 15.850000
## 18 49.54519 207 2014      6 16      167 22.500000 11.400000 16.950000
## 19 49.54519 207 2014      6 18      169 25.100000 12.000000 18.550000
## 20 49.54519 207 2014      6 23      174 24.500000 10.500000 17.500000
## 21 49.54519 207 2014      7  3      184 29.500000 10.200000 19.850000
## 22 49.54519 207 2014      7 10      191 24.600000 13.200000 18.900000
## 23 49.54519 207 2014      7 19      200 33.300000 18.800000 26.050000
## 24 49.54519 207 2014      7 30      211 24.200000 15.600000 19.900000
## 25 49.54519 207 2014      8  3      215 26.200000 15.700000 20.950000
## 26 49.54519 207 2014      8  8      220 25.200000 14.100000 19.650000
## 27 49.54519 207 2014      9 15      258 23.100000 11.800000 17.450000
##      Rainfall cdd_luht
## 1      0.00      0
## 2      0.00     36.4
## 3      0.00     69.55
## 4      0.40     85.75
## 5      0.20    110.7
## 6      0.00    150.55
## 7      0.30    176.45
## 8      0.00    216.05
## 9      0.00    263.25
## 10     7.60    292.1
## 11     6.60    182.85
## 12     0.00    263.25
## 13     0.00    379.75

```

```
## 14      0.00    472.3
## 15      0.10    502.3
## 16      0.00    532.3
## 17      0.00    557.3
## 18      0.00    580.5
## 19      0.00    605.25
## 20      0.00    664.4
## 21      0.00    785.45
## 22      1.10    875.4
## 23      0.00   1006.85
## 24      2.20   1171.55
## 25      4.30   1231.45
## 26     12.80   1300.75
## 27      0.00   1731.55
```

```
phen.mthurgau.luht[[46]] # 2015
```

```
##      Growth_stage
## 1           9
## 2          11
## 3          12
## 4          13
## 5          14
## 6          15
## 7          16
## 8          17
## 9          18
## 10         19
## 11         53
## 12         55
## 13         57
## 14         61
## 15         63
## 16         65
## 17         68
## 18         69
## 19         71
## 20         73
## 21         75
## 22         77
## 23         79
## 24         81
## 25         83
## 26         85
## 27         89
```

##	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2
## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6
## 8	Seven leaves unfolded	213.5
## 9	Eight leaves unfolded	248.8

```

## 10                               Nine leaves unfolded 285.2
## 11                               Inflorescences clearly visible 178.1
## 12      Inflorescences swelling, flowers closely pressed together 253.2
## 13          Inflorescences fully developed; flowers separating 375.5
## 14              Beginning of flowering: 10% flowerhoods fallen 463.3
## 15                  Early flowering: 30% flowerhoods fallen 494.5
## 16                      Full flowering: 50% flowerhoods fallen 517.5
## 17                          80% flowerhoods fallen 548.4
## 18                              End of flowering 569.6
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20                      Berries groat-sized, bunches begin to hang 659
## 21                          Berries pea-sized, bunches hang 774.9
## 22                              Begin of berry touch 870
## 23                                  Berry touch complete 999.4
## 24      Beginning of ripening: berries begin to brighten in color 1160.2
## 25                      Berries brightening in color 1219.4
## 26                          Softening of berries 1287.8
## 27                              Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69  67967.2      1 2015-04-24 2015-04-25      16550 1 6.354936
## 2  93625.69  67967.2      1 2015-05-01 2015-05-02      16557 1 6.354936
## 3  93625.69  67967.2      1 2015-05-04 2015-05-05      16560 1 6.354936
## 4  93625.69  67967.2      1 2015-05-06 2015-05-07      16562 1 6.354936
## 5  93625.69  67967.2      1 2015-05-09 2015-05-10      16565 1 6.354936
## 6  93625.69  67967.2      1 2015-05-12 2015-05-13      16568 1 6.354936
## 7  93625.69  67967.2      1 2015-05-15 2015-05-16      16571 1 6.354936
## 8  93625.69  67967.2      1 2015-05-21 2015-05-22      16577 1 6.354936
## 9  93625.69  67967.2      1 2015-05-25 2015-05-26      16581 1 6.354936
## 10 93625.69  67967.2      1 2015-05-29 2015-05-30      16585 1 6.354936
## 11 93625.69  67967.2      1 2015-05-16 2015-05-17      16572 1 6.354936
## 12 93625.69  67967.2      1 2015-05-25 2015-05-26      16581 1 6.354936
## 13 93625.69  67967.2      1 2015-06-06 2015-06-07      16593 1 6.354936
## 14 93625.69  67967.2      1 2015-06-13 2015-06-14      16600 1 6.354936
## 15 93625.69  67967.2      1 2015-06-15 2015-06-16      16602 1 6.354936
## 16 93625.69  67967.2      1 2015-06-17 2015-06-18      16604 1 6.354936
## 17 93625.69  67967.2      1 2015-06-20 2015-06-21      16607 1 6.354936
## 18 93625.69  67967.2      1 2015-06-23 2015-06-24      16610 1 6.354936
## 19 93625.69  67967.2      1 2015-06-26 2015-06-27      16613 1 6.354936
## 20 93625.69  67967.2      1 2015-06-30 2015-07-01      16617 1 6.354936
## 21 93625.69  67967.2      1 2015-07-07 2015-07-08      16624 1 6.354936
## 22 93625.69  67967.2      1 2015-07-14 2015-07-15      16631 1 6.354936
## 23 93625.69  67967.2      1 2015-07-23 2015-07-24      16640 1 6.354936
## 24 93625.69  67967.2      1 2015-08-05 2015-08-06      16653 1 6.354936
## 25 93625.69  67967.2      1 2015-08-09 2015-08-10      16657 1 6.354936
## 26 93625.69  67967.2      1 2015-08-13 2015-08-14      16661 1 6.354936
## 27 93625.69  67967.2      1 2015-09-19 2015-09-20      16698 1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2015      4 24      114 22.300000  4.000000 13.150000
## 2 49.54519 207 2015      5  1      121 11.600000  7.100000  9.350000
## 3 49.54519 207 2015      5  4      124 21.800000 12.800000 17.300000
## 4 49.54519 207 2015      5  6      126 17.500000  8.500000 13.000000
## 5 49.54519 207 2015      5  9      129 20.000000 11.700000 15.850000
## 6 49.54519 207 2015      5 12      132 26.500000 11.700000 19.100000
## 7 49.54519 207 2015      5 15      135 19.700000  8.500000 14.100000

```

```

## 8 49.54519 207 2015      5 21      141 19.000000  2.4000000 10.7000000
## 9 49.54519 207 2015      5 25      145 19.200000  8.3000000 13.7500000
## 10 49.54519 207 2015     5 29      149 16.800000  7.7000000 12.2500000
## 11 49.54519 207 2015     5 16      136 16.700000  5.4000000 11.0500000
## 12 49.54519 207 2015     5 25      145 19.200000  8.3000000 13.7500000
## 13 49.54519 207 2015     6  6      157 26.600000 16.1000000 21.3500000
## 14 49.54519 207 2015     6 13      164 24.000000 14.5000000 19.2500000
## 15 49.54519 207 2015     6 15      166 23.900000 14.5000000 19.2000000
## 16 49.54519 207 2015     6 17      168 24.300000  7.1000000 15.7000000
## 17 49.54519 207 2015     6 20      171 18.100000 10.6000000 14.3500000
## 18 49.54519 207 2015     6 23      174 19.400000  7.4000000 13.4000000
## 19 49.54519 207 2015     6 26      177 28.100000 11.4000000 19.7500000
## 20 49.54519 207 2015     6 30      181 31.700000 13.2000000 22.4500000
## 21 49.54519 207 2015     7  7      188 33.400000 14.7000000 24.0500000
## 22 49.54519 207 2015     7 14      195 24.800000 16.4000000 20.6000000
## 23 49.54519 207 2015     7 23      204 26.700000 14.9000000 20.8000000
## 24 49.54519 207 2015     8  5      217 29.900000 10.9000000 20.4000000
## 25 49.54519 207 2015     8  9      221 29.300000 18.6000000 23.9500000
## 26 49.54519 207 2015     8 13      225 36.000000 19.6000000 27.8000000
## 27 49.54519 207 2015     9 19      262 17.600000 11.4000000 14.5000000
##      Rainfall  cdd_luht
## 1      0.00      0
## 2      1.80     38.8
## 3      0.10     64.9
## 4      0.40     84.75
## 5      0.00    111.75
## 6      0.00    148.8
## 7      0.50    174.85
## 8      0.00    215.7
## 9      5.10    256.8
## 10     1.80    286.95
## 11     0.00    180.9
## 12     5.10    256.8
## 13     5.10    379.65
## 14     8.40    469.9
## 15     0.00    498.95
## 16     0.30    520.9
## 17     1.20    549.9
## 18     0.60    577.15
## 19     0.00    614.9
## 20     0.00    673.65
## 21     0.40    778.65
## 22     0.00    874.65
## 23     0.00   1009.65
## 24     0.00   1171.8
## 25     0.00   1231.8
## 26     5.00   1291.8
## 27     3.80   1721.95

```

```

write.csv(cdd.phen.mthurgau.luht[[46]], file="cdd.phen.mthurgau.luht_2015.csv")
write.csv(cdd.phen.mthurgau.luht[[47]], file="cdd.phen.mthurgau.luht_2016.csv")
write.csv(cdd.phen.mthurgau.luht[[48]], file="cdd.phen.mthurgau.luht_2017.csv")

```

```

phen.riesling.luht <- phenology.stages(cdd.phen = cdd.phen.riesling.luht,

```

```

ref.data = GrowthStage_CDD,
stage = GrowthStage_CDD[-1,1])

## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages

## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages

## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages

## Warning in (function (x, y) : cdd for the time series doesn't reach one or
## more phenological stages

phen.riesling.luht[[43]] # 2012

##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
## 14            61
## 15            63
## 16            65
## 17            68
## 18            69
## 19            71
## 20            73
## 21            75
## 22            77
## 23            79
## 24            81
## 25            83
## 26            85
## 27            89
##
##                                     Description      CDD
## 1          Budburst: green shoot tips clearly visible      NA
## 2      First leaf unfolded and spread away from shoot    34.9
## 3                Two leaves unfolded                    58.6
## 4          Three leaves unfolded                        80.8
## 5          Four leaves unfolded                       110.2
## 6          Five leaves unfolded                       144.4
## 7          Six leaves unfolded                        173.6

```



```

## 8          Seven leaves unfolded 213.5
## 9          Eight leaves unfolded 248.8
## 10         Nine leaves unfolded 285.2
## 11         Inflorescences clearly visible 178.1
## 12         Inflorescences swelling, flowers closely pressed together 253.2
## 13         Inflorescences fully developed; flowers separating 375.5
## 14         Beginning of flowering: 10% flowerhoods fallen 463.3
## 15         Early flowering: 30% flowerhoods fallen 494.5
## 16         Full flowering: 50% flowerhoods fallen 517.5
## 17         80% flowerhoods fallen 548.4
## 18         End of flowering 569.6
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20         Berries groat-sized, bunches begin to hang 659
## 21         Berries pea-sized, bunches hang 774.9
## 22         Begin of berry touch 870
## 23         Berry touch complete 999.4
## 24         Beginning of ripening: berries begin to brighten in color 1160.2
## 25         Berries brightening in color 1219.4
## 26         Softening of berries 1287.8
## 27         Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69  67967.2    1 2012-04-27 2012-04-28    15458 1 6.354936
## 2  93625.69  67967.2    1 2012-05-01 2012-05-02    15462 1 6.354936
## 3  93625.69  67967.2    1 2012-05-03 2012-05-04    15464 1 6.354936
## 4  93625.69  67967.2    1 2012-05-06 2012-05-07    15467 1 6.354936
## 5  93625.69  67967.2    1 2012-05-10 2012-05-11    15471 1 6.354936
## 6  93625.69  67967.2    1 2012-05-13 2012-05-14    15474 1 6.354936
## 7  93625.69  67967.2    1 2012-05-19 2012-05-20    15480 1 6.354936
## 8  93625.69  67967.2    1 2012-05-22 2012-05-23    15483 1 6.354936
## 9  93625.69  67967.2    1 2012-05-24 2012-05-25    15485 1 6.354936
## 10 93625.69  67967.2    1 2012-05-27 2012-05-28    15488 1 6.354936
## 11 93625.69  67967.2    1 2012-05-19 2012-05-20    15480 1 6.354936
## 12 93625.69  67967.2    1 2012-05-25 2012-05-26    15486 1 6.354936
## 13 93625.69  67967.2    1 2012-06-04 2012-06-05    15496 1 6.354936
## 14 93625.69  67967.2    1 2012-06-13 2012-06-14    15505 1 6.354936
## 15 93625.69  67967.2    1 2012-06-16 2012-06-17    15508 1 6.354936
## 16 93625.69  67967.2    1 2012-06-18 2012-06-19    15510 1 6.354936
## 17 93625.69  67967.2    1 2012-06-21 2012-06-22    15513 1 6.354936
## 18 93625.69  67967.2    1 2012-06-22 2012-06-23    15514 1 6.354936
## 19 93625.69  67967.2    1 2012-06-26 2012-06-27    15518 1 6.354936
## 20 93625.69  67967.2    1 2012-06-30 2012-07-01    15522 1 6.354936
## 21 93625.69  67967.2    1 2012-07-09 2012-07-10    15531 1 6.354936
## 22 93625.69  67967.2    1 2012-07-18 2012-07-19    15540 1 6.354936
## 23 93625.69  67967.2    1 2012-07-28 2012-07-29    15550 1 6.354936
## 24 93625.69  67967.2    1 2012-08-09 2012-08-10    15562 1 6.354936
## 25 93625.69  67967.2    1 2012-08-14 2012-08-15    15567 1 6.354936
## 26 93625.69  67967.2    1 2012-08-18 2012-08-19    15571 1 6.354936
## 27 93625.69  67967.2    1 2012-09-28 2012-09-29    15612 1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2012      4 27      118 13.800000  8.200000 11.000000
## 2 49.54519 207 2012      5  1      122 18.800000 10.000000 14.400000
## 3 49.54519 207 2012      5  3      124 17.300000  7.500000 12.400000
## 4 49.54519 207 2012      5  6      127 14.800000  6.500000 10.650000
## 5 49.54519 207 2012      5 10      131 27.400000 12.700000 20.050000

```

```

## 6 49.54519 207 2012 5 13 134 15.300000 3.2000000 9.2500000
## 7 49.54519 207 2012 5 19 140 23.600000 9.8000000 16.7000000
## 8 49.54519 207 2012 5 22 143 26.000000 13.7000000 19.8500000
## 9 49.54519 207 2012 5 24 145 29.000000 13.8000000 21.4000000
## 10 49.54519 207 2012 5 27 148 25.000000 11.4000000 18.2000000
## 11 49.54519 207 2012 5 19 140 23.600000 9.8000000 16.7000000
## 12 49.54519 207 2012 5 25 146 25.400000 13.1000000 19.2500000
## 13 49.54519 207 2012 6 4 156 19.000000 7.6000000 13.3000000
## 14 49.54519 207 2012 6 13 165 15.900000 10.5000000 13.2000000
## 15 49.54519 207 2012 6 16 168 16.600000 11.8000000 14.2000000
## 16 49.54519 207 2012 6 18 170 23.100000 11.6000000 17.3500000
## 17 49.54519 207 2012 6 21 173 23.800000 13.1000000 18.4500000
## 18 49.54519 207 2012 6 22 174 19.900000 10.7000000 15.3000000
## 19 49.54519 207 2012 6 26 178 23.600000 9.9000000 16.7500000
## 20 49.54519 207 2012 6 30 182 25.100000 11.6000000 18.3500000
## 21 49.54519 207 2012 7 9 191 21.600000 11.4000000 16.5000000
## 22 49.54519 207 2012 7 18 200 25.100000 12.5000000 18.8000000
## 23 49.54519 207 2012 7 28 210 24.200000 16.0000000 20.1000000
## 24 49.54519 207 2012 8 9 222 24.500000 13.8000000 19.1500000
## 25 49.54519 207 2012 8 14 227 26.500000 13.8000000 20.1500000
## 26 49.54519 207 2012 8 18 231 33.800000 14.6000000 24.2000000
## 27 49.54519 207 2012 9 28 272 17.900000 8.8000000 13.3500000
## Rainfall cdd_luht
## 1 3.90 0
## 2 0.70 44.25
## 3 0.10 61.15
## 4 5.50 82
## 5 0.30 121.15
## 6 0.00 144.75
## 7 0.00 179.35
## 8 0.00 219.4
## 9 0.00 249.2
## 10 0.00 290.3
## 11 0.00 179.35
## 12 0.00 263.45
## 13 1.50 382.65
## 14 12.10 466.05
## 15 14.40 497.65
## 16 0.00 522.2
## 17 0.90 560.4
## 18 0.00 570.7
## 19 0.00 610.65
## 20 0.10 668
## 21 1.60 783.3
## 22 0.00 879.45
## 23 3.80 1007.65
## 24 0.00 1162.5
## 25 0.00 1230.05
## 26 0.00 1289.5
## 27 0.00 1722.805

```

```
phen.riesling.luht[[44]] # 2013
```

```

## Growth_stage
## 1 9

```

## 2	11
## 3	12
## 4	13
## 5	14
## 6	15
## 7	16
## 8	17
## 9	18
## 10	19
## 11	53
## 12	55
## 13	57
## 14	61
## 15	63
## 16	65
## 17	68
## 18	69
## 19	71
## 20	73
## 21	75
## 22	77
## 23	79
## 24	81
## 25	83
## 26	85
## 27	89

##		Description	CDD
## 1		Budburst: green shoot tips clearly visible	NA
## 2		First leaf unfolded and spread away from shoot	34.9
## 3		Two leaves unfolded	58.6
## 4		Three leaves unfolded	80.8
## 5		Four leaves unfolded	110.2
## 6		Five leaves unfolded	144.4
## 7		Six leaves unfolded	173.6
## 8		Seven leaves unfolded	213.5
## 9		Eight leaves unfolded	248.8
## 10		Nine leaves unfolded	285.2
## 11		Inflorescences clearly visible	178.1
## 12		Inflorescences swelling, flowers closely pressed together	253.2
## 13		Inflorescences fully developed; flowers separating	375.5
## 14		Beginning of flowering: 10% flowerhoods fallen	463.3
## 15		Early flowering: 30% flowerhoods fallen	494.5
## 16		Full flowering: 50% flowerhoods fallen	517.5
## 17		80% flowerhoods fallen	548.4
## 18		End of flowering	569.6
## 19		Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20		Berries groat-sized, bunches begin to hang	659
## 21		Berries pea-sized, bunches hang	774.9
## 22		Begin of berry touch	870
## 23		Berry touch complete	999.4
## 24		Beginning of ripening: berries begin to brighten in color	1160.2
## 25		Berries brightening in color	1219.4
## 26		Softening of berries	1287.8
## 27		Berries ripe for harvest	1719.8

##	coords.x1	coords.x2	sp.ID	time	endTime	timeIndex	id	x	
## 1	93625.69	67967.2	1	2013-05-06	2013-05-07	15832	1	6.354936	
## 2	93625.69	67967.2	1	2013-05-10	2013-05-11	15836	1	6.354936	
## 3	93625.69	67967.2	1	2013-05-14	2013-05-15	15840	1	6.354936	
## 4	93625.69	67967.2	1	2013-05-18	2013-05-19	15844	1	6.354936	
## 5	93625.69	67967.2	1	2013-05-25	2013-05-26	15851	1	6.354936	
## 6	93625.69	67967.2	1	2013-05-31	2013-06-01	15857	1	6.354936	
## 7	93625.69	67967.2	1	2013-06-04	2013-06-05	15861	1	6.354936	
## 8	93625.69	67967.2	1	2013-06-07	2013-06-08	15864	1	6.354936	
## 9	93625.69	67967.2	1	2013-06-10	2013-06-11	15867	1	6.354936	
## 10	93625.69	67967.2	1	2013-06-13	2013-06-14	15870	1	6.354936	
## 11	93625.69	67967.2	1	2013-06-04	2013-06-05	15861	1	6.354936	
## 12	93625.69	67967.2	1	2013-06-10	2013-06-11	15867	1	6.354936	
## 13	93625.69	67967.2	1	2013-06-20	2013-06-21	15877	1	6.354936	
## 14	93625.69	67967.2	1	2013-06-29	2013-06-30	15886	1	6.354936	
## 15	93625.69	67967.2	1	2013-07-02	2013-07-03	15889	1	6.354936	
## 16	93625.69	67967.2	1	2013-07-04	2013-07-05	15891	1	6.354936	
## 17	93625.69	67967.2	1	2013-07-06	2013-07-07	15893	1	6.354936	
## 18	93625.69	67967.2	1	2013-07-08	2013-07-09	15895	1	6.354936	
## 19	93625.69	67967.2	1	2013-07-10	2013-07-11	15897	1	6.354936	
## 20	93625.69	67967.2	1	2013-07-14	2013-07-15	15901	1	6.354936	
## 21	93625.69	67967.2	1	2013-07-22	2013-07-23	15909	1	6.354936	
## 22	93625.69	67967.2	1	2013-07-28	2013-07-29	15915	1	6.354936	
## 23	93625.69	67967.2	1	2013-08-06	2013-08-07	15924	1	6.354936	
## 24	93625.69	67967.2	1	2013-08-19	2013-08-20	15937	1	6.354936	
## 25	93625.69	67967.2	1	2013-08-23	2013-08-24	15941	1	6.354936	
## 26	93625.69	67967.2	1	2013-08-30	2013-08-31	15948	1	6.354936	
## 27	93625.69	67967.2	1	2013-10-21	2013-10-22	16000	1	6.354936	
##	y	z	Year	Month	Day	DayYear	T.max	T.min	T.mean
## 1	49.54519	207	2013	5	6	126	23.000000	8.800000	15.900000
## 2	49.54519	207	2013	5	10	130	14.100000	8.000000	11.050000
## 3	49.54519	207	2013	5	14	134	15.900000	7.400000	11.650000
## 4	49.54519	207	2013	5	18	138	19.700000	8.400000	14.050000
## 5	49.54519	207	2013	5	25	145	14.500000	2.700000	8.600000
## 6	49.54519	207	2013	5	31	151	17.000000	7.600000	12.300000
## 7	49.54519	207	2013	6	4	155	20.700000	7.100000	13.900000
## 8	49.54519	207	2013	6	7	158	27.300000	10.300000	18.800000
## 9	49.54519	207	2013	6	10	161	16.800000	12.300000	14.550000
## 10	49.54519	207	2013	6	13	164	25.300000	9.800000	17.550000
## 11	49.54519	207	2013	6	4	155	20.700000	7.100000	13.900000
## 12	49.54519	207	2013	6	10	161	16.800000	12.300000	14.550000
## 13	49.54519	207	2013	6	20	171	25.800000	14.800000	20.300000
## 14	49.54519	207	2013	6	29	180	19.700000	10.200000	14.950000
## 15	49.54519	207	2013	7	2	183	25.600000	11.500000	18.550000
## 16	49.54519	207	2013	7	4	185	21.900000	13.100000	17.500000
## 17	49.54519	207	2013	7	6	187	27.000000	13.400000	20.200000
## 18	49.54519	207	2013	7	8	189	27.300000	13.500000	20.400000
## 19	49.54519	207	2013	7	10	191	27.100000	14.300000	20.700000
## 20	49.54519	207	2013	7	14	195	27.300000	10.900000	19.100000
## 21	49.54519	207	2013	7	22	203	33.900000	16.000000	24.950000
## 22	49.54519	207	2013	7	28	209	26.300000	17.600000	21.950000
## 23	49.54519	207	2013	8	6	218	24.600000	16.700000	20.650000
## 24	49.54519	207	2013	8	19	231	21.300000	13.100000	17.200000
## 25	49.54519	207	2013	8	23	235	25.600000	15.700000	20.650000

```

## 26 49.54519 207 2013      8 30      242 24.400000  9.8000000 17.1000000
## 27 49.54519 207 2013     10 21      294 19.200000 12.5000000 15.8500000
##      Rainfall cdd_luht
## 1         0.00      0
## 2         0.30     35.5
## 3         0.10     60.15
## 4         0.00     85.1
## 5         0.30    111.25
## 6         3.20    148.6
## 7         0.00    181.3
## 8         0.00    221.15
## 9         0.50    255.85
## 10        13.20    290.75
## 11         0.00    181.3
## 12         0.50    255.85
## 13        36.20    380.3
## 14         8.60    466.4
## 15         0.00    500.6
## 16         0.00    524.95
## 17         0.00    552.8
## 18         0.00    582.8
## 19         0.00    612.8
## 20         0.00    664.2
## 21         0.10    784.2
## 22         4.70    874.2
## 23         2.40   1006.8
## 24         5.70  1169.45
## 25         0.10  1219.9
## 26         0.00  1299.55
## 27         0.60  1725.6

```

```
phen.riesling.luht[[45]] # 2014
```

```

##      Growth_stage
## 1              9
## 2             11
## 3             12
## 4             13
## 5             14
## 6             15
## 7             16
## 8             17
## 9             18
## 10            19
## 11            53
## 12            55
## 13            57
## 14            61
## 15            63
## 16            65
## 17            68
## 18            69
## 19            71
## 20            73
## 21            75

```

## 22	77								
## 23	79								
## 24	81								
## 25	83								
## 26	85								
## 27	89								
##								Description	CDD
## 1								Budburst: green shoot tips clearly visible	NA
## 2								First leaf unfolded and spread away from shoot	34.9
## 3								Two leaves unfolded	58.6
## 4								Three leaves unfolded	80.8
## 5								Four leaves unfolded	110.2
## 6								Five leaves unfolded	144.4
## 7								Six leaves unfolded	173.6
## 8								Seven leaves unfolded	213.5
## 9								Eight leaves unfolded	248.8
## 10								Nine leaves unfolded	285.2
## 11								Inflorescences clearly visible	178.1
## 12								Inflorescences swelling, flowers closely pressed together	253.2
## 13								Inflorescences fully developed; flowers separating	375.5
## 14								Beginning of flowering: 10% flowerhoods fallen	463.3
## 15								Early flowering: 30% flowerhoods fallen	494.5
## 16								Full flowering: 50% flowerhoods fallen	517.5
## 17								80% flowerhoods fallen	548.4
## 18								End of flowering	569.6
## 19								Fruit set: young fruits begin to swell, remains of flowers lost	603.5
## 20								Berries groat-sized, bunches begin to hang	659
## 21								Berries pea-sized, bunches hang	774.9
## 22								Begin of berry touch	870
## 23								Berry touch complete	999.4
## 24								Beginning of ripening: berries begin to brighten in color	1160.2
## 25								Berries brightening in color	1219.4
## 26								Softening of berries	1287.8
## 27								Berries ripe for harvest	1719.8
##	coords.x1	coords.x2	sp.ID	time	endTime	timeIndex	id	x	
## 1	93625.69	67967.2	1	2014-04-19	2014-04-20	16180	1	6.354936	
## 2	93625.69	67967.2	1	2014-04-23	2014-04-24	16184	1	6.354936	
## 3	93625.69	67967.2	1	2014-04-25	2014-04-26	16186	1	6.354936	
## 4	93625.69	67967.2	1	2014-04-28	2014-04-29	16189	1	6.354936	
## 5	93625.69	67967.2	1	2014-05-02	2014-05-03	16193	1	6.354936	
## 6	93625.69	67967.2	1	2014-05-07	2014-05-08	16198	1	6.354936	
## 7	93625.69	67967.2	1	2014-05-11	2014-05-12	16202	1	6.354936	
## 8	93625.69	67967.2	1	2014-05-17	2014-05-18	16208	1	6.354936	
## 9	93625.69	67967.2	1	2014-05-20	2014-05-21	16211	1	6.354936	
## 10	93625.69	67967.2	1	2014-05-23	2014-05-24	16214	1	6.354936	
## 11	93625.69	67967.2	1	2014-05-11	2014-05-12	16202	1	6.354936	
## 12	93625.69	67967.2	1	2014-05-20	2014-05-21	16211	1	6.354936	
## 13	93625.69	67967.2	1	2014-06-01	2014-06-02	16223	1	6.354936	
## 14	93625.69	67967.2	1	2014-06-09	2014-06-10	16231	1	6.354936	
## 15	93625.69	67967.2	1	2014-06-11	2014-06-12	16233	1	6.354936	
## 16	93625.69	67967.2	1	2014-06-12	2014-06-13	16234	1	6.354936	
## 17	93625.69	67967.2	1	2014-06-15	2014-06-16	16237	1	6.354936	
## 18	93625.69	67967.2	1	2014-06-16	2014-06-17	16238	1	6.354936	
## 19	93625.69	67967.2	1	2014-06-19	2014-06-20	16241	1	6.354936	

##	20	93625.69	67967.2	1	2014-06-24	2014-06-25	16246	1	6.354936	
##	21	93625.69	67967.2	1	2014-07-03	2014-07-04	16255	1	6.354936	
##	22	93625.69	67967.2	1	2014-07-11	2014-07-12	16263	1	6.354936	
##	23	93625.69	67967.2	1	2014-07-20	2014-07-21	16272	1	6.354936	
##	24	93625.69	67967.2	1	2014-07-30	2014-07-31	16282	1	6.354936	
##	25	93625.69	67967.2	1	2014-08-03	2014-08-04	16286	1	6.354936	
##	26	93625.69	67967.2	1	2014-08-08	2014-08-09	16291	1	6.354936	
##	27	93625.69	67967.2	1	2014-09-15	2014-09-16	16329	1	6.354936	
##		y	z	Year	Month	Day	DayYear	T.max	T.min	T.mean
##	1	49.54519	207	2014	4	19	109	16.900000	4.300000	10.600000
##	2	49.54519	207	2014	4	23	113	22.700000	7.400000	15.050000
##	3	49.54519	207	2014	4	25	115	22.900000	10.800000	16.850000
##	4	49.54519	207	2014	4	28	118	18.100000	7.800000	12.950000
##	5	49.54519	207	2014	5	2	122	15.600000	8.900000	12.250000
##	6	49.54519	207	2014	5	7	127	17.200000	9.600000	13.400000
##	7	49.54519	207	2014	5	11	131	13.500000	6.900000	10.200000
##	8	49.54519	207	2014	5	17	137	22.000000	7.000000	14.500000
##	9	49.54519	207	2014	5	20	140	26.300000	12.800000	19.550000
##	10	49.54519	207	2014	5	23	143	21.300000	12.700000	17.000000
##	11	49.54519	207	2014	5	11	131	13.500000	6.900000	10.200000
##	12	49.54519	207	2014	5	20	140	26.300000	12.800000	19.550000
##	13	49.54519	207	2014	6	1	152	22.500000	10.300000	16.400000
##	14	49.54519	207	2014	6	9	160	34.000000	17.900000	25.950000
##	15	49.54519	207	2014	6	11	162	27.000000	17.700000	22.350000
##	16	49.54519	207	2014	6	12	163	27.100000	15.200000	21.150000
##	17	49.54519	207	2014	6	15	166	23.100000	9.400000	16.250000
##	18	49.54519	207	2014	6	16	167	22.500000	11.400000	16.950000
##	19	49.54519	207	2014	6	19	170	23.800000	10.500000	17.150000
##	20	49.54519	207	2014	6	24	175	26.000000	10.500000	18.250000
##	21	49.54519	207	2014	7	3	184	29.500000	10.200000	19.850000
##	22	49.54519	207	2014	7	11	192	26.200000	13.800000	20.000000
##	23	49.54519	207	2014	7	20	201	27.700000	18.300000	23.000000
##	24	49.54519	207	2014	7	30	211	24.200000	15.600000	19.900000
##	25	49.54519	207	2014	8	3	215	26.200000	15.700000	20.950000
##	26	49.54519	207	2014	8	8	220	25.200000	14.100000	19.650000
##	27	49.54519	207	2014	9	15	258	23.100000	11.800000	17.450000
##		Rainfall	cdd_luht							
##	1	0.00	0							
##	2	0.10	36.85							
##	3	0.00	59.95							
##	4	1.30	84.1							
##	5	0.00	116.15							
##	6	13.50	149.35							
##	7	5.20	178.45							
##	8	0.00	215.95							
##	9	0.00	253.65							
##	10	3.50	294.5							
##	11	5.20	178.45							
##	12	0.00	253.65							
##	13	0.00	381.55							
##	14	0.00	477.7							
##	15	0.20	507.7							
##	16	0.00	522.7							
##	17	0.00	558.95							

## 18	0.00	570.9
## 19	0.00	607.8
## 20	0.00	668.05
## 21	0.00	775.85
## 22	0.30	880.8
## 23	0.60	1012.25
## 24	2.20	1161.95
## 25	4.30	1221.85
## 26	12.80	1291.15
## 27	0.00	1721.95

phen.riesling.luht[[46]] # 2015

##	Growth_stage
## 1	9
## 2	11
## 3	12
## 4	13
## 5	14
## 6	15
## 7	16
## 8	17
## 9	18
## 10	19
## 11	53
## 12	55
## 13	57
## 14	61
## 15	63
## 16	65
## 17	68
## 18	69
## 19	71
## 20	73
## 21	75
## 22	77
## 23	79
## 24	81
## 25	83
## 26	85
## 27	89

##	Description	CDD
## 1	Budburst: green shoot tips clearly visible	NA
## 2	First leaf unfolded and spread away from shoot	34.9
## 3	Two leaves unfolded	58.6
## 4	Three leaves unfolded	80.8
## 5	Four leaves unfolded	110.2
## 6	Five leaves unfolded	144.4
## 7	Six leaves unfolded	173.6
## 8	Seven leaves unfolded	213.5
## 9	Eight leaves unfolded	248.8
## 10	Nine leaves unfolded	285.2
## 11	Inflorescences clearly visible	178.1
## 12	Inflorescences swelling, flowers closely pressed together	253.2
## 13	Inflorescences fully developed; flowers separating	375.5


```

## 14          Beginning of flowering: 10% flowerhoods fallen 463.3
## 15          Early flowering: 30% flowerhoods fallen 494.5
## 16          Full flowering: 50% flowerhoods fallen 517.5
## 17          80% flowerhoods fallen 548.4
## 18          End of flowering 569.6
## 19 Fruit set: young fruits begin to swell, remains of flowers lost 603.5
## 20          Berries groat-sized, bunches begin to hang 659
## 21          Berries pea-sized, bunches hang 774.9
## 22          Begin of berry touch 870
## 23          Berry touch complete 999.4
## 24          Beginning of ripening: berries begin to brighten in color 1160.2
## 25          Berries brightening in color 1219.4
## 26          Softening of berries 1287.8
## 27          Berries ripe for harvest 1719.8
##      coords.x1 coords.x2 sp.ID      time      endTime timeIndex id      x
## 1  93625.69  67967.2      1 2015-04-26 2015-04-27      16552  1 6.354936
## 2  93625.69  67967.2      1 2015-05-04 2015-05-05      16560  1 6.354936
## 3  93625.69  67967.2      1 2015-05-06 2015-05-07      16562  1 6.354936
## 4  93625.69  67967.2      1 2015-05-08 2015-05-09      16564  1 6.354936
## 5  93625.69  67967.2      1 2015-05-11 2015-05-12      16567  1 6.354936
## 6  93625.69  67967.2      1 2015-05-14 2015-05-15      16570  1 6.354936
## 7  93625.69  67967.2      1 2015-05-18 2015-05-19      16574  1 6.354936
## 8  93625.69  67967.2      1 2015-05-23 2015-05-24      16579  1 6.354936
## 9  93625.69  67967.2      1 2015-05-27 2015-05-28      16583  1 6.354936
## 10 93625.69  67967.2      1 2015-06-01 2015-06-02      16588  1 6.354936
## 11 93625.69  67967.2      1 2015-05-18 2015-05-19      16574  1 6.354936
## 12 93625.69  67967.2      1 2015-05-28 2015-05-29      16584  1 6.354936
## 13 93625.69  67967.2      1 2015-06-08 2015-06-09      16595  1 6.354936
## 14 93625.69  67967.2      1 2015-06-14 2015-06-15      16601  1 6.354936
## 15 93625.69  67967.2      1 2015-06-17 2015-06-18      16604  1 6.354936
## 16 93625.69  67967.2      1 2015-06-19 2015-06-20      16606  1 6.354936
## 17 93625.69  67967.2      1 2015-06-22 2015-06-23      16609  1 6.354936
## 18 93625.69  67967.2      1 2015-06-25 2015-06-26      16612  1 6.354936
## 19 93625.69  67967.2      1 2015-06-27 2015-06-28      16614  1 6.354936
## 20 93625.69  67967.2      1 2015-07-01 2015-07-02      16618  1 6.354936
## 21 93625.69  67967.2      1 2015-07-09 2015-07-10      16626  1 6.354936
## 22 93625.69  67967.2      1 2015-07-15 2015-07-16      16632  1 6.354936
## 23 93625.69  67967.2      1 2015-07-24 2015-07-25      16641  1 6.354936
## 24 93625.69  67967.2      1 2015-08-06 2015-08-07      16654  1 6.354936
## 25 93625.69  67967.2      1 2015-08-10 2015-08-11      16658  1 6.354936
## 26 93625.69  67967.2      1 2015-08-15 2015-08-16      16663  1 6.354936
## 27 93625.69  67967.2      1 2015-09-21 2015-09-22      16700  1 6.354936
##      y      z Year Month Day DayYear      T.max      T.min      T.mean
## 1 49.54519 207 2015      4 26      116 20.900000 11.200000 16.050000
## 2 49.54519 207 2015      5  4      124 21.800000 12.800000 17.300000
## 3 49.54519 207 2015      5  6      126 17.500000  8.500000 13.000000
## 4 49.54519 207 2015      5  8      128 21.400000  6.400000 13.900000
## 5 49.54519 207 2015      5 11      131 26.300000  8.600000 17.450000
## 6 49.54519 207 2015      5 14      134 18.800000  7.500000 13.150000
## 7 49.54519 207 2015      5 18      138 21.400000  5.000000 13.200000
## 8 49.54519 207 2015      5 23      143 20.700000  9.600000 15.150000
## 9 49.54519 207 2015      5 27      147 18.400000  5.100000 11.750000
## 10 49.54519 207 2015      6  1      152 17.400000  9.400000 13.400000
## 11 49.54519 207 2015      5 18      138 21.400000  5.000000 13.200000

```

```
## 12 49.54519 207 2015      5 28      148 20.800000      8.4000000 14.6000000
## 13 49.54519 207 2015      6  8      159 22.400000     11.0000000 16.7000000
## 14 49.54519 207 2015      6 14      165 28.000000     11.7000000 19.8500000
## 15 49.54519 207 2015      6 17      168 24.300000      7.1000000 15.7000000
## 16 49.54519 207 2015      6 19      170 18.300000      7.5000000 12.9000000
## 17 49.54519 207 2015      6 22      173 16.300000      7.9000000 12.1000000
## 18 49.54519 207 2015      6 25      176 25.700000     10.0000000 17.8500000
## 19 49.54519 207 2015      6 27      178 25.100000     14.3000000 19.7000000
## 20 49.54519 207 2015      7  1      182 35.300000     16.0000000 25.6500000
## 21 49.54519 207 2015      7  9      190 22.600000     11.9000000 17.2500000
## 22 49.54519 207 2015      7 15      196 29.700000     14.5000000 22.1000000
## 23 49.54519 207 2015      7 24      205 31.400000     14.4000000 22.9000000
## 24 49.54519 207 2015      8  6      218 35.800000     15.5000000 25.6500000
## 25 49.54519 207 2015      8 10      222 27.100000     17.6000000 22.3500000
## 26 49.54519 207 2015      8 15      227 20.000000     15.0000000 17.5000000
## 27 49.54519 207 2015      9 21      264 19.600000      6.5000000 13.0500000
##      Rainfall  cdd_luht
## 1      11.20      0
## 2       0.10     45.65
## 3       0.40     65.5
## 4       0.00     81.65
## 5       0.00    115.45
## 6       3.70    146.5
## 7       0.00    179.25
## 8       0.00    216.35
## 9       0.00    250.85
## 10      1.70    291.85
## 11      0.00    179.25
## 12      0.00    260.45
## 13      0.00    385.6
## 14      0.00    465.5
## 15      0.30    501.65
## 16      0.00    521.3
## 17     15.50    549.5
## 18      0.00    580.9
## 19      2.60    610.35
## 20      0.00    669.4
## 21      0.10    784.2
## 22      0.00    870.4
## 23      6.00   1005.4
## 24      0.00  1167.55
## 25      0.50  1227.55
## 26      1.10  1300.05
## 27      0.20   1720
```

Dataset observations Remich

```
# data_remich_bbch09 <- read.csv("~/Documents/02_working_post-doc/3-Production/02_projects/02_VinoManAO
# data_remich_bbch81 <- read.csv("~/Documents/02_working_post-doc/3-Production/02_projects/02_VinoManAO

# save(data_remich_bbch09, file="data_remich_bbch09.rda")
# save(data_remich_bbch81, file="data_remich_bbch81.rda")
```

Comparison bud break computation versus observations in Remich (Growth stage BBCH-09)

```
data("data_remich_bbch09")
data_remich_bbch09
```

##	Year	Elbling	Rivaner	Auxerrois	P.Blanc	P.Gris	Riesling	Gew.Tr.	Average
## 1	1972	123	124	124	123	123	125	123	123.6
## 2	1973	132	133	132	135	134	135	134	133.6
## 3	1974	103	104	104	104	104	105	104	104.0
## 4	1975	123	123	124	123	124	124	123	123.4
## 5	1976	120	122	122	122	122	123	120	121.6
## 6	1977	124	124	125	124	124	125	125	124.4
## 7	1978	105	107	107	107	106	108	104	106.3
## 8	1979	133	133	133	134	134	134	133	133.4
## 9	1980	124	126	126	127	126	127	127	126.1
## 10	1981	103	104	105	105	106	105	104	104.6
## 11	1982	126	129	129	128	128	129	127	128.0
## 12	1983	124	125	125	126	125	126	124	125.0
## 13	1984	124	126	125	126	126	126	125	125.4
## 14	1985	128	130	129	129	128	129	128	128.7
## 15	1986	130	131	131	131	131	131	130	130.7
## 16	1987	119	120	120	120	120	120	119	119.7
## 17	1988	117	119	118	119	118	119	117	118.1
## 18	1989	109	110	110	111	110	111	111	110.3
## 19	1990	114	117	117	116	117	117	116	116.3
## 20	1991	106	107	108	107	108	108	108	107.4
## 21	1992	118	119	119	119	119	120	118	118.9
## 22	1993	115	116	115	115	116	116	113	115.1
## 23	1994	117	118	118	118	118	119	117	117.9
## 24	1995	119	120	120	120	120	120	120	119.9
## 25	1996	118	119	119	118	118	119	119	118.6
## 26	1997	115	115	116	116	115	115	114	115.1
## 27	1998	119	120	120	119	119	120	119	119.4
## 28	1999	115	117	118	117	118	119	117	117.3
## 29	2000	117	117	117	117	117	115	116	116.6
## 30	2001	125	126	126	125	125	126	125	125.4
## 31	2002	112	113	113	113	113	113	112	112.7
## 32	2003	111	111	111	111	111	111	112	111.1
## 33	2004	116	116	116	115	114	114	112	114.7
## 34	2005	113	113	114	114	114	115	112	113.6
## 35	2006	122	122	123	121	124	125	122	122.7
## 36	2007	103	104	104	106	106	106	106	105.0
## 37	2008	122	122	122	124	124	125	124	123.3
## 38	2009	108	108	108	110	110	110	109	109.0
## 39	2010	117	117	117	119	119	119	119	118.1
## 40	2011	104	105	105	104	104	105	104	104.4
## 41	2012	117	117	117	118	118	119	118	117.7
## 42	2013	123	123	124	124	124	126	124	124.0
## 43	2014	101	102	102	103	103	104	102	102.4
## 44	2015	117	119	119	116	115	118	118	117.4
## 45	2016	NA	123	NA	NA	NA	NA	NA	123.0
## 46	2017	NA	109	NA	NA	NA	NA	NA	109.0

```
## 47 2018      NA    113      NA    NA    NA    NA    NA    113.0
## 48 2019      NA    111      NA    NA    NA    NA    NA    111.0
```

```
# Comparison of growth stage BBCH-09 for Mueller-Thurgau
bbch09.rivaner <- compare.stage(ref.data = data_remich_bbch09[,c("Year", "Rivaner")],
                               phen = phen.mthurgau.luht, growth.stage = 9)
```

```
bbch09.rivaner
```

##	Year	Growth_stage	Description	Month	Day
## 1	1972	9	Budburst: green shoot tips clearly visible	4	29
## 2	1973	9	Budburst: green shoot tips clearly visible	5	5
## 3	1974	9	Budburst: green shoot tips clearly visible	4	22
## 4	1975	9	Budburst: green shoot tips clearly visible	5	7
## 5	1976	9	Budburst: green shoot tips clearly visible	5	6
## 6	1977	9	Budburst: green shoot tips clearly visible	5	2
## 7	1978	9	Budburst: green shoot tips clearly visible	5	3
## 8	1979	9	Budburst: green shoot tips clearly visible	5	8
## 9	1980	9	Budburst: green shoot tips clearly visible	5	5
## 10	1981	9	Budburst: green shoot tips clearly visible	4	15
## 11	1982	9	Budburst: green shoot tips clearly visible	5	4
## 12	1983	9	Budburst: green shoot tips clearly visible	4	30
## 13	1984	9	Budburst: green shoot tips clearly visible	5	6
## 14	1985	9	Budburst: green shoot tips clearly visible	5	5
## 15	1986	9	Budburst: green shoot tips clearly visible	5	5
## 16	1987	9	Budburst: green shoot tips clearly visible	5	1
## 17	1988	9	Budburst: green shoot tips clearly visible	4	27
## 18	1989	9	Budburst: green shoot tips clearly visible	4	23
## 19	1990	9	Budburst: green shoot tips clearly visible	4	27
## 20	1991	9	Budburst: green shoot tips clearly visible	4	22
## 21	1992	9	Budburst: green shoot tips clearly visible	4	27
## 22	1993	9	Budburst: green shoot tips clearly visible	4	26
## 23	1994	9	Budburst: green shoot tips clearly visible	4	28
## 24	1995	9	Budburst: green shoot tips clearly visible	5	2
## 25	1996	9	Budburst: green shoot tips clearly visible	5	2
## 26	1997	9	Budburst: green shoot tips clearly visible	4	27
## 27	1998	9	Budburst: green shoot tips clearly visible	4	27
## 28	1999	9	Budburst: green shoot tips clearly visible	4	26
## 29	2000	9	Budburst: green shoot tips clearly visible	4	25
## 30	2001	9	Budburst: green shoot tips clearly visible	4	28
## 31	2002	9	Budburst: green shoot tips clearly visible	4	24
## 32	2003	9	Budburst: green shoot tips clearly visible	4	19
## 33	2004	9	Budburst: green shoot tips clearly visible	4	24
## 34	2005	9	Budburst: green shoot tips clearly visible	4	19
## 35	2006	9	Budburst: green shoot tips clearly visible	4	27
## 36	2007	9	Budburst: green shoot tips clearly visible	4	17
## 37	2008	9	Budburst: green shoot tips clearly visible	4	29
## 38	2009	9	Budburst: green shoot tips clearly visible	4	20
## 39	2010	9	Budburst: green shoot tips clearly visible	4	25
## 40	2011	9	Budburst: green shoot tips clearly visible	4	18
## 41	2012	9	Budburst: green shoot tips clearly visible	4	25
## 42	2013	9	Budburst: green shoot tips clearly visible	5	5
## 43	2014	9	Budburst: green shoot tips clearly visible	4	17
## 44	2015	9	Budburst: green shoot tips clearly visible	4	24
## 45	2016	9	Budburst: green shoot tips clearly visible	5	1

```
## 46 2017          9 Budburst: green shoot tips clearly visible      4 17
##   DayYear Rivaner Difference
## 1    120    124         4
## 2    125    133         8
## 3    112    104        -8
## 4    127    123        -4
## 5    127    122        -5
## 6    122    124         2
## 7    123    107       -16
## 8    128    133         5
## 9    126    126         0
## 10   105    104        -1
## 11   124    129         5
## 12   120    125         5
## 13   127    126        -1
## 14   125    130         5
## 15   125    131         6
## 16   121    120        -1
## 17   118    119         1
## 18   113    110        -3
## 19   117    117         0
## 20   112    107        -5
## 21   118    119         1
## 22   116    116         0
## 23   118    118         0
## 24   122    120        -2
## 25   123    119        -4
## 26   117    115        -2
## 27   117    120         3
## 28   116    117         1
## 29   116    117         1
## 30   118    126         8
## 31   114    113        -1
## 32   109    111         2
## 33   115    116         1
## 34   109    113         4
## 35   117    122         5
## 36   107    104        -3
## 37   120    122         2
## 38   110    108        -2
## 39   115    117         2
## 40   108    105        -3
## 41   116    117         1
## 42   125    123        -2
## 43   107    102        -5
## 44   114    119         5
## 45   122    123         1
## 46   107    109         2
```

```
rivaner.09.n <- length(which(is.na(bbch09.rivaner$Difference) == FALSE))
rivaner.09.mean <- mean(bbch09.rivaner$Difference, na.rm = TRUE)
print(paste0("Mean BBCH-09 (Rivaner): ",
             round(rivaner.09.mean, 2), " days (sample: ", rivaner.09.n, " years)"))
```

```
## [1] "Mean BBCH-09 (Rivaner): 0.26 days (sample: 46 years)"
```

```
# Comparison of growth stage BBCH-09 for Riesling
bbch09.riesling <- compare.stage(ref.data = data_remich_bbch09[,c("Year", "Riesling")],
                                phen = phen.riesling.luht, growth.stage = 9)
bbch09.riesling
```

##	Year	Growth_stage	Description	Month	Day
## 1	1972	9	Budburst: green shoot tips clearly visible	5	1
## 2	1973	9	Budburst: green shoot tips clearly visible	5	8
## 3	1974	9	Budburst: green shoot tips clearly visible	4	24
## 4	1975	9	Budburst: green shoot tips clearly visible	5	9
## 5	1976	9	Budburst: green shoot tips clearly visible	5	7
## 6	1977	9	Budburst: green shoot tips clearly visible	5	4
## 7	1978	9	Budburst: green shoot tips clearly visible	5	5
## 8	1979	9	Budburst: green shoot tips clearly visible	5	10
## 9	1980	9	Budburst: green shoot tips clearly visible	5	7
## 10	1981	9	Budburst: green shoot tips clearly visible	4	17
## 11	1982	9	Budburst: green shoot tips clearly visible	5	6
## 12	1983	9	Budburst: green shoot tips clearly visible	5	2
## 13	1984	9	Budburst: green shoot tips clearly visible	5	9
## 14	1985	9	Budburst: green shoot tips clearly visible	5	7
## 15	1986	9	Budburst: green shoot tips clearly visible	5	7
## 16	1987	9	Budburst: green shoot tips clearly visible	5	3
## 17	1988	9	Budburst: green shoot tips clearly visible	4	30
## 18	1989	9	Budburst: green shoot tips clearly visible	4	26
## 19	1990	9	Budburst: green shoot tips clearly visible	4	30
## 20	1991	9	Budburst: green shoot tips clearly visible	4	26
## 21	1992	9	Budburst: green shoot tips clearly visible	4	30
## 22	1993	9	Budburst: green shoot tips clearly visible	4	27
## 23	1994	9	Budburst: green shoot tips clearly visible	4	29
## 24	1995	9	Budburst: green shoot tips clearly visible	5	3
## 25	1996	9	Budburst: green shoot tips clearly visible	5	5
## 26	1997	9	Budburst: green shoot tips clearly visible	4	29
## 27	1998	9	Budburst: green shoot tips clearly visible	4	30
## 28	1999	9	Budburst: green shoot tips clearly visible	4	27
## 29	2000	9	Budburst: green shoot tips clearly visible	4	27
## 30	2001	9	Budburst: green shoot tips clearly visible	4	30
## 31	2002	9	Budburst: green shoot tips clearly visible	4	26
## 32	2003	9	Budburst: green shoot tips clearly visible	4	21
## 33	2004	9	Budburst: green shoot tips clearly visible	4	26
## 34	2005	9	Budburst: green shoot tips clearly visible	4	22
## 35	2006	9	Budburst: green shoot tips clearly visible	4	29
## 36	2007	9	Budburst: green shoot tips clearly visible	4	19
## 37	2008	9	Budburst: green shoot tips clearly visible	5	2
## 38	2009	9	Budburst: green shoot tips clearly visible	4	21
## 39	2010	9	Budburst: green shoot tips clearly visible	4	27
## 40	2011	9	Budburst: green shoot tips clearly visible	4	20
## 41	2012	9	Budburst: green shoot tips clearly visible	4	27
## 42	2013	9	Budburst: green shoot tips clearly visible	5	6
## 43	2014	9	Budburst: green shoot tips clearly visible	4	19
## 44	2015	9	Budburst: green shoot tips clearly visible	4	26
## 45	2016	9	Budburst: green shoot tips clearly visible	5	3
## 46	2017	9	Budburst: green shoot tips clearly visible	4	21
##	DayYear	Riesling	Difference		
## 1	122	125	3		

```
## 2      128      135      7
## 3      114      105     -9
## 4      129      124     -5
## 5      128      123     -5
## 6      124      125      1
## 7      125      108    -17
## 8      130      134      4
## 9      128      127     -1
## 10     107      105     -2
## 11     126      129      3
## 12     122      126      4
## 13     130      126     -4
## 14     127      129      2
## 15     127      131      4
## 16     123      120     -3
## 17     121      119     -2
## 18     116      111     -5
## 19     120      117     -3
## 20     116      108     -8
## 21     121      120     -1
## 22     117      116     -1
## 23     119      119      0
## 24     123      120     -3
## 25     126      119     -7
## 26     119      115     -4
## 27     120      120      0
## 28     117      119      2
## 29     118      115     -3
## 30     120      126      6
## 31     116      113     -3
## 32     111      111      0
## 33     117      114     -3
## 34     112      115      3
## 35     119      125      6
## 36     109      106     -3
## 37     123      125      2
## 38     111      110     -1
## 39     117      119      2
## 40     110      105     -5
## 41     118      119      1
## 42     126      126      0
## 43     109      104     -5
## 44     116      118      2
## 45     124      NA      NA
## 46     111      NA      NA
```

```
riesling.09.n    <- length(which(is.na(bbch09.riesling$Difference) == FALSE))
riesling.09.mean <- mean(bbch09.riesling$Difference, na.rm = TRUE)
print(paste0("Mean BBCH-09 (Riesling): ",
             round(riesling.09.mean, 2), " days (sample: ", riesling.09.n, " years)"))
```

```
## [1] "Mean BBCH-09 (Riesling): -1.16 days (sample: 44 years)"
```

Comparison bud break computation versus observations in Remich (Growth stage BBCH-81)

```
data("data_remich_bbch81")
data_remich_bbch81
```

##	Year	Elbling	Rivaner	Auxerrois	P.Blanc	P.Gris	Riesling	Gew.Tr.	Average
## 1	1972	268	240	244	249	248	266	249	252.0
## 2	1973	247	236	237	246	239	242	236	240.4
## 3	1974	254	234	246	249	237	252	249	245.9
## 4	1975	242	228	232	242	232	241	236	236.1
## 5	1976	233	224	227	232	230	232	228	229.4
## 6	1977	NA	NA	NA	NA	NA	NA	NA	NA
## 7	1978	NA	246	NA	NA	NA	NA	NA	246.0
## 8	1979	NA	NA	NA	NA	NA	NA	NA	NA
## 9	1980	NA	253	NA	NA	NA	NA	NA	253.0
## 10	1981	NA	229	NA	NA	NA	NA	NA	229.0
## 11	1982	NA	226	NA	NA	NA	NA	NA	226.0
## 12	1983	NA	233	NA	NA	NA	NA	NA	233.0
## 13	1984	NA	258	NA	NA	NA	NA	NA	258.0
## 14	1985	NA	238	NA	NA	NA	NA	NA	238.0
## 15	1986	NA	235	NA	NA	NA	NA	NA	235.0
## 16	1987	NA	245	NA	NA	NA	NA	NA	245.0
## 17	1988	NA	230	NA	NA	NA	NA	NA	230.0
## 18	1989	NA	224	NA	NA	NA	NA	NA	224.0
## 19	1990	NA	231	NA	NA	NA	NA	NA	231.0
## 20	1991	NA	236	NA	NA	NA	NA	NA	236.0
## 21	1992	NA	224	NA	NA	NA	NA	NA	224.0
## 22	1993	NA	224	NA	NA	NA	NA	NA	224.0
## 23	1994	NA	227	NA	NA	NA	NA	NA	227.0
## 24	1995	NA	230	NA	NA	NA	NA	NA	230.0
## 25	1996	NA	236	NA	NA	NA	NA	NA	236.0
## 26	1997	NA	230	NA	NA	NA	NA	NA	230.0
## 27	1998	NA	232	NA	NA	NA	NA	NA	232.0
## 28	1999	NA	230	NA	NA	NA	NA	NA	230.0
## 29	2000	NA	228	NA	NA	NA	NA	NA	228.0
## 30	2001	NA	229	NA	NA	NA	NA	NA	229.0
## 31	2002	NA	227	NA	NA	NA	NA	NA	227.0
## 32	2003	NA	217	NA	NA	NA	NA	NA	217.0
## 33	2004	NA	235	NA	NA	NA	NA	NA	235.0
## 34	2005	NA	225	NA	NA	NA	NA	NA	225.0
## 35	2006	NA	226	NA	NA	NA	NA	NA	226.0
## 36	2007	NA	214	NA	NA	NA	NA	NA	214.0
## 37	2008	NA	224	NA	NA	NA	NA	NA	224.0
## 38	2009	NA	220	NA	NA	NA	NA	NA	220.0
## 39	2010	NA	226	NA	NA	NA	NA	NA	226.0
## 40	2011	NA	210	NA	NA	NA	NA	NA	210.0
## 41	2012	NA	228	NA	NA	NA	NA	NA	228.0
## 42	2013	NA	233	NA	NA	NA	NA	NA	233.0
## 43	2014	222	219	221	223	224	228	223	222.9
## 44	2015	229	218	224	227	224	235	223	225.7

```
# Comparison of growth stage BBCH-81 for Mueller-Thurgau
bbch81.rivaner <- compare.stage(ref.data = data_remich_bbch81[,c("Year", "Rivaner")],
```



```
phen = phen.mthurgau.luht, growth.stage = 81)
```

```
bbch81.rivaner
```

```
##      Year Growth_stage
## 1  1972           81
## 2  1973           81
## 3  1974           81
## 4  1975           81
## 5  1976           81
## 6  1977           81
## 7  1978           81
## 8  1979           81
## 9  1980           81
## 10 1981           81
## 11 1982           81
## 12 1983           81
## 13 1984           81
## 14 1985           81
## 15 1986           81
## 16 1987           81
## 17 1988           81
## 18 1989           81
## 19 1990           81
## 20 1991           81
## 21 1992           81
## 22 1993           81
## 23 1994           81
## 24 1995           81
## 25 1996           81
## 26 1997           81
## 27 1998           81
## 28 1999           81
## 29 2000           81
## 30 2001           81
## 31 2002           81
## 32 2003           81
## 33 2004           81
## 34 2005           81
## 35 2006           81
## 36 2007           81
## 37 2008           81
## 38 2009           81
## 39 2010           81
## 40 2011           81
## 41 2012           81
## 42 2013           81
## 43 2014           81
## 44 2015           81
```

```
##                                     Description Month Day
## 1 Beginning of ripening: berries begin to brighten in color      8 26
## 2 Beginning of ripening: berries begin to brighten in color      8 15
## 3 Beginning of ripening: berries begin to brighten in color      8 21
## 4 Beginning of ripening: berries begin to brighten in color      8 15
```

## 5	Beginning of ripening: berries begin to brighten in color	8	10
## 6	Beginning of ripening: berries begin to brighten in color	8	19
## 7	Beginning of ripening: berries begin to brighten in color	8	30
## 8	Beginning of ripening: berries begin to brighten in color	8	21
## 9	Beginning of ripening: berries begin to brighten in color	8	30
## 10	Beginning of ripening: berries begin to brighten in color	8	15
## 11	Beginning of ripening: berries begin to brighten in color	8	10
## 12	Beginning of ripening: berries begin to brighten in color	8	16
## 13	Beginning of ripening: berries begin to brighten in color	8	30
## 14	Beginning of ripening: berries begin to brighten in color	8	19
## 15	Beginning of ripening: berries begin to brighten in color	8	13
## 16	Beginning of ripening: berries begin to brighten in color	8	28
## 17	Beginning of ripening: berries begin to brighten in color	8	10
## 18	Beginning of ripening: berries begin to brighten in color	8	7
## 19	Beginning of ripening: berries begin to brighten in color	8	11
## 20	Beginning of ripening: berries begin to brighten in color	8	17
## 21	Beginning of ripening: berries begin to brighten in color	8	3
## 22	Beginning of ripening: berries begin to brighten in color	8	6
## 23	Beginning of ripening: berries begin to brighten in color	8	6
## 24	Beginning of ripening: berries begin to brighten in color	8	12
## 25	Beginning of ripening: berries begin to brighten in color	8	18
## 26	Beginning of ripening: berries begin to brighten in color	8	10
## 27	Beginning of ripening: berries begin to brighten in color	8	9
## 28	Beginning of ripening: berries begin to brighten in color	8	4
## 29	Beginning of ripening: berries begin to brighten in color	8	5
## 30	Beginning of ripening: berries begin to brighten in color	8	5
## 31	Beginning of ripening: berries begin to brighten in color	8	5
## 32	Beginning of ripening: berries begin to brighten in color	7	21
## 33	Beginning of ripening: berries begin to brighten in color	8	5
## 34	Beginning of ripening: berries begin to brighten in color	7	31
## 35	Beginning of ripening: berries begin to brighten in color	7	31
## 36	Beginning of ripening: berries begin to brighten in color	7	23
## 37	Beginning of ripening: berries begin to brighten in color	7	31
## 38	Beginning of ripening: berries begin to brighten in color	8	3
## 39	Beginning of ripening: berries begin to brighten in color	8	5
## 40	Beginning of ripening: berries begin to brighten in color	7	31
## 41	Beginning of ripening: berries begin to brighten in color	8	9
## 42	Beginning of ripening: berries begin to brighten in color	8	18
## 43	Beginning of ripening: berries begin to brighten in color	7	30
## 44	Beginning of ripening: berries begin to brighten in color	8	5
##	DayYear Rivaner Difference		
## 1	239 240	1	
## 2	227 236	9	
## 3	233 234	1	
## 4	227 228	1	
## 5	223 224	1	
## 6	231 NA	NA	
## 7	242 246	4	
## 8	233 NA	NA	
## 9	243 253	10	
## 10	227 229	2	
## 11	222 226	4	
## 12	228 233	5	
## 13	243 258	15	

```
## 14      231      238          7
## 15      225      235         10
## 16      240      245          5
## 17      223      230          7
## 18      219      224          5
## 19      223      231          8
## 20      229      236          7
## 21      216      224          8
## 22      218      224          6
## 23      218      227          9
## 24      224      230          6
## 25      231      236          5
## 26      222      230          8
## 27      221      232         11
## 28      216      230         14
## 29      218      228         10
## 30      217      229         12
## 31      217      227         10
## 32      202      217         15
## 33      218      235         17
## 34      212      225         13
## 35      212      226         14
## 36      204      214         10
## 37      213      224         11
## 38      215      220          5
## 39      217      226          9
## 40      212      210         -2
## 41      222      228          6
## 42      230      233          3
## 43      211      219          8
## 44      217      218          1
```

```
rivaner.81.n    <- length(which(is.na(bbch81.rivaner$Difference) == FALSE))
rivaner.81.mean <- mean(bbch81.rivaner$Difference, na.rm = TRUE)
print(paste0("Mean BBCH-81 (Rivaner): ",
             round(rivaner.81.mean, 2), " days (sample: ", rivaner.81.n, " years)"))
```

```
## [1] "Mean BBCH-81 (Rivaner): 7.4 days (sample: 42 years)"
```

```
# Comparison of growth stage BBCH-09 for Riesling
bbch81.riesling <- compare.stage(ref.data = data_remich_bbch81[,c("Year", "Riesling")],
                                phen = phen.riesling.luht, growth.stage = 81)
bbch81.riesling
```

```
##      Year Growth_stage
## 1  1972             81
## 2  1973             81
## 3  1974             81
## 4  1975             81
## 5  1976             81
## 6  1977             81
## 7  1978             81
## 8  1979             81
## 9  1980             81
## 10 1981             81
```

## 11 1982	81
## 12 1983	81
## 13 1984	81
## 14 1985	81
## 15 1986	81
## 16 1987	81
## 17 1988	81
## 18 1989	81
## 19 1990	81
## 20 1991	81
## 21 1992	81
## 22 1993	81
## 23 1994	81
## 24 1995	81
## 25 1996	81
## 26 1997	81
## 27 1998	81
## 28 1999	81
## 29 2000	81
## 30 2001	81
## 31 2002	81
## 32 2003	81
## 33 2004	81
## 34 2005	81
## 35 2006	81
## 36 2007	81
## 37 2008	81
## 38 2009	81
## 39 2010	81
## 40 2011	81
## 41 2012	81
## 42 2013	81
## 43 2014	81
## 44 2015	81

##	Description	Month	Day
## 1	Beginning of ripening: berries begin to brighten in color	8	28
## 2	Beginning of ripening: berries begin to brighten in color	8	16
## 3	Beginning of ripening: berries begin to brighten in color	8	22
## 4	Beginning of ripening: berries begin to brighten in color	8	16
## 5	Beginning of ripening: berries begin to brighten in color	8	11
## 6	Beginning of ripening: berries begin to brighten in color	8	21
## 7	Beginning of ripening: berries begin to brighten in color	9	1
## 8	Beginning of ripening: berries begin to brighten in color	8	22
## 9	Beginning of ripening: berries begin to brighten in color	8	31
## 10	Beginning of ripening: berries begin to brighten in color	8	16
## 11	Beginning of ripening: berries begin to brighten in color	8	11
## 12	Beginning of ripening: berries begin to brighten in color	8	17
## 13	Beginning of ripening: berries begin to brighten in color	8	30
## 14	Beginning of ripening: berries begin to brighten in color	8	20
## 15	Beginning of ripening: berries begin to brighten in color	8	15
## 16	Beginning of ripening: berries begin to brighten in color	8	29
## 17	Beginning of ripening: berries begin to brighten in color	8	11
## 18	Beginning of ripening: berries begin to brighten in color	8	8
## 19	Beginning of ripening: berries begin to brighten in color	8	12

## 20	Beginning of ripening: berries begin to brighten in color	8	18
## 21	Beginning of ripening: berries begin to brighten in color	8	4
## 22	Beginning of ripening: berries begin to brighten in color	8	7
## 23	Beginning of ripening: berries begin to brighten in color	8	7
## 24	Beginning of ripening: berries begin to brighten in color	8	12
## 25	Beginning of ripening: berries begin to brighten in color	8	19
## 26	Beginning of ripening: berries begin to brighten in color	8	11
## 27	Beginning of ripening: berries begin to brighten in color	8	10
## 28	Beginning of ripening: berries begin to brighten in color	8	5
## 29	Beginning of ripening: berries begin to brighten in color	8	7
## 30	Beginning of ripening: berries begin to brighten in color	8	7
## 31	Beginning of ripening: berries begin to brighten in color	8	6
## 32	Beginning of ripening: berries begin to brighten in color	7	22
## 33	Beginning of ripening: berries begin to brighten in color	8	6
## 34	Beginning of ripening: berries begin to brighten in color	8	1
## 35	Beginning of ripening: berries begin to brighten in color	8	1
## 36	Beginning of ripening: berries begin to brighten in color	7	24
## 37	Beginning of ripening: berries begin to brighten in color	8	1
## 38	Beginning of ripening: berries begin to brighten in color	8	3
## 39	Beginning of ripening: berries begin to brighten in color	8	7
## 40	Beginning of ripening: berries begin to brighten in color	8	2
## 41	Beginning of ripening: berries begin to brighten in color	8	9
## 42	Beginning of ripening: berries begin to brighten in color	8	19
## 43	Beginning of ripening: berries begin to brighten in color	7	30
## 44	Beginning of ripening: berries begin to brighten in color	8	6
##	DayYear Riesling Difference		
## 1	241 266 25		
## 2	228 242 14		
## 3	234 252 18		
## 4	228 241 13		
## 5	224 232 8		
## 6	233 NA NA		
## 7	244 NA NA		
## 8	234 NA NA		
## 9	244 NA NA		
## 10	228 NA NA		
## 11	223 NA NA		
## 12	229 NA NA		
## 13	243 NA NA		
## 14	232 NA NA		
## 15	227 NA NA		
## 16	241 NA NA		
## 17	224 NA NA		
## 18	220 NA NA		
## 19	224 NA NA		
## 20	230 NA NA		
## 21	217 NA NA		
## 22	219 NA NA		
## 23	219 NA NA		
## 24	224 NA NA		
## 25	232 NA NA		
## 26	223 NA NA		
## 27	222 NA NA		
## 28	217 NA NA		

```
## 29      220      NA      NA
## 30      219      NA      NA
## 31      218      NA      NA
## 32      203      NA      NA
## 33      219      NA      NA
## 34      213      NA      NA
## 35      213      NA      NA
## 36      205      NA      NA
## 37      214      NA      NA
## 38      215      NA      NA
## 39      219      NA      NA
## 40      214      NA      NA
## 41      222      NA      NA
## 42      231      NA      NA
## 43      211      228      17
## 44      218      235      17
```

```
riesling.81.n    <- length(which(is.na(bbch81.riesling$Difference) == FALSE))
riesling.81.mean <- mean(bbch81.riesling$Difference, na.rm = TRUE)
print(paste0("Mean BBCH-81 (Riesling): ",
             round(riesling.81.mean, 2), " days (sample: ", riesling.81.n, " years)"))
```

```
## [1] "Mean BBCH-81 (Riesling): 16 days (sample: 7 years)"
```

Timing

```
timing.end <- Sys.time()
(timing.elapsed <- timing.end - timing.ini)
```

```
## Time difference of 5.294792 secs
```