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Description Predicts the occurrence times (in day of year) of spring phenological events. Three methods, including the accumulated degree days (ADD) method, the accumulated days transferred to a standardized temperature (ADTS) method, and the accumulated developmental progress (ADP) method, were used. See Shi et al. (2017a) <[doi:10.1016/j.agrformet.2017.04.001](https://doi.org/10.1016/j.agrformet.2017.04.001)> and Shi et al. (2017b) <[doi:10.1093/aesa/sax063](https://doi.org/10.1093/aesa/sax063)> for details.

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ADD

*Function for Implementing the Accumulated Degree Days Method***Description**

Estimates the starting date (S in day of year) and base temperature (T_0 in $^{\circ}\text{C}$) in the accumulated degree days method using mean daily air temperatures (Aono, 1993; Shi et al., 2017a, 2017b).

Usage

```
ADD(S.pd = NULL, T0.arr, Year1, Time, Year2, DOY, Temp, DOY.ul = 120,
    fig.opt = TRUE, S.def = 54, verbose = TRUE)
```

Arguments

S.pd	the pre-determined starting date for thermal accumulation (in day of year)
T0.arr	the candidate base temperatures (in $^{\circ}\text{C}$)
Year1	the vector of the years recording a particular phenological event
Time	the vector of the occurrence times (in day of year) of a particular phenological event across many years
Year2	the vector of the years recording the climate data corresponding to the occurrence times
DOY	the vector of the dates (in day of year) when the climate data exist
Temp	the mean daily air temperature data (in $^{\circ}\text{C}$) corresponding to DOY
DOY.ul	the upper limit of DOY used to predict the occurrence time
fig.opt	an optional argument of drawing the figures associated with the determinations of the starting date and base temperature, and a comparison between the predicted and observed occurrence times
S.def	a mandatory definition of the starting date when (i) S.pd is NULL and (ii) the minimum correlation coefficient method fails to find a suitable starting date
verbose	an optional argument of allowing users to suppress printing of computation progress

Details

The default of S.pd is NULL. In this case, the date associated with the minimum correlation coefficient [between the mean of the mean daily temperatures (from a candidate starting date to the observed occurrence time) and the observed occurrence time] will be determined to be the starting date on the condition that it is smaller than the minimum phenological occurrence time. If the determined date associated with the minimum correlation coefficient is greater than the minimum phenological occurrence time, S.def will be used as the starting date. If S.pd is not NULL, the starting date will be directly assigned as S.pd irrespective of the minimum correlation coefficient

method and the value of `S.def`. This means, `S.pd` is superior to `S.def` in determining the starting date.

The function does not require that `Year1` is the same as the unique of `Year2`, and the intersection of two years will be finally kept. The unused years that have phenological records but lack the climate data will be showed in `unused.years` in the returned list.

The numerical value of `DOY.ul` should be larger than or equal to the maximum `Time`.

Value

<code>S.arr</code>	the candidate starting dates (in day of year), whose default ranges from the minimum DOY to $\min(\text{DOY.ul}, \text{the maximum DOY})$
<code>cor.coef.arr</code>	the candidate correlation coefficients between the mean of the mean daily temperatures (from a candidate starting date to the observed occurrence time) and the observed occurrence time
<code>cor.coef</code>	the minimum correlation coefficient, i.e., $\min(\text{cor.coef.arr})$
<code>search.failure</code>	a value of 0 or 1 of showing whether the starting date is successfully determined by the minimum correlation coefficient method when <code>S.pd = NULL</code> , where 0 represents success and 1 represents failure
<code>mAADD.arr</code>	an vector saving the interannual mean of the annual accumulated degree days (AADD) values for each of the candidate base temperatures
<code>RMSE.arr</code>	a vector saving the candidate root-mean-square errors (in days) between the observed and predicted occurrence times for each of the candidate base temperatures
<code>AADD.arr</code>	the annual accumulated degree days (AADD) values in different years
<code>Year</code>	The intersected years between <code>Year1</code> and <code>Year2</code>
<code>Time</code>	The observed occurrence times (day of year) in the intersected years between <code>Year1</code> and <code>Year2</code>
<code>Time.pred</code>	the predicted occurrence times in different years
<code>S</code>	the determined starting date (day of year)
<code>T0</code>	the determined base temperature (in °C)
<code>AADD</code>	the expected annual accumulated degree days
<code>RMSE</code>	the smallest RMSE (in days) from the different candidate base temperatures
<code>unused.years</code>	the years that have phenological records but lack the climate data

Note

The entire mean daily temperature data in the spring of each year should be provided. `AADD` is represented by the mean of `AADD.arr` in the output. When the argument of `S.pd` is not `NULL`, the returned value of `search.failure` will be `NA`. When the argument of `S.pd` is `NULL`, and the minimum correlation coefficient method fails to find a suitable starting date, the argument of `S.def` is then defined as the determined starting date, i.e., the returned value of `S`. At the same time, the returned value of `cor.coef` is defined as `NA`.

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References

Aono, Y. (1993) Climatological studies on blooming of cherry tree (*Prunus yedoensis*) by means of DTS method. *Bulletin of the University of Osaka Prefecture. Ser. B, Agriculture and life sciences* 45, 155–192 (in Japanese with English abstract).

Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001

Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

See Also

[predADD](#)

Examples

```
data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT

Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
Temp.val <- X2$MDT
DOY.ul.val <- 120
T0.arr0 <- seq(-5, 5, by = 0.1)
S.pd0 <- NULL

res1 <- ADD( S.pd = S.pd0, T0.arr = T0.arr0, Year1 = Year1.val, Time = Time.val,
            Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val,
            DOY.ul = DOY.ul.val, fig.opt = TRUE, S.def=54, verbose = TRUE )

res1

S0 <- res1$S.arr
r0 <- res1$cor.coef.arr

dev.new()
par1 <- par(family="serif")
par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
plot( S0, r0, cex.lab = 1.5, cex.axis = 1.5, xlab = "Candidate starting date (day of year)",
      ylab="Correlation coefficient between the mean temperature and FFD", type="l" )
```

```

ind <- which.min(r0)
points(S0[ind], r0[ind], cex = 1.5, pch = 16)
text(S0[ind], r0[ind] + 0.1, bquote(paste(italic(S), " = ", .(S0[ind]), sep = "")), cex = 1.5)
par(par1)
par(par2)
par(par3)

resu1 <- ADD( S.pd = 47, T0.arr = seq(-10, 0, by = 0.1), Year1 = Year1.val, Time = Time.val,
             Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val,
             DOY.ul = DOY.ul.val, fig.opt = TRUE, S.def = 54, verbose = TRUE )

resu1

# graphics.off()

```

ADP

Function for Implementing the Accumulated Developmental Progress Method

Description

Estimates the starting date (S in day of year) and the parameters in a developmental rate model in the accumulated developmental progress (ADP) method using mean daily air temperatures (Wagner et al., 1984; Shi et al., 2017a, 2017b).

Usage

```
ADP( S.arr, expr, ini.val, Year1, Time, Year2, DOY, Temp, DOY.ul = 120,
     fig.opt = TRUE, control = list(), verbose = TRUE )
```

Arguments

<code>S.arr</code>	the candidate starting dates for thermal accumulation (in day of year)
<code>expr</code>	a user-defined model that is used in the accumulated developmental progress (ADP) method
<code>ini.val</code>	a vector or a list that saves the initial values of the parameters in <code>expr</code>
<code>Year1</code>	the vector of the years recording a particular phenological event
<code>Time</code>	the vector of the occurrence times (in day of year) of a particular phenological event across many years
<code>Year2</code>	the vector of the years recording the climate data corresponding to the occurrence times
<code>DOY</code>	the vector of the dates (in day of year) when the climate data exist
<code>Temp</code>	the mean daily air temperature data (in °C) corresponding to <code>DOY</code>
<code>DOY.ul</code>	the upper limit of <code>DOY</code> used to predict the occurrence time

fig.opt	an optional argument of drawing the figures associated with the temperature-dependent developmental rate curve, the mean daily temperatures versus years, and a comparison between the predicted and observed occurrence times
control	the list of control parameters for using the <code>optim</code> function in package stats
verbose	an optional argument of allowing users to suppress printing of computation progress

Details

It is better not to set too much candidate starting dates, which will be time-consuming. If `expr` is selected as Arrhenius' equation, `S.arr` can be selected as `S` obtained from the output of carrying out the `ADTS` function. Here, `expr` can be other nonlinear temperature-dependent developmental rate functions (see Shi et al. [2017b] for details). Here, `expr` can be any an arbitrary user-defined temperature-dependent developmental rate function, e.g., a function named `myfun`, but it needs to take the following form of `myfun <- function(P, x){...}`, where `P` is the vector of the model parameter(s), and `x` is the vector of the predictor variable, i.e., the temperature variable.

The function does not require that `Year1` is the same as the unique of `Year2`, and the intersection of two years will be finally kept. The unused years that have phenological records but lack the climate data will be showed in `unused.years` in the returned list.

The numerical value of `DOY.ul` should be larger than or equal to the maximum `Time`.

Let r represent the temperature-dependent developmental rate, i.e., the reciprocal of the developmental duration at a constant temperature required for completing a particular phenological event. In the accumulated developmental progress (ADP) method, when the annual accumulated developmental progress (AADP) reaches 100%, the phenological event is predicted to occur for each year. Let $AADP_i$ denote the AADP of the i th year, which equals

$$AADP_i = \sum_{j=S}^{E_i} r_{ij}(\mathbf{P}; T_{ij}),$$

where S represents the starting date (in day of year), E_i represents the ending date (in day of year), i.e., the occurrence time of a particular phenological event in the i th year, \mathbf{P} is the vector of the model parameters in `expr`, and T_{ij} represents the mean daily temperature of the j th day of the i th year (in °C or K). In theory, $AADP_i = 100\%$, i.e., the AADP values of different years are a constant of 100%. However, in practice, there is a certain deviation of $AADP_i$ from 100%. The following approach is used to determine the predicted occurrence time. When $\sum_{j=S}^F r_{ij} = 100\%$ (where $F \geq S$), it follows that F is the predicted occurrence time; when $\sum_{j=S}^F r_{ij} < 100\%$ and $\sum_{j=S}^{F+1} r_{ij} > 100\%$, the trapezoid method (Ring and Harris, 1983) is used to determine the predicted occurrence time. Assume that there are n -year phenological records. When the starting date S and the temperature-dependent developmental rate model are known, the model parameters can be estimated using the Nelder-Mead optimization method (Nelder and Mead, 1965) to minimize the root-mean-square error (RMSE) between the observed and predicted occurrence times, i.e.,

$$\hat{\mathbf{P}} = \arg \min_{\mathbf{P}} \{\text{RMSE}\} = \arg \min_{\mathbf{P}} \sqrt{\frac{\sum_{i=1}^n (E_i - \hat{E}_i)^2}{n}}.$$

Because S is not determined, a group of candidate S values (in day of year) need to be provided. Assume that there are m candidate S values, i.e., $S_1, S_2, S_3, \dots, S_m$. For each S_q (where q ranges between 1 and m), we can obtain a vector of the estimated model parameters, $\hat{\mathbf{P}}_q$, by minimizing RMSE_q using the Nelder-Mead optimization method. Then we finally selected $\hat{\mathbf{P}}$ associated with $\min \{\text{RMSE}_1, \text{RMSE}_2, \text{RMSE}_3, \dots, \text{RMSE}_m\}$ as the target parameter vector.

Value

TDDR	the temperature-dependent developmental rate matrix consisting of the year, day of year, mean daily temperature and developmental rate columns
MAT	a matrix consisting of the candidate starting dates, the estimates of candidate model parameters with the corresponding RMSEs
Dev.accum	the calculated annual accumulated developmental progresses in different years
Year	The intersected years between Year1 and Year2
Time	The observed occurrence times (day of year) in the intersected years between Year1 and Year2
Time.pred	the predicted occurrence times in different years
S	the determined starting date (day of year)
par	the estimates of model parameters
RMSE	the RMSE (in days) between the observed and predicted occurrence times
unused.years	the years that have phenological records but lack the climate data

Note

The entire mean daily temperature data in the spring of each year should be provided. In TDDR, the first column of Year saves the years, the second column of DOY saves the day of year values, the third column of Temperature saves the mean daily air temperatures between the starting date to the occurrence times, and the fourth column of Rate saves the calculated developmental rates corresponding to the mean daily temperatures.

Author(s)

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References

- Nelder, J.A., Mead, R. (1965) A simplex method for function minimization. *Computer Journal* 7, 308–313. doi:10.1093/comjnl/7.4.308
- Ring, D.R., Harris, M.K. (1983) Predicting pecan nut casebearer (Lepidoptera: Pyralidae) activity at College Station, Texas. *Environmental Entomology* 12, 482–486. doi:10.1093/ee/12.2.482
- Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001
- Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

Wagner, T.L., Wu, H.-I., Sharpe, P.J.H., Shcoolfield, R.M., Coulson, R.N. (1984) Modelling insect development rates: a literature review and application of a biophysical model. *Annals of the Entomological Society of America* 77, 208–225. doi:10.1093/aesa/77.2.208

See Also

[predADP](#)

Examples

```

data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT

Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
Temp.val <- X2$MDT
DOY.ul.val <- 120
S.arr0 <- 47

#### Defines a re-parameterized Arrhenius' equation #####
Arrhenius.eqn <- function(P, x){
  B <- P[1]
  Ea <- P[2]
  R <- 1.987 * 10^(-3)
  x <- x + 273.15
  10^12*exp(B-Ea/(R*x))
}
#####

#### Provides the initial values of the parameter of Arrhenius' equation ####
ini.val0 <- list( B = 20, Ea = 14 )
#####

res5 <- ADP( S.arr = S.arr0, expr = Arrhenius.eqn, ini.val = ini.val0, Year1 = Year1.val,
            Time = Time.val, Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val,
            DOY.ul = DOY.ul.val, fig.opt = TRUE, control = list(trace = FALSE,
            reltol = 1e-12, maxit = 5000), verbose = TRUE )

res5

TDDR <- res5$TDDR
T <- TDDR$Temperature
r <- TDDR$Rate
Y <- res5$Year
DP <- res5$Dev.accum

dev.new()
par1 <- par(family="serif")

```



```

par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
Ind <- sort(T, index.return=TRUE)$ix
T1 <- T[Ind]
r1 <- r[Ind]
plot( T1, r1, cex.lab = 1.5, cex.axis = 1.5, pch = 1, cex = 1.5, col = 2, type = "l",
      xlab = expression(paste("Mean daily temperature (", degree, "C)", sep = "")),
      ylab = expression(paste("Calculated developmental rate (", {day}^{-1}), ")", sep = "")) )
par(par1)
par(par2)
par(par3)

dev.new()
par1 <- par(family="serif")
par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
plot( Y, DP * 100, xlab = "Year",
      ylab = "Accumulated developmental progress (%)",
      ylim = c(50, 150), cex.lab=1.5, cex.axis = 1.5, cex = 1.5 )
abline( h = 1 * 100, lwd = 1, col = 4, lty = 2 )
par(par1)
par(par2)
par(par3)

# graphics.off()

```

ADTS

Function for Implementing the Accumulated Days Transferred to a Standardized Temperature Method

Description

Estimates the starting date (S in day of year) and activation free energy (E_a in $\text{kcal} \cdot \text{mol}^{-1}$) in the accumulated days transferred to a standardized temperature (ADTS) method using mean daily air temperatures (Konno and Sugihara, 1986; Aono, 1993; Shi et al., 2017a, 2017b).

Usage

```
ADTS( S.arr, Ea.arr, Year1, Time, Year2, DOY, Temp, DOY.ul = 120,
      fig.opt = TRUE, verbose = TRUE )
```

Arguments

S.arr	the candidate starting dates for thermal accumulation (in day of year)
Ea.arr	the candidate activation free energy values (in $\text{kcal} \cdot \text{mol}^{-1}$)
Year1	the vector of the years recording a particular phenological event
Time	the vector of the occurrence times (in day of year) of a particular phenological event across many years

Year2	the vector of the years recording the climate data corresponding to the occurrence times
DOY	the vector of the dates (in day of year) when the climate data exist
Temp	the mean daily air temperature data (in °C) corresponding to DOY
DOY.u1	the upper limit of DOY used to predict the occurrence time
fig.opt	an optional argument of drawing the figures associated with the determination of the combination the starting date and activation free energy, and a comparison between the predicted and observed occurrence times
verbose	an optional argument of allowing users to suppress printing of computation progress

Details

When `fig.opt` is equal to `TRUE`, it will show the contours of the root-mean-square errors (RMSEs) based on different combinations of S and E_a .

The function does not require that `Year1` is the same as the unique of `Year2`, and the intersection of two years will be finally kept. The unused years that have phenological records but lack the climate data will be showed in `unused.years` in the returned list.

The numerical value of `DOY.u1` should be larger than or equal to the maximum `Time`.

Value

<code>mAADTS.mat</code>	a matrix consisting of the means of the annual accumulated days transferred to a standardized temperature (AADTS) values from the combinations of S and E_a
<code>RMSE.mat</code>	the matrix consisting of the RMSEs (in days) from different combinations of S and E_a
<code>AADTS.arr</code>	the AADTS values in different years associated with the smallest value in <code>RMSE.mat</code>
<code>Year</code>	The intersected years between <code>Year1</code> and <code>Year2</code>
<code>Time</code>	The observed occurrence times (day of year) in the intersected years between <code>Year1</code> and <code>Year2</code>
<code>Time.pred</code>	the predicted occurrence times in different years
<code>S</code>	the determined starting date (day of year)
<code>Ea</code>	the determined activation free energy values (in $\text{kcal}\cdot\text{mol}^{-1}$)
<code>AADD</code>	the expected AADTS
<code>RMSE</code>	the smallest RMSE (in days) in <code>RMSE.mat</code> from different combinations of S and E_a
<code>unused.years</code>	the years that have phenological records but lack the climate data

Note

The entire mean daily temperature data in the spring of each year should be provided. AADTS is represented by the mean of `AADTS.arr` in the output.

Author(s)

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References

Aono, Y. (1993) Climatological studies on blooming of cherry tree (*Prunus yedoensis*) by means of ADTS method. *Bulletin of the University of Osaka Prefecture. Ser. B, Agriculture and life sciences* 45, 155–192 (in Japanese with English abstract).

Konno, T., Sugihara, S. (1986) Temperature index for characterizing biological activity in soil and its application to decomposition of soil organic matter. *Bulletin of National Institute for Agro-Environmental Sciences* 1, 51–68 (in Japanese with English abstract).

Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001

Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

See Also

[predADTS](#)

Examples

```
data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT

Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
Temp.val <- X2$MDT
DOY.ul.val <- 120
S.arr0 <- seq(40, 60, by = 1)
Ea.arr0 <- seq(10, 20, by = 1)

res3 <- ADTS( S.arr = S.arr0, Ea.arr = Ea.arr0, Year1 = Year1.val, Time = Time.val,
             Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val, DOY.ul = DOY.ul.val,
             fig.opt = TRUE, verbose = TRUE)

res3

RMSE.mat0 <- res3$RMSE.mat
RMSE.range <- range(RMSE.mat0)

dev.new()
par1 <- par(family="serif")
par2 <- par(mar=c(5, 5, 2, 2))
```

```

par3 <- par(mgp=c(3, 1, 0))
image( S.arr0, Ea.arr0, RMSE.mat0, col = terrain.colors(200), axes = TRUE,
       cex.axis = 1.5, cex.lab = 1.5, xlab = "Starting date (day of year)",
       ylab = expression(paste(italic(E["a"]), " (kcal" %.% "mol"^-1}, ") ", sep = "")))
points( res3$S, res3$Ea, cex = 1.5, pch = 16, col = 2 )
contour( S.arr0, Ea.arr0, RMSE.mat0, levels = round(seq(RMSE.range[1],
             RMSE.range[2], len = 20), 4), add = TRUE, cex = 1.5, col = "#696969", labcex = 1.5)
par(par1)
par(par2)
par(par3)

resu3 <- ADTS( S.arr = 47, Ea.arr = seq(10, 20, by = 0.5), Year1 = Year1.val, Time = Time.val,
             Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val, DOY.ul = DOY.ul.val,
             fig.opt = TRUE, verbose = TRUE)

resu3

# graphics.off()

```

apricotFFD

First flowering date records of Prunus armeniaca

Description

The data consist of the first flowering date records of *Prunus armeniaca* at the Summer Palace (39°54'38" N, 116°8'28" E, 50 m a.s.l.) in Beijing of China between 1963 and 2010. **Data source:** Chinese Phenological Observation Network (Guo et al., 2015).

Usage

```
data(apricotFFD)
```

Details

In the data set, there are two columns of vectors: Year, and Time. Code saves the recording years; and Time saves 1963–2010 first flowering dates of *Prunus armeniaca* in day of year.

References

Guo, L., Xu, J., Dai, J., Cheng, J., Wu, H., Luedeling, E. (2015) Statistical identification of chilling and heat requirements for apricotflower buds in Beijing, China. *Scientia Horticulturae* 195, 138–144. doi:10.1016/j.scienta.2015.09.006

Examples

```
data(apricotFFD)
attach(apricotFFD)
```

```
dev.new()
par1 <- par(family="serif")
par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
plot( Year, Time, asp = 1, cex.lab = 1.5, cex.axis = 1.5,
      xlab = "Year", ylab = "First flowering date (day of year)" )
par(par1)
par(par2)
par(par3)

# graphics.off()
```

BJMDT

Mean Daily Temperature Data of Beijing from 1951 to 2012 with the exception of 1968.

Description

The data include the mean daily temperatures (in °C) of Beijing between 1951 and 2012 with the exception of 1968. **Data source:** China Meteorological Data Service Centre (<https://data.cma.cn/en>).

Usage

```
data(BJMDT)
```

Details

In the data set, there are five columns of vectors: Year, Month, Day, DOY, and MDT. Year saves the recording years; Month saves the recording months; Day saves the recording days; DOY saves the dates in day of year; and MDT saves the mean daily temperatures (in °C) corresponding to DOY.

References

Guo, L., Xu, J., Dai, J., Cheng, J., Wu, H., Luedeling, E. (2015) Statistical identification of chilling and heat requirements for apricotflower buds in Beijing, China. *Scientia Horticulturae* 195, 138–144. doi:10.1016/j.scienta.2015.09.006

Examples

```
data(BJMDT)
attach(BJMDT)

x <- as.numeric( tapply(DOY, DOY, mean) )
y <- as.numeric( tapply(MDT, DOY, mean) )
y.sd <- as.numeric( tapply(MDT, DOY, sd) )

dev.new()
par1 <- par(family="serif")
```

```

par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
plot( x, y, cex = 1.5, xlim = c(0, 367), ylim = c(-10, 30),
      cex.lab = 1.5, cex.axis = 1.5, type = "n", xlab = "Day of Year",
      ylab = expression(paste("Mean daily temperature (", degree, "C)", sep="")) )
for(i in 1:length(x)){
  lines(c(x[i], x[i]), c(y[i]-y.sd[i], y[i]+y.sd[i]), col=4)
}
points(x, y, cex = 1.5)
par(par1)
par(par2)
par(par3)

# graphics.off()

```

predADD

Prediction Function of the Accumulated Degree Days Method

Description

Predicts the occurrence times using the accumulated degree days method based on observed or predicted mean daily air temperatures (Aono, 1993; Shi et al., 2017a, 2017b).

Usage

```
predADD(S, T0, AADD, Year2, DOY, Temp, DOY.u1 = 120)
```

Arguments

S	the starting date for thermal accumulation (in day of year)
T0	the base temperature (in °C)
AADD	the expected annual accumulated degree days
Year2	the vector of the years recording the climate data for predicting the occurrence times
DOY	the vector of the dates (in day of year) when the climate data exist
Temp	the mean daily air temperature data (in °C) corresponding to DOY
DOY.u1	the upper limit of DOY used to predict the occurrence time

Details

In the accumulated degree days (ADD) method (Shi et al., 2017a, 2017b), the starting date (S) and the base temperature (T_0), and the annual accumulated degree days (AADD which is denoted by k) are assumed to be constants across different years. Let k_i denote the AADD of the i th year, which equals

$$k_i = \sum_{j=S}^{E_i} (T_{ij} - T_0),$$

where E_i represents the ending date (in day of year), i.e., the occurrence time of a particular phenological event in the i th year, and T_{ij} represents the mean daily temperature of the j th day of the i th year (in °C). In theory, $k_i = k$, i.e., the AADD values of different years are a constant. However, in practice, there is a certain deviation of k_i from k . The following approach is used to determine the predicted occurrence time. When $\sum_{j=S}^F (T_{ij} - T_0) = k$ (where $F \geq S$), it follows that F is the predicted occurrence time; when $\sum_{j=S}^F (T_{ij} - T_0) < k$ and $\sum_{j=S}^{F+1} (T_{ij} - T_0) > k$, the trapezoid method (Ring and Harris, 1983) is used to determine the predicted occurrence time.

Value

Year	the years with climate data
Time.pred	the predicted occurrence times (day of year) in different years

Note

The entire mean daily temperature data in the spring of each year should be provided.

Author(s)

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References

- Aono, Y. (1993) Climatological studies on blooming of cherry tree (*Prunus yedoensis*) by means of DTS method. *Bulletin of the University of Osaka Prefecture. Ser. B, Agriculture and life sciences* 45, 155–192 (in Japanese with English abstract).
- Ring, D.R., Harris, M.K. (1983) Predicting pecan nut casebearer (Lepidoptera: Pyralidae) activity at College Station, Texas. *Environmental Entomology* 12, 482–486. doi:10.1093/ee/12.2.482
- Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001
- Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

See Also

[ADD](#)

Examples

```
data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT
Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
```

```

Temp.val  <- X2$MDT
DOY.ul.val <- 120
S.val     <- 65
T0.val   <- -0.5
AADD.val  <- 235.6447

res2 <- predADD( S = S.val, T0 = T0.val, AADD = AADD.val,
                Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val,
                DOY.ul = DOY.ul.val )

res2

ind1 <- res2$Year %in% intersect(res2$Year, Year1.val)
ind2 <- Year1.val %in% intersect(res2$Year, Year1.val)
RMSE1 <- sqrt( sum((Time.val[ind2]-res2$Time.pred[ind1])^2) / length(Time.val[ind2]) )
RMSE1

```

predADP	<i>Prediction Function of the Accumulated Developmental Progress Method</i>
---------	---

Description

Predicts the occurrence times using the accumulated developmental progress (ADP) method based on observed or predicted mean daily air temperatures (Wagner et al., 1984; Shi et al., 2017a, 2017b).

Usage

```
predADP(S, expr, theta, Year2, DOY, Temp, DOY.ul = 120)
```

Arguments

S	the starting date for thermal accumulation (in day of year)
expr	a user-defined model that is used in the accumulated developmental progress (ADP) method
theta	a vector saves the numerical values of the parameters in expr
Year2	the vector of the years recording the climate data for predicting the occurrence times
DOY	the vector of the dates (in day of year) when the climate data exist
Temp	the mean daily air temperature data (in °C) corresponding to DOY
DOY.ul	the upper limit of DOY used to predict the occurrence time

Details

Organisms showing phenological events in early spring often experience several cold days during the development. In this case, Arrhenius' equation (Shi et al., 2017a, 2017b, and references therein) has been recommended to describe the effect of the absolute temperature (T in Kelvin [K]) on the developmental rate (r):

$$r = \exp\left(B - \frac{E_a}{RT}\right),$$

where E_a represents the activation free energy (in $\text{kcal} \cdot \text{mol}^{-1}$); R is the universal gas constant ($= 1.987 \text{ cal} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$); B is a constant. To keep the consistency of the unit used in E_a and R , we need to re-assign R to be 1.987×10^{-3} to make its unit $1.987 \times 10^{-3} \text{ kcal} \cdot \text{mol}^{-1} \cdot \text{K}^{-1}$ in the above formula.

In the accumulated developmental progress (ADP) method, when the annual accumulated developmental progress (AADP) reaches 100%, the phenological event is predicted to occur for each year. Let AADP_i denote the AADP of the i th year, which equals

$$\text{AADP}_i = \sum_{j=S}^{E_i} r_{ij},$$

where E_i represents the ending date (in day of year), i.e., the occurrence time of a particular phenological event in the i th year. If the temperature-dependent developmental rate follows Arrhenius' equation, the AADP of the i th year is equal to

$$\text{AADP}_i = \sum_{j=S}^{E_i} \exp\left(B - \frac{E_a}{RT_{ij}}\right),$$

where T_{ij} represents the mean daily temperature of the j th day of the i th year (in K). In theory, $\text{AADP}_i = 100\%$, i.e., the AADP values of different years are a constant of 100%. However, in practice, there is a certain deviation of AADP_i from 100%. The following approach is used to determine the predicted occurrence time. When $\sum_{j=S}^F r_{ij} = 100\%$ (where $F \geq S$), it follows that F is the predicted occurrence time; when $\sum_{j=S}^F r_{ij} < 100\%$ and $\sum_{j=S}^{F+1} r_{ij} > 100\%$, the trapezoid method (Ring and Harris, 1983) is used to determine the predicted occurrence time.

The argument of `expr` can be any an arbitrary user-defined temperature-dependent developmental rate function, e.g., a function named `myfun`, but it needs to take the following form of `myfun <- function(P, x){...}`, where `P` is the vector of the model parameter(s), and `x` is the vector of the predictor variable, i.e., the temperature variable.

Value

Year	the years with climate data
Time.pred	the predicted occurrence times (day of year) in different years

Note

The entire mean daily temperature data in the spring of each year should be provided. There is a need to note that the unit of Temp in **Arguments** is $^{\circ}\text{C}$, not K. In addition, when using Arrhenius'

equation to describe r , to reduce the size of B in this equation, Arrhenius' equation is multiplied by 10^{12} in calculating the AADP value for each year, i.e.,

$$\text{AADP}_i = \sum_{j=S}^{E_i} \left[10^{12} \cdot \exp \left(B - \frac{E_a}{RT_{ij}} \right) \right].$$

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References

Ring, D.R., Harris, M.K. (1983) Predicting pecan nut casebearer (Lepidoptera: Pyralidae) activity at College Station, Texas. *Environmental Entomology* 12, 482–486. doi:10.1093/ee/12.2.482

Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001

Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

Wagner, T.L., Wu, H.-I., Sharpe, P.J.H., Shcoolfield, R.M., Coulson, R.N. (1984) Modelling insect development rates: a literature review and application of a biophysical model. *Annals of the Entomological Society of America* 77, 208–225. doi:10.1093/aesa/77.2.208

See Also

[ADP](#)

Examples

```
data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT
Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
Temp.val <- X2$MDT
DOY.ul.val <- 120
S.val <- 47

# Defines a re-parameterized Arrhenius' equation
Arrhenius.eqn <- function(P, x){
  B <- P[1]
  Ea <- P[2]
  R <- 1.987 * 10^(-3)
  x <- x + 273.15
  10^12*exp(B-Ea/(R*x))
}
```

```

}

P0 <- c(-4.7823, 14.8198)
T2 <- seq(-10, 20, len = 2000)
r2 <- Arrhenius.eqn(P = P0, x = T2)

dev.new()
par1 <- par(family="serif")
par2 <- par(mar=c(5, 5, 2, 2))
par3 <- par(mgp=c(3, 1, 0))
plot( T2, r2, cex.lab = 1.5, cex.axis = 1.5, pch = 1, cex = 1.5, col = 2, type = "l",
      xlab = expression(paste("Temperature (", degree, "C)", sep = "")),
      ylab = expression(paste("Developmental rate (", {day}^{"-1"}, ") ", sep = "")) )
par(par1)
par(par2)
par(par3)

res6 <- predADP( S = S.val, expr = Arrhenius.eqn, theta = P0, Year2 = Year2.val,
                DOY = DOY.val, Temp = Temp.val, DOY.ul = DOY.ul.val )

res6

ind5 <- res6$Year %in% intersect(res6$Year, Year1.val)
ind6 <- Year1.val %in% intersect(res6$Year, Year1.val)
RMSE3 <- sqrt( sum((Time.val[ind6]-res6$Time.pred[ind5])^2) / length(Time.val[ind6]) )
RMSE3

```

predADTS

Prediction Function of the Accumulated Days Transferred to a Standardized Temperature Method

Description

Predicts the occurrence times using the accumulated days transferred to a standardized temperature (ADTS) method based on observed or predicted mean daily air temperatures (Konno and Sugihara, 1986; Aono, 1993; Shi et al., 2017a, 2017b).

Usage

```
predADTS(S, Ea, AADTS, Year2, DOY, Temp, DOY.ul = 120)
```

Arguments

S	the starting date for thermal accumulation (in day of year)
Ea	the activation free energy (in kcal · mol ⁻¹)
AADTS	the expected annual accumulated days transferred to a standardized temperature
Year2	the vector of the years recording the climate data for predicting the occurrence times

DOY	the vector of the dates (in day of year) when the climate data exist
Temp	the mean daily air temperature data (in °C) corresponding to DOY
DOY.ul	the upper limit of DOY used to predict the occurrence time

Details

Organisms showing phenological events in early spring often experience several cold days during the development. In this case, Arrhenius' equation (Shi et al., 2017a, 2017b, and references therein) has been recommended to describe the effect of the absolute temperature (T in Kelvin [K]) on the developmental rate (r):

$$r = \exp\left(B - \frac{E_a}{RT}\right),$$

where E_a represents the activation free energy (in kcal · mol⁻¹); R is the universal gas constant (= 1.987 cal · mol⁻¹ · K⁻¹); B is a constant. To keep the consistency of the unit used in E_a and R , we need to re-assign R to be 1.987×10^{-3} to make its unit 1.987×10^{-3} kcal · mol⁻¹ · K⁻¹ in the above formula.

According to the definition of the developmental rate (r), it is the developmental progress per unit time (e.g., per day, per hour), which equals the reciprocal of the developmental duration D , i.e., $r = 1/D$. Let T_s represent the standard temperature (in K), and r_s represent the developmental rate at T_s . let r_j represent the developmental rate at T_j , an arbitrary temperature (in K). It is apparent that $D_s r_s = D_j r_j = 1$. It follows that

$$\frac{D_s}{D_j} = \frac{r_j}{r_s} = \exp\left[\frac{E_a(T_j - T_s)}{RT_j T_s}\right],$$

where D_s/D_j is referred to as the number of days transferred to a standardized temperature (DTS) (Konno and Sugihara, 1986; Aono, 1993).

In the accumulated days transferred to a standardized temperature (ADTS) method, the annual accumulated days transferred to a standardized temperature (AADTS) is assumed to be a constant. Let AADTS_{*i*} denote the AADTS of the *i*th year, which equals

$$\text{AADTS}_i = \sum_{j=S}^{E_i} \left\{ \exp\left[\frac{E_a(T_{ij} - T_s)}{RT_{ij} T_s}\right] \right\},$$

where E_i represents the ending date (in day of year), i.e., the occurrence time of a particular phenological event in the *i*th year, and T_{ij} represents the mean daily temperature of the *j*th day of the *i*th year (in K). In theory, AADTS_{*i*} = AADTS, i.e., the AADTS values of different years are a constant. However, in practice, there is a certain deviation of AADTS_{*i*} from AADTS. The following approach is used to determine the predicted occurrence time. When $\sum_{j=S}^F \left\{ \exp\left[\frac{E_a(T_{ij} - T_s)}{RT_{ij} T_s}\right] \right\} = \text{AADTS}$ (where $F \geq S$), it follows that F is the predicted occurrence time; when $\sum_{j=S}^F \left\{ \exp\left[\frac{E_a(T_{ij} - T_s)}{RT_{ij} T_s}\right] \right\} < \text{AADTS}$ and $\sum_{j=S}^{F+1} \left\{ \exp\left[\frac{E_a(T_{ij} - T_s)}{RT_{ij} T_s}\right] \right\} > \text{AADTS}$, the trapezoid method (Ring and Harris, 1983) is used to determine the predicted occurrence time.

Value

Year	the years with climate data
Time.pred	the predicted occurrence times (day of year) in different years

Note

The entire mean daily temperature data in the spring of each year should be provided. There is a need to note that the unit of Temp in **Arguments** is °C, not K.

Author(s)

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References

- Aono, Y. (1993) Climatological studies on blooming of cherry tree (*Prunus yedoensis*) by means of DTS method. *Bulletin of the University of Osaka Prefecture. Ser. B, Agriculture and life sciences* 45, 155–192 (in Japanese with English abstract).
- Konno, T., Sugihara, S. (1986) Temperature index for characterizing biological activity in soil and its application to decomposition of soil organic matter. *Bulletin of National Institute for Agro-Environmental Sciences* 1, 51–68 (in Japanese with English abstract).
- Ring, D.R., Harris, M.K. (1983) Predicting pecan nut casebearer (Lepidoptera: Pyralidae) activity at College Station, Texas. *Environmental Entomology* 12, 482–486. doi:10.1093/ee/12.2.482
- Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001
- Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

See Also

[ADTS](#)

Examples

```
data(apricotFFD)
data(BJMDT)
X1 <- apricotFFD
X2 <- BJMDT
Year1.val <- X1$Year
Time.val <- X1$Time
Year2.val <- X2$Year
DOY.val <- X2$DOY
Temp.val <- X2$MDT
DOY.ul.val <- 120
S.val <- 47
Ea.val <- 14
AADTS.val <- 9.607107
```

```

res4 <- predADTS( S = S.val, Ea = Ea.val, AADTS = AADTS.val,
                 Year2 = Year2.val, DOY = DOY.val, Temp = Temp.val,
                 DOY.ul = DOY.ul.val )

res4

ind3 <- res4$Year %in% intersect(res4$Year, Year1.val)
ind4 <- Year1.val %in% intersect(res4$Year, Year1.val)
RMSE2 <- sqrt( sum((Time.val[ind4]-res4$Time.pred[ind3])^2) / length(Time.val[ind4]) )
RMSE2

```

spphpr

Spring Phenological Prediction

Description

Predicts the occurrence times (in day of year) of spring phenological events. Three methods, including the accumulated degree days (ADD) method, the accumulated days transferred to a standardized temperature (ADTS) method, and the accumulated developmental progress (ADP) method, were used. See Shi et al. (2017a, 2017b) for details.

Details

The DESCRIPTION file:

```

Package:      spphpr
Type:         Package
Title:        Spring Phenological Prediction
Version:      0.1.4
Date:         2024-12-12
Authors@R:   c(person(given="Peijian", family="Shi", email="pjshi@njfu.edu.cn", role=c("aut", "cre")), person(given=c("Zhen", "Hong", "Chen"), family="Chen", email="zhenhong.chen@njfu.edu.cn", role="aut"), person(given="Brady K.", family="Quinn", email="brady.k.quinn@njfu.edu.cn", role="aut"))
Author:       Peijian Shi [aut, cre], Zhenghong Chen [aut], Brady K. Quinn [aut]
Maintainer:   Peijian Shi <pjshi@njfu.edu.cn>
Description:  Predicts the occurrence times (in day of year) of spring phenological events. Three methods, including the accumulated degree days (ADD) method, the accumulated days transferred to a standardized temperature (ADTS) method, and the accumulated developmental progress (ADP) method, were used. See Shi et al. (2017a, 2017b) for details.
Depends:      R (>= 4.2.0)
License:      GPL (>= 2)

```

Index of help topics:

ADD	Function for Implementing the Accumulated Degree Days Method
ADP	Function for Implementing the Accumulated Developmental Progress Method
ADTS	Function for Implementing the Accumulated Days Transferred to a Standardized Temperature Method

BJMDT	Mean Daily Temperature Data of Beijing from 1951 to 2012 with the exception of 1968.
apricotFFD	First flowering date records of <i>Prunus armeniaca</i>
predADD	Prediction Function of the Accumulated Degree Days Method
predADP	Prediction Function of the Accumulated Developmental Progress Method
predADTS	Prediction Function of the Accumulated Days Transferred to a Standardized Temperature Method
spphpr	Spring Phenological Prediction
toDOY	Function for Transferring a Date to the Value of Day of Year

Note

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Author(s)

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Maintainer: Peijian Shi <pjshi@njfu.edu.cn>

References

Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:10.1016/j.agrformet.2017.04.001

Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:10.1093/aesa/sax063

toDOY

Function for Transferring a Date to the Value of Day of Year

Description

Transfers the date (from year, month and day) to the value of day of year.

Usage

toDOY(Year, Month, Day)

Arguments

Year	the vector of years
Month	the vector of months
Day	the vector of days

Details

The user needs to provide the three separate vectors of Year, Month and Day, rather than providing a single date vector. The arguments can be numerical vectors or character vectors.

Value

The returned value is a vector of transferred dates in day of year.

Note

The returned vector, DOY, usually mathes with the year vector and the mean daily temperature vector as arguments in other functions, e.g., the [ADD](#) function.

Author(s)

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References

Shi, P., Chen, Z., Reddy, G.V.P., Hui, C., Huang, J., Xiao, M. (2017a) Timing of cherry tree blooming: Contrasting effects of rising winter low temperatures and early spring temperatures. *Agricultural and Forest Meteorology* 240–241, 78–89. doi:[10.1016/j.agrformet.2017.04.001](https://doi.org/10.1016/j.agrformet.2017.04.001)

Shi, P., Fan, M., Reddy, G.V.P. (2017b) Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (III) Phenological applications. *Annals of the Entomological Society of America* 110, 558–564. doi:[10.1093/aesa/sax063](https://doi.org/10.1093/aesa/sax063)

See Also

[BJMDT](#)

Examples

```
data(BJMDT)
X2 <- BJMDT
DOY2 <- toDOY(X2$Year, X2$Month, X2$Day)
# cbind(X2$DOY, DOY2)
```


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