

# Package ‘LakeMetabolizer’

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**Title** Tools for the Analysis of Ecosystem Metabolism

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**Version** 1.5.6

**Description** A collection of tools for the calculation of freewater metabolism from in situ time series of dissolved oxygen, water temperature, and, optionally, additional environmental variables. LakeMetabolizer implements 5 different metabolism models with diverse statistical underpinnings: bookkeeping, ordinary least squares, maximum likelihood, Kalman filter, and Bayesian. Each of these 5 metabolism models can be combined with 1 of 7 models for computing the coefficient of gas exchange across the air–water interface ( $k$ ). LakeMetabolizer also features a variety of supporting functions that compute conversions and implement calculations commonly applied to raw data prior to estimating metabolism (e.g., oxygen saturation and optical conversion models).

**License** GPL ( $\geq 2$ )

**Imports** plyr, methods

**Suggests** R2jags, testthat

**Depends** R ( $\geq 2.15.0$ ), rLakeAnalyzer ( $\geq 1.4$ )

**Repository** CRAN

**BugReports** <https://github.com/GLEON/LakeMetabolizer/issues>

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---

calc.lw.net

*Estimate net long wave heat radiation*

---

## Description

Returns the net long wave radiation based on Crawford and Duchon, 1999.

**Usage**

```
calc.lw.net(ts.data, lat, atm.press)
```

```
calc.lw.net.base(dateTime, sw, Ts, lat, atm.press, airT, RH)
```

**Arguments**

ts.data	Object of class data.frame including the required variables(see details for list of variables and their units)
lat	latitude in degrees north
atm.press	atmospheric pressure in mb
dateTime	vector of datetime in POSIXct format
sw	numeric value of short wave radiation, W/m <sup>2</sup>
Ts	numeric value of surface water temperature, degC
airT	numeric value of air temperature, degC
RH	numeric value of relative humidity, %

**Value**

```
## for calc.lw.net.base
```

```
A numeric value of net long wave heat flux in W/m2
```

```
## for calc.lw.net
```

```
A data.frame with columns datetime and lwnet in W/m2
```

**Author(s)**

R Iestyn Woolway Jordan S. Read Hilary Dugan Luke Winslow

**References**

Crawford, T.M., and Duchon, C.E. 1999. *An improved parameterization for estimating effective atmospheric emissivity for use in calculating daytime downwelling longwave radiation*. Journal of Applied Meteorology 38: 474-480.

**See Also**

[k.read](#) and [k.macIntyre](#)

**Examples**

```
## Base example
dateTime <- as.POSIXct("2013-12-30 23:00")
Uz <- 3
airT <- 20
RH <- 90
sw <- 800
wndZ <- 2
```

```

Kd <- 2
lat <- 54
lake.area <- 5000
atm.press <- 1013
Ts <- 22
calc.lw.net.base(dateTime,sw,Ts,lat,atm.press,airT,RH)

## Example using timeseries in a data frame
data.path = system.file('extdata', package="LakeMetabolizer")

sp.data = load.all.data('sparkling', data.path)

# Prep the input data
ts.data = sp.data$data #pull out just the timeseries data
atm.press = 1018
lat = sp.data$metadata$latitude

lw.net = calc.lw.net(ts.data, lat, atm.press)
plot(lw.net$datetime, lw.net$lw.net)

```

---

calc.zeng

*Estimate sensible and latent heat fluxes*


---

### Description

Returns the sensible and latent heat fluxes based on Zeng et al, 1998'

### Usage

```
calc.zeng(dateTime, Ts, airT, Uz, RH, atm.press, wnd.z, airT.z, RH.z)
```

### Arguments

dateTime	vector of datetime in POSIXct format
Ts	numeric value of surface water temperature, degC
airT	numeric value of air temperature, degC
Uz	numeric value of wind speed, m/s
RH	numeric value of relative humidity, %
atm.press	atmospheric pressure in mb
wnd.z	height of wind measurement, m
airT.z	height of air temperature measurement, m (optional)
RH.z	height of relative humidity measurement, m (optional)

### Value

A data.frame including sensible and latent heat flux estimates, and other variables used in calculating these fluxes.

**Author(s)**

R. Iestyn. Woolway

**References**

Zeng, X., M. Zhao., and Dickinson, R.E. 1998. *Intercomparison of bulk aerodynamic algorithms for the computation of sea surface fluxes using TOGA COARE and TAO data*. Journal of Climate 11: 2628-2644.

**See Also**

[k.read](#)

**Examples**

```
dateTime <- as.POSIXct("2013-12-30 23:00")
Ts <- 22.51
airT <- 20
Uz <- 3
RH <- 90
atm.press <- 1013
wnd.z <- 2
calc.zeng(dateTime, Ts, airT, Uz, RH, atm.press, wnd.z)
```

---

get.Ts	<i>gets surface water temperatures</i>
--------	--

---

**Description**

grabs best available data for surface water temperature

**Usage**

```
get.Ts(data, s.range = c(0, 1))
```

**Arguments**

data	Object of class data.frame
s.range	a numeric vector of length=2 with the range for depth measurements to still be considered 'surface'

**Value**

An object of class data.frame

**Author(s)**

Jordan S. Read

**See Also**

[has.vars](#) [get.vars](#) [rmv.vars](#)

---

get.vars                      *subsets data.frame according to header names*

---

**Description**

subsets data according to header names

**Usage**

```
get.vars(data, var.names)
```

**Arguments**

data                      Object of class data.frame  
var.names                A character vector of names to get from data

**Value**

An object of class data.frame

**Author(s)**

Luke A. Winslow

**See Also**

[has.vars](#) [rmv.vars](#)

---

getSchmidt                      *Returns Schmidt number for a specific gas at a given temperature*

---

**Description**

Schmidt number is temperature dependant, and is the ratio of the kinematic viscosity of water to a diffusion coefficient. Coefficients are included for He, O2, CO2, CH4, SF6, N2O, Ar, and N2.

**Usage**

```
getSchmidt(temperature, gas)
```

**Arguments**

temperature	Numeric vector of water temperatures in deg. Celsius
gas	String for gas code. Valid inputs include: He, O2, CO2, CH4, SF6, N2O, Ar, and N2

**Value**

Schmidt number (unitless)

**Note**

Temperature range is only valid from 4-35 deg Celsius

**Author(s)**

Jordan S. Read

**References**

Raymond, Peter A., Christopher J. Zappa, David Butman, Thomas L. Bott, Jody Potter, Patrick Mulholland, Andrew E. Laursen, William H. McDowell, and Denis Newbold. *Scaling the gas transfer velocity and hydraulic geometry in streams and small rivers*. *Limnology & Oceanography: Fluids & Environments* 2 (2012): 41-53.

**Examples**

```
getSchmidt(temperature=12, gas="O2")
```

---

has.vars                      *tests data.frame for column names*

---

**Description**

tests data for data column names

**Usage**

```
has.vars(data, var.names)
```

**Arguments**

data	Object of class data.frame
var.names	A character vector of names to test against data

**Value**

a boolean vector of same length as var.names

**Author(s)**

Luke A. Winslow

**See Also**

[get.vars](#) [rmv.vars](#)

---

is.day	<i>determines if measurement was taken during the daytime</i>
--------	---

---

**Description**

determines if measurement was taken during the daytime

**Usage**

```
is.day(datetimes, lat)
```

**Arguments**

datetimes	Vector of dates as POSIXct or POSIXlt (see <a href="#">DateTimeClasses</a> ) format
lat	Single latitude value of site. South should be negative, north positive

**Value**

a boolean vector of same length as datetimes

**Author(s)**

Luke A. Winslow

**See Also**

[is.night](#) [sun.rise.set](#)

---

is.night	<i>determines if measurement was taken during the night</i>
----------	---

---

**Description**

determines if measurement was taken during the nighttime

**Usage**

```
is.night(datetimes, lat)
```

**Arguments**

datetimes	Vector of dates as POSIXct or POSIXlt (see <a href="#">DateTimeClasses</a> ) format
lat	Single latitude value of site. South should be negative, north positive

**Value**

a boolean vector of same length as datetimes

**Author(s)**

Luke A. Winslow

**See Also**

[is.day sun.rise.set](#)

---

k.read	<i>Returns a timeseries of gas exchange velocity</i>
--------	--

---

**Description**

Returns the gas exchange velocity based on the chosen model in units of m/day

**Usage**

```
k.cole(ts.data)
```

```
k.crusius(ts.data, method='power')
```

```
k.read(ts.data, wnd.z, Kd, atm.press, lat, lake.area)
```

```
k.read.soloviev(ts.data, wnd.z, Kd, atm.press, lat, lake.area)
```

```
k.macIntyre(ts.data, wnd.z, Kd, atm.press, params=c(1.2, 0.4872, 1.4784))
```

```
k.vachon(ts.data, lake.area, params=c(2.51,1.48,0.39))
```

```
k.heiskanen(ts.data, wnd.z, Kd, atm.press)
```

### Arguments

ts.data	vector of datetime in POSIXct format
wnd.z	height of wind measurement, m
Kd	Light attenuation coefficient (Units:m <sup>-1</sup> )
atm.press	atmospheric pressure in mb
lat	Latitude, degrees north
lake.area	Lake area, m <sup>2</sup>
method	Only for <a href="#">k.crusius</a> . String of valid method . Either "linear", "bilinear", or "power"
params	Only for <a href="#">k.vachon.base</a> and <a href="#">k.macIntyre</a> . See details.

### Details

Can change default parameters of MacIntyre and Vachon models. Default for Vachon is c(2.51,1.48,0.39). Default for MacIntyre is c(1.2,0.4872,1.4784). Heiskanen 2014 uses MacIntyre model with c(0.5,0.77,0.3) and z.aml constant at 0.15.

### Value

Returns a data.frame with a datetime column and a k600 column. k600 is in units of meters per day (m/d).

### Author(s)

Hilary Dugan, Jake Zwart, Luke Winslow, R. Iestyn. Woolway, Jordan S. Read

### References

- Cole, J., J. Nina, and F. Caraco. *Atmospheric exchange of carbon dioxide in a low-wind oligotrophic lake measured by the addition of SF<sub>6</sub>*. *Limnology and Oceanography* 43 (1998): 647-656.
- MacIntyre, Sally, Anders Jonsson, Mats Jansson, Jan Aberg, Damon E. Turney, and Scott D. Miller. *Buoyancy flux, turbulence, and the gas transfer coefficient in a stratified lake*. *Geophysical Research Letters* 37, no. 24 (2010).
- Read, Jordan S., David P. Hamilton, Ankur R. Desai, Kevin C. Rose, Sally MacIntyre, John D. Lenters, Robyn L. Smyth et al. *Lake-size dependency of wind shear and convection as controls on gas exchange*. *Geophysical Research Letters* 39, no. 9 (2012).
- Crusius, John, and Rik Wanninkhof. *Gas transfer velocities measured at low wind speed over a lake*. *Limnology and Oceanography* 48, no. 3 (2003): 1010-1017.
- Dominic Vachon and Yves T. Prairie. *The ecosystem size and shape dependence of gas transfer velocity versus wind speed relationships in lakes*. *Can. J. Fish. Aquat. Sci.* 70 (2013): 1757-1764.

Jouni J. Heiskanen, Ivan Mammarella, Sami Haapanala, Jukka Pumpanen, Timo Vesala, Sally MacIntyre Anne Ojala. *Effects of cooling and internal wave motions on gas transfer coefficients in a boreal lake*. Tellus B 66, no.22827 (2014)

Alexander Soloviev, Mark Donelan, Hans Graber, Brian Haus, Peter Schlüssel. *An approach to estimation of near-surface turbulence and CO2 transfer velocity from remote sensing data*. Journal of Marine Systems 66, (2007): 182-194.

## See Also

[k.cole](#) [k.crusius](#) [k.macIntyre](#) [k.vachon](#) [k.heiskanen](#)

## Examples

```
data.path = system.file('extdata', package="LakeMetabolizer")

tb.data = load.all.data('sparkling', data.path)

ts.data = tb.data$data #pull out just the timeseries data

#calculate U10 and add it back onto the original

u10 = wind.scale(ts.data)
ts.data = rmv.vars(ts.data, 'wnd', ignore.offset=TRUE) #drop old wind speed column
ts.data = merge(ts.data, u10) #merge new u10 into big dataset

k600_cole = k.cole(ts.data)

k600_crusius = k.crusius(ts.data)

kd      = tb.data$metadata$averagekd
wnd.z   = 10 #because we converted to u10
atm.press = 1018
lat     = tb.data$metadata$latitude
lake.area = tb.data$metadata$lakearea

#for k.read and k.macIntyre, we need LW_net.
#Calculate from the observations we have available.

lwnet = calc.lw.net(ts.data, lat, atm.press)
ts.data = merge(ts.data, lwnet)

k600_read = k.read(ts.data, wnd.z=wnd.z, Kd=kd, atm.press=atm.press,
lat=lat, lake.area=lake.area)

k600_soloviev = k.read.soloviev(ts.data, wnd.z=wnd.z, Kd=kd,
atm.press=atm.press, lat=lat, lake.area=lake.area)

k600_macIntyre = k.macIntyre(ts.data, wnd.z=wnd.z, Kd=kd, atm.press=atm.press)
```

---

k.read.base *Returns a timeseries of gas exchange velocity*

---

### Description

Returns the gas exchange velocity based on the chosen model in units of m/day

### Usage

```
k.cole.base(wnd)
```

```
k.crusius.base(wnd, method='power')
```

```
k.read.base(wnd.z, Kd, lat, lake.area, atm.press, dateTime, Ts, z.aml,
airT, wnd, RH, sw, lwnet)
```

```
k.read.soloviev.base(wnd.z, Kd, lat, lake.area, atm.press, dateTime, Ts, z.aml,
airT, wnd, RH, sw, lwnet)
```

```
k.macIntyre.base(wnd.z, Kd, atm.press, dateTime, Ts, z.aml, airT, wnd, RH, sw,
lwnet, params=c(1.2,0.4872,1.4784))
```

```
k.vachon.base(wnd, lake.area, params=c(2.51,1.48,0.39))
```

```
k.heiskanen.base(wnd.z, Kd, atm.press, dateTime, Ts, z.aml, airT, wnd, RH, sw, lwnet)
```

### Arguments

wnd.z	Height of wind measurement, (Units: m)
Kd	Light attenuation coefficient (Units: m <sup>-1</sup> )
lat	Latitude, degrees north
lake.area	Lake area, m <sup>2</sup>
atm.press	Atmospheric pressure, (Units: millibar)
dateTime	datetime (Y-%m-%d %H:%M), (Format: <a href="#">POSIXct</a> )
Ts	Numeric vector of surface water temperature, (Units(deg C))
z.aml	Numeric vector of actively mixed layer depths. Must be the same length as the Ts parameter
airT	Numeric value of air temperature, Units(deg C)
wnd	Numeric value of wind speed, (Units:m/s)
RH	Numeric value of relative humidity, %
sw	Numeric value of short wave radiation, W m <sup>-2</sup>
lwnet	Numeric value net long wave radiation, W m <sup>-2</sup>

method	Only for <a href="#">k.crusius.base</a> . String of valid method . Either "constant", "bilinear", or "power"
params	Optional parameter input, only for <a href="#">k.vachon.base</a> and <a href="#">k.macIntyre.base</a> . See details.

### Details

Can change default parameters of MacIntyre and Vachon models. Default for Vachon is c(2.51,1.48,0.39). Default for MacIntyre is c(1.2,0.4872,1.4784). Heiskanen et al. (2014) uses MacIntyre model with c(0.5,0.77,0.3) and z.aml constant at 0.15.

### Value

Numeric value of gas exchange velocity (k600) in units of m/day. Before use, should be converted to appropriate gas using [k600.2.kGAS](#).

### Author(s)

R. Iestyn. Woolway, Hilary Dugan, Luke Winslow, Jordan S Read, GLEON fellows

### References

- Cole, J., J. Nina, and F. Caraco. *Atmospheric exchange of carbon dioxide in a low-wind oligotrophic lake measured by the addition of SF<sub>6</sub>*. *Limnology and Oceanography* 43 (1998): 647-656.
- MacIntyre, Sally, Anders Jonsson, Mats Jansson, Jan Aberg, Damon E. Turney, and Scott D. Miller. *Buoyancy flux, turbulence, and the gas transfer coefficient in a stratified lake*. *Geophysical Research Letters* 37, no. 24 (2010).
- Read, Jordan S., David P. Hamilton, Ankur R. Desai, Kevin C. Rose, Sally MacIntyre, John D. Lenters, Robyn L. Smyth et al. *Lake-size dependency of wind shear and convection as controls on gas exchange*. *Geophysical Research Letters* 39, no. 9 (2012).
- Crusius, John, and Rik Wanninkhof. *Gas transfer velocities measured at low wind speed over a lake*. *Limnology and Oceanography* 48, no. 3 (2003): 1010-1017.
- Dominic Vachon and Yves T. Prairie. *The ecosystem size and shape dependence of gas transfer velocity versus wind speed relationships in lakes*. *Can. J. Fish. Aquat. Sci.* 70 (2013): 1757-1764.
- Jouni J. Heiskanen, Ivan Mammarella, Sami Haapanala, Jukka Pumpanen, Timo Vesala, Sally MacIntyre Anne Ojala. *Effects of cooling and internal wave motions on gas transfer coefficients in a boreal lake*. *Tellus B* 66, no.22827 (2014)
- Alexander Soloviev, Mark Donelan, Hans Graber, Brian Haus, Peter Schlüssel. *An approach to estimation of near-surface turbulence and CO<sub>2</sub> transfer velocity from remote sensing data*. *Journal of Marine Systems* 66, (2007): 182-194.

### See Also

[k.cole](#) [k.read](#) [k.crusius](#) [k.macIntyre](#) [k.vachon](#) [k.heiskanen](#)

### Examples

```
wnd.z <- 2
Kd <- 2
lat <- 54
lake.area <- 5000
atm.press <- 1013
dateTime <- as.POSIXct("2013-12-30 14:00")
Ts <- 16.5
z.aql <- 2.32
airT <- 20
wnd <- 6
RH <- 90
sw <- 800
lwnet <- -55
timeStep <- 30

U10 <- wind.scale.base(wnd, wnd.z)

k600_cole <- k.cole.base(U10)

k600_crusius <- k.crusius.base(U10)

k600_read <- k.read.base(wnd.z, Kd, lat, lake.area, atm.press,
dateTime, Ts, z.aql, airT, wnd, RH, sw, lwnet)

k600_soloviev <- k.read.soloviev.base(wnd.z, Kd, lat, lake.area,
atm.press, dateTime, Ts, z.aql, airT, wnd, RH, sw, lwnet)

k600_macIntyre <- k.macIntyre.base(wnd.z, Kd, atm.press,
dateTime, Ts, z.aql, airT, wnd, RH, sw, lwnet)
```

---

k600.2.kGAS	<i>Returns the gas exchange velocity for gas of interest w/ no unit conversions</i>
-------------	---

---

### Description

Returns the gas exchange velocity for gas of interest w/ no unit conversions

### Usage

```
k600.2.kGAS.base(k600, temperature, gas="O2")
```

```
k600.2.kGAS(ts.data, gas="O2")
```

### Arguments

k600	k600 as vector array of numbers or single number
------	--

temperature	Water temperature (deg C) as vector array of numbers or single number
gas	gas for conversion, as string (e.g., 'CO2' or 'O2')
ts.data	Object of class data.frame with named columns datetime and k600 and wtr (water temp in deg C). Other columns are ignored

**Value**

Numeric value of gas exchange velocity for gas

**Author(s)**

Jordan S. Read

**See Also**

[k.read](#) and [k.read.base](#) for functions that calculate k600 estimates

**Examples**

```
## single example
k02 <- k600.2.kGAS.base(k600=2.4, temperature=20.4, gas='O2')

## Timeseries example
#load data
data.path = system.file('extdata', package="LakeMetabolizer")
sp.data = load.all.data('sparkling', data.path)
ts.data = sp.data$data #pull out just the timeseries data

#calculate U10 and add it back onto the original
u10 = wind.scale(ts.data)
ts.data = rmv.vars(ts.data, 'wnd', ignore.offset=TRUE) #drop old wind speed column
ts.data = merge(ts.data, u10) #merge new u10 into big dataset

k600 = k.cole(ts.data)
ts.data = merge(k600, ts.data)

k.gas = k600.2.kGAS(ts.data, 'O2')
```

---

load.all.data

*Attempts to load and merge all timeseries data for a given site name*


---

**Description**

Loads and returns all the data available in the specified directory for a given site. All timeseries data are merged by “datetime” into a single [data.frame](#). Data are identified by the column header information.

**Usage**

```
load.all.data(lake.name, data.path, checkMerge=TRUE)
```

**Arguments**

lake.name	The file prefix to be matched. For example, “sparkling” matches “sparkling.wtr” but not “troutbog.wtr”
data.path	The directory to look for files
checkMerge	Should check merge size before attempting to prevent potential merge problems.

**Value**

A list with two items

data

metadata

**Author(s)**

Luke A. Winslow

**See Also**

[load.ts](#) [load.meta](#)

---

load.meta

*Loads a metadata file from the specified path*

---

**Description**

Parses a formatted metadata file. Useful for site-specific metadata that is not contained in the timeseries files.

**Usage**

```
load.meta(fPath)
```

**Arguments**

fPath	The file path as a string
-------	---------------------------

**Value**

A list with the metadata parsed from the file.

**Author(s)**

Luke A Winslow

**See Also**

[load.ts](#) [load.all.data](#)

---

metab

*Calculate metabolism*


---

**Description**

Returns daily time series of gross primary production (GPP), respiration (R), and net ecosystem production (NEP). Depending on the method used, other information may be returned as well. Calculations are made using one of 5 statistical methods.

**Usage**

```
metab(data, method, wtr.name="wtr", irr.name="irr", do.obs.name="do.obs", ...)
```

**Arguments**

data	a data.frame whose columns are "datetime" = class POSIXct vector "do.obs" = numeric vector of oxygen concentration in mg/L "do.sat" = numeric vector of saturated oxygen concentration in mg/L "k.gas" = numeric vector of gas exchange coefficient values in m/day, should be 0 when depth of do.obs is deeper than z.mix "z.mix" = numeric vector of mixing depth values in meters "irr" = numeric vector of PAR values, arbitrary units "wtr" = numeric vector of water temperature values, arbitrary units Columns that are not used by a particular statistical method do not need to be supplied.
method	a character string specifying one of the 5 statistical methods (bayesian, book-keep, kalman, ols, mle)
wtr.name	the name of the column containing temperature at the depth of do.obs (predictor variable for R)
irr.name	the name of the column containing irradiance (predictor variable for GPP)
do.obs.name	the name of the column in data containing the DO observations (in mg/L) to be used as the response variable
...	arguments to be passed on to the metabolism model specified by method

**Value**

A data.frame containing columns for year, doy (day of year, julian day plus fraction of day), GPP, R, and NEP

year	integer year
doy	numeric, day of year + fraction of day, where the day is the julian day, and a fraction of 0.5 corresponds to noon
GPP	numeric, gross primary production, in units of mg O2 per liter per day. By convention, this value is positive.
R	numeric, respiration, in units of mg O2 per liter per day. By convention, this value is negative
NEP	numeric, net ecosystem production, in units of mg O2 per liter per day. For most methods this equal GPP+R, but this is not necessarily the case for "method"="bookkeep"

Note that different models will have different [attributes](#) attached to them. See examples.

**Author(s)**

Ryan D. Batt

**See Also**

Metabolism models: [metab.bookkeep](#), [metab.ols](#), [metab.mle](#), [metab.kalman](#), [metab.bayesian](#)

For smoothing noisy temperature: [temp.kalman](#)

To calculate do.sat: [o2.at.sat](#)

To calculate k.gas: [k600.2.kGAS](#)

To calculate k600 values for k.gas: [k.cole](#), [k.crusius](#), [k.macIntyre](#), [k.read](#)

**Examples**

```
# fake data
datetime <- seq(as.POSIXct("2014-06-16 00:00:00", tz="GMT"),
  as.POSIXct("2014-06-17 23:55:00", tz="GMT"), length.out=288*2)
do.obs <- 2*sin(2*pi*(1/288)*(1:(288*2))+1.1*pi) + 8 + rnorm(288*2, 0, 0.5)
wtr <- 3*sin(2*pi*(1/288)*(1:(288*2))+pi) + 17 + rnorm(288*2, 0, 0.15)
do.sat <- LakeMetabolizer::o2.at.sat.base(wtr, 960)
irr <- (1500*sin(2*pi*(1/288)*(1:(288*2))+1.5*pi) + 650 + rnorm(288*2, 0, 0.25)) *
  ifelse(is.day(datetime, 42.3), 1, 0)
k.gas <- 0.4
z.mix <- 1

# plot time series
plot(wtr, type="l", xaxt="n", yaxt="n", xlab="", ylab="")
par(new=TRUE); plot(do.obs, type="l", col="blue", xaxt="n", yaxt="n", xlab="", ylab="")
par(new=TRUE); plot(irr, type="l", col="orange", xaxt="n", yaxt="n", xlab="", ylab="")
abline(v=144, lty="dotted")
abline(v=288)
legend("topleft", legend=c("wtr", "do.obs", "irr"), lty=1,
```

```

col=c("black", "blue", "orange"), inset=c(0.08, 0.01))

# put data in a data.frame
data <- data.frame(datetime=datetime, do.obs=do.obs, do.sat=do.sat, k.gas=k.gas,
  z.mix=z.mix, irr=irr, wtr=wtr)

# run each metabolism model
m.bk <- metab(data, "bookkeep", lake.lat=42.6)
m.bk <- metab(data, lake.lat=42.6) # no method defaults to "bookkeep"
m.ols <- metab(data, "ols", lake.lat=42.6)
m.mle <- metab(data, "mle", lake.lat=42.6)
m.kal <- metab(data, "kalman", lake.lat=42.6)
## Not run: m.bay <- metab(data, "bayesian", lake.lat=42.6)

# example attributes
names(attributes(m.ols))
attr(m.ols, "mod")

# To get full JAGS model
# including posterior draws:
## Not run: names(attributes(m.bay))
## Not run: attr(m.bay, "model")

```

---

metab.bayesian	<i>Metabolism model based on a bayesian parameter estimation framework</i>
----------------	--

---

## Description

This function runs the bayesian metabolism model on the supplied gas concentration and other supporting data. This allows for both estimates of metabolism along with uncertainty around the parameters.

## Usage

```
metab.bayesian(do.obs, do.sat, k.gas, z.mix, irr, wtr, priors, ...)
```

## Arguments

do.obs	Vector of dissolved oxygen concentration observations, mg L <sup>-1</sup>
do.sat	Vector of dissolved oxygen saturation values based on water temperature. Calculate using <a href="#">o2.at.sat</a>
k.gas	Vector of kGAS values calculated from any of the gas flux models (e.g., <a href="#">k.cole</a> ) and converted to kGAS using <a href="#">k600.2.kGAS</a>
z.mix	Vector of mixed-layer depths in meters. To calculate, see <a href="#">ts.meta.depths</a>
irr	Vector of photosynthetically active radiation in $\mu\text{mol m}^{-2}\text{s}^{-1}$
wtr	Vector of water temperatures in °C. Used in scaling respiration with temperature

priors           Parameter priors supplied as a named numeric vector (example: `c("gppMu"=0, "gppSig2"=1E5, "rMu"=0, "rSig2"=1E5, "kSig2"=NA)`)

...               additional arguments; currently "datetime" is the only recognized argument passed through ...

### Value

A list of length 4 with components:

model            the jags model, including posterior draws (see [jags](#))

params           parameter estimates of interest from model (medians)

metab.sd         standard deviation of metabolism estimates

metab            daily metabolism estimates as a data.frame with columns corresponding to

GPP   numeric estimate of Gross Primary Production,  $mgO_2L^{-1}d^{-1}$

R     numeric estimate of Respiration,  $mgO_2L^{-1}d^{-1}$

NEP   numeric estimate of Net Ecosystem production,  $mgO_2L^{-1}d^{-1}$

### Author(s)

Ryan Batt, Luke A. Winslow

### References

Holtgrieve, Gordon W., Daniel E. Schindler, Trevor a. Branch, and Z. Teresa A'mar. 2010. *Simultaneous Quantification of Aquatic Ecosystem Metabolism and Reaeration Using a Bayesian Statistical Model of Oxygen Dynamics*. *Limnology and Oceanography* 55 (3): 1047-1062. doi:10.4319/lo.2010.55.3.1047. [http://www.aslo.org/lo/toc/vol\\_55/issue\\_3/1047.html](http://www.aslo.org/lo/toc/vol_55/issue_3/1047.html).

### See Also

[metab.mle](#), [metab.bookkeep](#), [metab.kalman](#)

### Examples

```
## Not run:
library(rLakeAnalyzer)

doobs = load.ts(system.file('extdata',
                           'sparkling.doobs', package="LakeMetabolizer"))
wtr = load.ts(system.file('extdata',
                          'sparkling.wtr', package="LakeMetabolizer"))
wnd = load.ts(system.file('extdata',
                          'sparkling.wnd', package="LakeMetabolizer"))
irr = load.ts(system.file('extdata',
                          'sparkling.par', package="LakeMetabolizer"))

#Subset a day
mod.date = as.POSIXct('2009-07-08', 'GMT')
doobs = doobs[trunc(doobs$datetime, 'day') == mod.date, ]
```

```

wtr = wtr[trunc(wtr$datetime, 'day') == mod.date, ]
wnd = wnd[trunc(wnd$datetime, 'day') == mod.date, ]
irr = irr[trunc(irr$datetime, 'day') == mod.date, ]

k600 = k.cole.base(wnd[,2])
k.gas = k600.2.kGAS.base(k600, wtr[,3], '02')
do.sat = o2.at.sat(wtr[,1:2], altitude=300)

metab.bayesian(irr=irr[,2], z.mix=rep(1, length(k.gas)),
              do.sat=do.sat[,2], wtr=wtr[,2],
              k.gas=k.gas, do.obs=doobs[,2])

## End(Not run)

```

---

metab.bookkeep	<i>Metabolism model based on simple day/night summation NEP-interpreted changes in DO.</i>
----------------	--

---

## Description

This model is a simple model based on the assumption that movements in DO during the day are due to NEP and gas exchange. Respiration is estimated from night-time decreases. GPP is calculated from the algebraic manipulation of NEP and R. Based on Cole et al 2000.

## Usage

```
metab.bookkeep(do.obs, do.sat, k.gas, z.mix, irr, ...)
```

## Arguments

do.obs	Vector of dissolved oxygen concentration observations, $\text{mg L}^{-1}$
do.sat	Vector of dissolved oxygen saturation values based on water temperature. Calculate using <a href="#">o2.at.sat</a>
k.gas	Vector of kGAS values calculated from any of the gas flux models (e.g., <a href="#">k.cole</a> ) and converted to kGAS using <a href="#">k600.2.kGAS</a>
z.mix	Vector of mixed-layer depths in meters. To calculate, see <a href="#">ts.meta.depths</a>
irr	Integer vector of 1's (daytime) and 0's (nighttime), or numeric vector of irradiance that will be converted to boolean 1's and 0's if "datetime" is passed via ...
...	additional arguments to be passed, particularly POSIXct class "datetime"

## Value

A data.frame with columns corresponding to components of metabolism

**GPP** numeric estimate of Gross Primary Production,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

**R** numeric estimate of Respiration,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

**NEP** numeric estimate of Net Ecosystem production,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

**Author(s)**

R. Iestyn Woolway, Hilary Dugan, Luke A Winslow, Ryan Batt, Jordan S Read, GLEON fellows

**References**

Cole, Jonathan J., Michael L. Pace, Stephen R. Carpenter, and James F. Kitchell. 2000. *Persistence of Net Heterotrophy in Lakes during Nutrient Addition and Food Web Manipulations*. *Limnology and Oceanography* 45 (8): 1718-1730. doi:10.4319/lo.2000.45.8.1718.

**See Also**

[metab.bayesian](#), [metab.mle](#), [metab.kalman](#)

**Examples**

```
library(rLakeAnalyzer)
Sys.setenv(TZ='GMT')

doobs = load.ts(system.file('extdata',
                           'sparkling.doobs', package="LakeMetabolizer"))
wtr = load.ts(system.file('extdata',
                          'sparkling.wtr', package="LakeMetabolizer"))
wnd = load.ts(system.file('extdata',
                          'sparkling.wnd', package="LakeMetabolizer"))

#Subset a day
mod.date = as.POSIXct('2009-07-08', 'GMT')
doobs = doobs[trunc(doobs$datetime, 'day') == mod.date, ]
wtr = wtr[trunc(wtr$datetime, 'day') == mod.date, ]
wnd = wnd[trunc(wnd$datetime, 'day') == mod.date, ]

k.gas = k600.2.kGAS.base(k.cole.base(wnd[,2]), wtr[,3], '02')
do.sat = o2.at.sat.base(wtr[,3], altitude=300)

# Must supply 1 for daytime timesteps and 0 for nighttime timesteps
irr = as.integer(is.day(doobs[,1], 45))

metab.bookkeep(doobs[,2], do.sat, k.gas, z.mix=1, irr, datetime=doobs$datetime)
```

---

metab.kalman

*Metabolism calculated from parameters estimated using a Kalman filter*

---

**Description**

A state space model accounting for process and observation error, with the maximum likelihood of parameters estimated using a Kalman filter. Also provides a smoothed time series of oxygen concentration.

**Usage**

```
metab.kalman(do.obs, do.sat, k.gas, z.mix, irr, wtr, ...)
```

**Arguments**

do.obs	Vector of dissolved oxygen concentration observations, $mgO[2]L^{-1}$
do.sat	Vector of dissolved oxygen saturation values based on water temperature. Calculate using <a href="#">o2.at.sat</a>
k.gas	Vector of kGAS values calculated from any of the gas flux models (e.g., <a href="#">k.cole</a> ) and converted to kGAS using <a href="#">k600.2.kGAS</a>
z.mix	Vector of mixed-layer depths in meters. To calculate, see <a href="#">ts.meta.depths</a>
irr	Vector of photosynthetically active radiation in $\mu mol\ m^{-2}\ s^{-1}$
wtr	Vector of water temperatures in $^{\circ}C$ . Used in scaling respiration with temperature
...	additional arguments; currently "datetime" is the only recognized argument passed through ...

**Details**

The model has four parameters,  $c_1, c_2, Q, H$ , and consists of equations involving the prediction of upcoming state conditional on information of the previous state ( $a_{t|t-1}, P_{t|t-1}$ ), as well as updates of those predictions that are conditional upon information of the current state ( $a_{t|t}, P_{t|t}$ ).  $a$  is the

$$v = k.gas/z.mix$$

$$a_t = c_1 * irr_{t-1} + c_2 * \log_e(wtr_{t-1}) + v_{t-1} * do.sat_{t-1}$$

$$beta = e^{-v}$$

$$do.obs_t = a_t/v_{t-1} + -e^{-v_{t-1}} * a_t/v_{t-1} + beta_{t-1} * do.obs_{t-1} + epsilon_t$$

The above model is used during model fitting, but if gas flux is not integrated between time steps, those equations simplify to the following:

$$F_{t-1} = k.gas_{t-1} * (do.sat_{t-1} - do.obs_{t-1})/z.mix_{t-1}$$

$$do.obs_t = do.obs_{t-1} + c_1 * irr_{t-1} + c_2 * \log_e(wtr_{t-1}) + F_{t-1} + epsilon_t$$

The parameters are fit using maximum likelihood, and the optimization (minimization of the negative log likelihood function) is performed by `optim` using default settings.

GPP is then calculated as `mean(c1*irr, na.rm=TRUE)*freq`, where `freq` is the number of observations per day, as estimated from the typical size between time steps. Thus, generally `freq=length(do.obs)`.

Similarly, R is calculated as `mean(c2*log(wtr), na.rm=TRUE)*freq`.

NEP is the sum of GPP and R.

**Value**

A data.frame with columns corresponding to components of metabolism

**GPP** numeric estimate of Gross Primary Production,  $mgO_2L^{-1}d^{-1}$

**R** numeric estimate of Respiration,  $mgO_2L^{-1}d^{-1}$

**NEP** numeric estimate of Net Ecosystem production,  $mgO_2L^{-1}d^{-1}$

Use [attributes](#) to access more model output:

smoothDO smoothed time series of oxygen concentration ( $mgO[2]L^{-1}$ ), from Kalman smoother

params parameters estimated by the Kalman filter ( $c_1, c_2, Q, H$ )

**Note**

If observation error is substantial, consider applying a Kalman filter to the water temperature time series by supplying wtr as the output from [temp.kalman](#)

**Author(s)**

Ryan Batt, Luke A. Winslow

**References**

Batt, Ryan D. and Stephen R. Carpenter. 2012. *Free-water lake metabolism: addressing noisy time series with a Kalman filter*. *Limnology and Oceanography: Methods* 10: 20-30. doi: 10.4319/lom.2012.10.20

**See Also**

[temp.kalman](#), [watts.in](#), [metab](#), [metab.bookkeep](#), [metab.ols](#), [metab.mle](#), [metab.bayesian](#)

**Examples**

```
library(rLakeAnalyzer)
doobs <- load.ts(system.file('extdata',
                             'sparkling.doobs', package="LakeMetabolizer"))
wtr <- load.ts(system.file('extdata',
                           'sparkling.wtr', package="LakeMetabolizer"))
wnd <- load.ts(system.file('extdata',
                           'sparkling.wnd', package="LakeMetabolizer"))
irr <- load.ts(system.file('extdata',
                           'sparkling.par', package="LakeMetabolizer"))

#Subset a day
Sys.setenv(TZ='GMT')
mod.date <- as.POSIXct('2009-07-08', 'GMT')
doobs <- doobs[trunc(doobs$datetime, 'day') == mod.date, ]
wtr <- wtr[trunc(wtr$datetime, 'day') == mod.date, ]
wnd <- wnd[trunc(wnd$datetime, 'day') == mod.date, ]
irr <- irr[trunc(irr$datetime, 'day') == mod.date, ]

k600 <- k.cole.base(wnd[,2])
```

```

k.gas <- k600.2.kGAS.base(k600, wtr[,3], 'O2')
do.sat <- o2.at.sat.base(wtr[,3], altitude=300)

metab.kalman(irr=irr[,2], z.mix=rep(1, length(k.gas)),
             do.sat=do.sat, wtr=wtr[,2],
             k.gas=k.gas, do.obs=doobs[,2])

```

---

metab.mle	<i>Metabolism calculated from the maximum likelihood estimates of the parameters in a standard linear regression model</i>
-----------	--

---

### Description

Process-error-only model with parameters fitted via maximum likelihood estimation (MLE). This function runs the maximum likelihood metabolism model on the supplied gas concentration and other supporting data.

### Usage

```
metab.mle(do.obs, do.sat, k.gas, z.mix, irr, wtr, error.type = "OE", ...)
```

### Arguments

do.obs	Vector of dissolved oxygen concentration observations, $mgO[2]L^{-1}$
do.sat	Vector of dissolved oxygen saturation values based on water temperature. Calculate using <a href="#">o2.at.sat</a>
k.gas	Vector of kGAS values calculated from any of the gas flux models (e.g., <a href="#">k.cole</a> ) and converted to kGAS using <a href="#">k600.2.kGAS</a>
z.mix	Vector of mixed-layer depths in meters. To calculate, see <a href="#">ts.meta.depths</a>
irr	Vector of photosynthetically active radiation in $\mu mol\ m^{-2}\ s^{-1}$
wtr	Vector of water temperatures in $^{\circ}C$ . Used in scaling respiration with temperature
error.type	Option specifying if model should assume pure Process Error 'PE' or Observation Error 'OE'. Defaults to observation error 'OE'.
...	additional arguments; currently "datetime" is the only recognized argument passed through ...

### Details

The model has the three parameters,  $c_1$ ,  $c_2$ ,  $\epsilon$ , and has the form

$$v = k.gas/z.mix$$

$$a_t = c_1 * irr_{t-1} + c_2 * \log_e(wtr_{t-1}) + v_{t-1} * do.sat_{t-1}$$

$$\beta = e^{-v}$$

$$do.obs_t = a_t/v_{t-1} + -e^{-v_{t-1}} * a_t/v_{t-1} + \beta_{t-1} * do.obs_{t-1} + \epsilon_t$$

The above model is used during model fitting, but if gas flux is not integrated between time steps, those equations simplify to the following:

$$F_{t-1} = k.gas_{t-1} * (do.sat_{t-1} - do.obs_{t-1})/z.mix_{t-1}$$

$$do.obs_t = do.obs_{t-1} + c_1 * irr_{t-1} + c_2 * \log_e(wtr_{t-1}) + F_{t-1} + \epsilon_t$$

The parameters are fit using maximum likelihood, and the optimization (minimization of the negative log likelihood function) is performed by `optim` using default settings.

GPP is then calculated as `mean(c1*irr, na.rm=TRUE)*freq`, where `freq` is the number of observations per day, as estimated from the typical size between time steps. Thus, generally `freq=length(do.obs)`.

Similarly, R is calculated as `mean(c2*log(wtr), na.rm=TRUE)*freq`.

NEP is the sum of GPP and R.

### Value

A `data.frame` with columns corresponding to components of metabolism

**GPP** numeric estimate of Gross Primary Production,  $mgO_2L^{-1}d^{-1}$

**R** numeric estimate of Respiration,  $mgO_2L^{-1}d^{-1}$

**NEP** numeric estimate of Net Ecosystem production,  $mgO_2L^{-1}d^{-1}$

The maximum likelihood estimates of model parameters can be accessed via `attributes(metab.mle(...))["params"]`

### Note

Currently, missing values in any arguments will result in an error, so `freq` must always equal `nobs`.

### Author(s)

Luke A Winslow, Ryan Batt, GLEON Fellows

### References

Hanson, PC, SR Carpenter, N Kimura, C Wu, SP Cornelius, TK Kratz. 2008 *Evaluation of metabolism models for free-water dissolved oxygen in lakes*. *Limnology and Oceanography: Methods* 6: 454:465.

Solomon CT, DA Bruesewitz, DC Richardson, KC Rose, MC Van de Bogert, PC Hanson, TK Kratz, B Larget, R Adrian, B Leroux Babin, CY Chiu, DP Hamilton, EE Gaiser, S Hendricks, V Istvanovics, A Laas, DM O'Donnell, ML Pace, E Ryder, PA Staehr, T Torgersen, MJ Vanni, KC Weathers, G Zhuw. 2013. *Ecosystem Respiration: Drivers of Daily Variability and Background Respiration in Lakes around the Globe*. *Limnology and Oceanography* 58 (3): 849:866. doi:10.4319/lo.2013.58.3.0849.

**See Also**

[metab](#), [metab.bookkeep](#), [metab.ols](#), [metab.kalman](#), [metab.bayesian](#)

**Examples**

```
library(rLakeAnalyzer)
doobs = load.ts(system.file('extdata',
                           'sparkling.doobs', package="LakeMetabolizer"))
wtr = load.ts(system.file('extdata',
                          'sparkling.wtr', package="LakeMetabolizer"))
wnd = load.ts(system.file('extdata',
                          'sparkling.wnd', package="LakeMetabolizer"))
irr = load.ts(system.file('extdata',
                          'sparkling.par', package="LakeMetabolizer"))

#Subset a day
mod.date = as.POSIXct('2009-07-08', 'GMT')
doobs = doobs[trunc(doobs$datetime, 'day') == mod.date, ]
wtr = wtr[trunc(wtr$datetime, 'day') == mod.date, ]
wnd = wnd[trunc(wnd$datetime, 'day') == mod.date, ]
irr = irr[trunc(irr$datetime, 'day') == mod.date, ]
z.mix = ts.thermo.depth(wtr)

k600 = k.cole.base(wnd[,2])
k.gas = k600.2.kGAS.base(k600, wtr[,3], '02')
do.sat = o2.at.sat.base(wtr[,3], altitude=300)

metab.mle(doobs[,2], do.sat, k.gas, z.mix[,2], irr[,2], wtr[,3])
```

---

metab.ols

*Metabolism model based on a ordinary least squares parameter estimation framework.*

---

**Description**

This function runs the ordinary least squares metabolism model on the supplied gas concentration and other supporting data. This is a common approach that allows for the concurrent estimation of metabolism paramters from a timeseries.

**Usage**

```
metab.ols(do.obs, do.sat, k.gas, z.mix, irr, wtr, ...)
```

**Arguments**

do.obs            Vector of dissolved oxygen concentration observations, mg L<sup>-1</sup>  
do.sat            Vector of dissolved oxygen saturation values based on water temperature. Calculate using [o2.at.sat](#)

k.gas	Vector of kGAS values calculated from any of the gas flux models (e.g., <a href="#">k.cole</a> ) and converted to kGAS using <a href="#">k600.2.kGAS</a>
z.mix	Vector of mixed-layer depths in meters. To calculate, see <a href="#">ts.meta.depths</a>
irr	Vector of photosynthetically active radiation in $\mu\text{mol m}^{-2}\text{s}^{-1}$
wtr	Vector of water temperatures in $^{\circ}\text{C}$ . Used in scaling respiration with temperature
...	additional arguments; currently "datetime" is the only recognized argument passed through ...

### Value

A data.frame with columns corresponding to components of metabolism

**GPP** numeric estimate of Gross Primary Production,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

**R** numeric estimate of Respiration,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

**NEP** numeric estimate of Net Ecosystem production,  $\text{mgO}_2\text{L}^{-1}\text{d}^{-1}$

### Author(s)

Luke A Winslow, Ryan Batt, GLEON Fellows

### See Also

[metab](#), [metab.bookkeep](#), [metab.mle](#), [metab.kalman](#), [metab.bayesian](#),

### Examples

```
library(rLakeAnalyzer)
doobs = load.ts(system.file('extdata',
                           'sparkling.doobs', package="LakeMetabolizer"))
wtr = load.ts(system.file('extdata',
                          'sparkling.wtr', package="LakeMetabolizer"))
wnd = load.ts(system.file('extdata',
                          'sparkling.wnd', package="LakeMetabolizer"))
irr = load.ts(system.file('extdata',
                          'sparkling.par', package="LakeMetabolizer"))

#Subset a day
mod.date = as.POSIXct('2009-07-08')
doobs = doobs[trunc(doobs$datetime, 'day') == mod.date, ]
wtr = wtr[trunc(wtr$datetime, 'day') == mod.date, ]
wnd = wnd[trunc(wnd$datetime, 'day') == mod.date, ]
irr = irr[trunc(irr$datetime, 'day') == mod.date, ]
z.mix = ts.thermo.depth(wtr)

k600 = k.cole.base(wnd[,2])
k.gas = k600.2.kGAS.base(k600, wtr[,3], '02')
do.sat = o2.at.sat.base(wtr[,3], altitude=300)

metab.ols(doobs[,2], do.sat, k.gas, z.mix[,2], irr[,2], wtr[,3])
```

---

o2.at.sat	<i>Calculates the equilibrium saturation concentration of oxygen in water at the supplied conditions</i>
-----------	--

---

### Description

Used to calculate the equilibrium concentration of oxygen in water. The equilibration concentration of oxygen in water varies with both temperature, salinity, and the partial pressure of oxygen in contact with the water (calculated from supplied elevation or barometric pressure).

### Usage

```
o2.at.sat(ts.data, baro, altitude = 0, salinity = 0, model = "garcia-benson")

o2.at.sat.base(
  temp,
  baro,
  altitude = 0,
  salinity = rep(0, length(temp)),
  model = "garcia-benson"
)
```

### Arguments

ts.data	Object of class data.frame with two named columns "datetime" and "wtr" (water temp in deg C).
baro	barometric pressure in millibars.
altitude	a numeric value indicating the elevation above mean sea level in meters. Defaults to mean sea level. An alternative to supplying barometric pressure.
salinity	a numeric vector of salinity in PSU. Defaults to zero. Length must be one or equal to length of temperature.
model	the empirical model to be used. "garcia-benson", "garcia", "weiss" and "benson" are the available options. "garcia-benson" is our current recommendation. The models correspond to the like-named references described below, where both "garcia" and "garcia-benson" are from Garcia & Gordon (1992).
temp	a numeric vector of water temperature in degrees Celsius.

### Details

DO solubility is converted from mL/L to mg/L by multiplying by 1.42905, per USGS memo 2011.03. Corrections for vapor pressure are made according to barometric pressure as in Equations 2&3 of USGS memos 81.11 and 81.15. When barometric pressure is not supplied, it is estimated from altitude by the barometric formula as in Colt (2012).

**Value**

The equilibration concentration at the supplied conditions in mg/L of oxygen.

**Author(s)**

Luke A Winslow

**References**

Colt, John. *1 - Solubility of Atmospheric Gases in Freshwater*. In *Computation of Dissolved Gas Concentration in Water as Functions of Temperature, Salinity and Pressure (Second Edition)*, edited by John Colt, 1-71. London: Elsevier, 2012. <http://www.sciencedirect.com/science/article/pii/B9780124159167000012>.

Garcia, H., and L. Gordon (1992), *Oxygen solubility in seawater: Better fitting equations*, *Limnol. Oceanogr.*, 37(6).

Benson, B. B. & Krause, D. (1984). *The concentration and isotopic fractionation of oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere*. *Limnology and Oceanography*, 29(3), 620-632. doi:10.4319/lo.1984.29.3.0620

Staehr, Peter A., Darren Bade, Matthew C. Van de Bogert, Gregory R. Koch, Craig Williamson, Paul Hanson, Jonathan J. Cole, and Tim Kratz. *Lake Metabolism and the Diel Oxygen Technique: State of the Science*. *Limnology and Oceanography: Methods* 8, no. 11 (November 1, 2010): 628-44. doi:10.4319/lom.2010.8.0628

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**See Also**

[water.density](#), [o2.at.sat.base](#)

**Examples**

```
temp.range = 1:25
sal.range = 1:25

par(mfrow=c(1,2))
plot(temp.range, o2.at.sat.base(temp.range), xlab='Temperature (C)',
ylab='Oxygen Saturation (mg/L)')
plot(o2.at.sat.base(rep(20,25), salinity=sal.range), xlab='Salinity (PSU)', ylab='')
```

---

par.to.sw	<i>Convert PAR to shortwave</i>
-----------	---------------------------------

---

**Description**

Returns incoming shortwave radiation by converting PAR measurement.

**Usage**

```
par.to.sw.base(par, coeff=0.473)
par.to.sw(data, par.col='par', coeff=0.473)
```

**Arguments**

data	Object of class data.frame with column name 'par' (units $\mu\text{mol}/\text{m}^2/\text{sec}$ )
par.col	String of alternative name for PAR column
coeff	Numerical coefficient to convert PAR ( $\mu\text{mol}/\text{m}^2/\text{sec}$ ) to SW ( $\text{W}/\text{m}^2$ ). Defaults to value from Britton and Dodd (1976).
par	Numeric vector of PAR values ( $\mu\text{mol}/\text{m}^2/\text{sec}$ )

**Value**

```
#For par.to.sw
Object of class data.frame with column name 'sw' and other values from ts.data
#For par.to.sw.base
Numeric vector of shortwave values with units  $\text{W}/\text{m}^2$ 
```

**Author(s)**

LakeMetabolizer

**References**

Britton, C. M., and J. D. Dodd. *Relationships of photosynthetically active radiation and shortwave irradiance*. Agricultural Meteorology 17, no. 1 (1976): 1-7.

**See Also**

[sw.to.par](#)

**Examples**

```
par <- 800
par.to.sw.base(par)
```

---

rmv.vars	<i>subsets data.frame according to header names</i>
----------	---

---

**Description**

subsets data according to header names. Excludes all matches to var.name

**Usage**

```
rmv.vars(data, var.name, ignore.missing=TRUE, ignore.offset=FALSE)
```

**Arguments**

data	Object of class data.frame
var.name	A character vector of names to remove from data
ignore.missing	Boolean, should an error be thrown if no matching data found
ignore.offset	Should the numerical offset be ignored in the match, (e.g. all wtr columns removed, or wtr_0 specifically)

**Value**

An object of class data.frame

**Author(s)**

Luke A. Winslow

**See Also**

[has.vars](#) [get.vars](#)

---

sun.rise.set	<i>Calculates the time of sunrise and sunset</i>
--------------	--

---

**Description**

Calculates the time of sunrise and sunset based on latitude and date.

**Usage**

```
sun.rise.set(datetimes, lat)
```

**Arguments**

datetimes	Vector of dates as POSIXct or POSIXlt (see <a href="#">DateTimeClasses</a> ) format
lat	Single latitude value of site. South should be negative, north positive

**Value**

A 2-column data frame, first column sunrise, second column sunset, as [POSIXct](#) format in standard time. Value is NA when there is no defined sunrise or sunset for that day (winter/summer at high and low latitudes).

**Author(s)**

Luke A. Winslow

**References**

Iqbal, Muhammad. 1983. An Introduction to Solar Radiation. Elsevier.

**See Also**

[is.night](#) [is.day](#)

**Examples**

```
sun.rise.set(lat=40.75, datetimes=as.POSIXlt('2013-03-31'))
```

---

sw.to.par

*Convert shortwave radiation to PAR*

---

**Description**

Returns PAR by converting incoming shortwave radiation measurement.

**Usage**

```
sw.to.par(data, sw.col='sw', coeff=2.114)
```

```
sw.to.par.base(sw, coeff=2.114)
```

**Arguments**

data	Object of class data.frame with column name sw (or specified alternate)
sw.col	Name of column containing shortwave data (units must be W/m <sup>2</sup> )
coeff	Numerical coefficient to convert SW (W/m <sup>2</sup> ) to PAR (umol/m <sup>2</sup> /sec). Defaults to value from Britton and Dodd (1976).
sw	Numeric shortwave value in W/m <sup>2</sup>

**Value**

#For sw.to.par

Object of class data.frame with column name 'par' and other values from ts.data

#for sw.to.par.base

Numeric vector of PAR values in units umol/m<sup>2</sup>/sec

**Author(s)**

Luke Winslow and others

**References**

Britton, C. M., and J. D. Dodd. *Relationships of photosynthetically active radiation and shortwave irradiance*. Agricultural Meteorology 17, no. 1 (1976): 1-7.

**See Also**

[par.to.sw](#)

**Examples**

```
#For base function
sw <- 800
sw.to.par.base(sw)
```

---

temp.kalman

*Smooth temperature time series using a Kalman filter/ smoother*


---

**Description**

Smooths a temperature time series uses a Kalman filter/ smoother.

**Usage**

```
temp.kalman(wtr, watts, ampH=1, ...)
```

**Arguments**

wtr	Vector (regular time series) of water temperature in degrees C
watts	estimate of watts entering the layer at each time step, from <a href="#">watts.in</a>
ampH	factor by which to artificially amplify the observation error variance, H
...	parameters to be passed to <a href="#">optim</a>

**Details**

basic model process is  $x[t] = \text{beta} * x[t-1] + c1 * \text{watts}[t-1]$

**Value**

a smoothed temperature time series

**Author(s)**

Ryan Batt

## References

Batt, Ryan D. and Stephen R. Carpenter. 2012. *Free-water lake metabolism: addressing noisy time series with a Kalman filter*. *Limnology and Oceanography: Methods* 10: 20-30. doi: 10.4319/lom.2012.10.20

## See Also

[watts.in metab.kalman](#)

---

var.indx	<i>finds matching column names in data.frame</i>
----------	--

---

## Description

returns index of column matches for data according to header names matches with var.names.

## Usage

```
var.indx(data, var.name)
```

## Arguments

data	Object of class data.frame
var.name	A character vector of names to find matches with data

## Value

a boolean vector with same length as var.names

## Author(s)

Luke A. Winslow

## See Also

[has.vars](#) [get.vars](#) [rmv.vars](#)

---

`watts.in`*Simple estimate of energy gained by a layer of water*

---

**Description**

Estimate the amount of energy gained by a layer of water as the difference between energy entering from the top of the layer and energy leaving at the bottom. Energy gained/ lost is calculated from photosynthetically active radiation (PAR, which is then converted to watts) and an estimate of kd (light attenuation coefficient) which is derived from the depth of 1 percent surface light.

**Usage**

```
watts.in(top, bot, irr, z1perc)
```

**Arguments**

<code>top</code>	Depth of the top of the layer, in meters
<code>bot</code>	Depth of the bottom of the layer, in meters
<code>irr</code>	PAR in uE/s ( $\mu\text{mol} / \text{m}^2 / \text{s}$ )
<code>z1perc</code>	Depth of 1 percent of surface light, in meters

**Details**

This rough estimate is used in the Kalman filter/ smoother for water temperature. It does not account for a variety of potentially important factors, and is made specifically for use with `temp.kalman()`, which uses maximum likelihood to fit a linear coefficient that converts this heat gain estimate into temperature change.

**Value**

numeric vector of estimates of energy gain

**Author(s)**

Ryan Batt, Luke Winslow

**References**

Batt, Ryan D. and Stephen R. Carpenter. 2012. *Free-water lake metabolism: addressing noisy time series with a Kalman filter*. *Limnology and Oceanography: Methods* 10: 20-30. doi: 10.4319/lom.2012.10.20

**See Also**

[temp.kalman](#) [metab.kalman](#)

**Examples**

```
watts.in(3.2, 4, 1200, 4.5)
```

---

`wind.scale`*Wind Scaling U10 - exponential conversion to 10m wind speed*

---

**Description**

Scale wind speed to standard U10 (10 meters) based on height of observations

**Usage**

```
## Used for timeseries data in a data.frame
wind.scale(ts.data, wnd.z)

## Used for raw numeric data
wind.scale.base(wnd, wnd.z)
```

**Arguments**

<code>ts.data</code>	Object of class data.frame containing a wnd column.
<code>wnd.z</code>	height of anemometer (Units: meters)
<code>wnd</code>	measured wind speed (Units: typically m s <sup>-1</sup> , but it is unit agnostic)

**Details**

This function transforms wind speed to the standard U10, speed at 10 meters, based on the common exponential wind profile assumption. `wind.scale` defaults to using the supplied `wnd.z` value. If `wnd.z` is not supplied, it attempts to determine the anemometer height from the suffix of the header (e.g., a header of `wnd_3` would mean an anemometer height of 3 meters).

**Value**

```
## wind.scale Returns a data frame with columns datetime and wnd_10 and the same number of
rows as ts.data

## wind.scale.base Returns a vector with the same length as wnd
```

**Author(s)**

Aline Jaimes, Luke A. Winslow

**References**

Saucier, W. 2003. *Principles of Meteorological Analysis*. Dover Publications. New York. p433

**See Also**

Models of gas flux [k.cole](#), [k.crusius](#), [k.macIntyre](#), & [k.read](#).

**Examples**

```
wndSpeed <- c(5.1,6.3,6.3,5.2,7,7.2)
wndHeight <- 2
```

```
wind.scale.base(wndSpeed, wndHeight)
```

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