Package 'ccrtm'

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Type Package

Title Coupled Chain Radiative Transfer Models

Version 0.1.6

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Description A set of radiative transfer models to quantitatively describe the absorption, reflectance and transmission of solar energy in vegetation, and model remotely sensed spectral signatures of vegetation at distinct spatial scales (leaf,canopy and stand). The main principle behind ccrtm is that many radiative transfer models can form a coupled chain, basically models that feed into each other in a linked chain (from leaf, to canopy, to stand, to atmosphere). It allows the simulation of spectral datasets in the solar spectrum (400-2500nm) using leaf models as PROSPECT5, 5b, and D which can be coupled with canopy models as 'FLIM', 'SAIL' and 'SAIL2'. Currently, only a simple atmospheric model ('skyl') is implemented. Jacquemoud et al 2008 provide the most comprehensive overview of these models <doi:10.1016/j.rse.2008.01.026>.

License GPL (>= 2)

URL `https://github.com/MarcoDVisser/ccrtm`

BugReports `https://github.com/MarcoDVisser/ccrtm/issues`

Imports graphics, grDevices, stats, testthat, Rcpp (>= 1.0.3), expint, pracma

LinkingTo Rcpp

Repository CRAN

RoxygenNote 7.0.2

NeedsCompilation yes

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Depends R (>= 3.5.0)

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R topics documented:

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bRTM *Generates an invertable model for backward implementation of Radiative Transfer Models*

Description

Generates an invertable model for backward implementation of Radiative Transfer Models

Usage

```
bRTM(fm = rho ~ prospect5, data = NULL, pars = NULL, fixed = NULL,
  wl = 400:2500)
```

Arguments

fm	A formula specifying which rtm to run
data	ignored as of yet

`pars`	a list of _named_ parameter vectors for all models. The parameter list for a model call as rho ~ prospect + foursail therefore contains two named vectors the first with parameters for prospect and the second with parameters for foursail if left empty default parameters are generated
`fixed`	a list of parameters to fix
`wl`	wavelengths (in nm) add only if certain wavelengths are required as output. Input is expected to integers between 400 and 2500, or will be forced to be an integer. Integers outside the 400:2500 range will not be returned.

`cambell` *Leaf inclination distribution function Ellipsoidal distribution function*

Description

Leaf inclination distribution function Ellipsoidal distribution function

Usage

```
cambell(ala, tx1, tx2)
```

Arguments

`ala`	average leaf angle parameter
`tx1`	angle in degree
`tx2`	angle in degree

Value

angle fraction value

`ccrtm` *ccrtm: Coupled Chain Radiative Transfer Models.*

Description

A collection of radiative transfer models that can form a coupled chain to model radiative transfer across multiple spatial scales from leaf to canopy to stand.

Details

Currently implemented models:

- [1] = PROSPECT 5, 5B and D
- [2] = FOURSAIL, and FOURSAIL2
- [3] = FLIM

Currently being tested or to be implemented models

- [1] = LIBERTY, PROCOSINE
- [2] = INFORM

Author(s)

Marco D. Visser

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cdcum — *Leaf inclination distribution function cummulative lagden function from Wout Verhoef's dissertation Extended here for any angle*

Description

Leaf inclination distribution function cummulative lagden function from Wout Verhoef's dissertation Extended here for any angle

Usage

```
cdcum(a, b, theta)
```

Arguments

`a`	parameter
`b`	parameter
`theta`	angle in degrees

Value

angle fraction value

`data_prospect5` *refractive index and specific absorption coefficient for PROSPECT 5*

Description

see http://teledetection.ipgp.jussieu.fr/prosail/ for more details on the data.

Usage

```
data(prospect5)
```

details

*** data_prospect5 (february, 25th 2008) The dataset contains the following labels (columns): ***

- [1] = wavelength (nm)
- [2] = refractive index of leaf material (or the ratio of the velocity of light in a vacuum to its velocity in "leaf medium").
- [3] = specific absorption coefficient of chlorophyll (a+b) (cm2.microg-1)
- [4] = specific absorption coefficient of carotenoids (cm2.microg-1)
- [5] = specific absorption coefficient of brown pigments (arbitrary units)
- [6] = specific absorption coefficient of water (cm-1)
- [7] = specific absorption coefficient of dry matter (g.cm-1)
- [8] = direct light
- [9] = diffuse light
- [10] = dry soil
- [11] = wet soil

references

Feret et al. (2008), PROSPECT-4 and 5: Advances in the Leaf Optical Properties Model Separating Photosynthetic Pigments, Remote Sensing of Environment

data_prospectd — *refractive index and specific absorption coefficient for PROSPECT D*

Description

see http://teledetection.ipgp.jussieu.fr/prosail/ for more details on the data.

Usage

```
data(prospectd)
```

details

*** data_prospect5 (february, 25th 2008) The dataset contains the following labels (columns): ***

- [1] = wavelength (nm)
- [2] = refractive index of leaf material (or the ratio of the velocity of light in a vacuum to its velocity in "leaf medium").
- [3] = specific absorption coefficient of chlorophyll (a+b) (cm2.microg-1)
- [4] = specific absorption coefficient of carotenoids (cm2.microg-1)
- [5] = specific absorption coefficient of brown pigments (arbitrary units)
- [6] = specific absorption coefficient of water (cm-1)
- [7] = specific absorption coefficient of dry matter (g.cm-1)
- [8] = direct light
- [9] = diffuse light
- [10] = dry soil
- [11] = wet soil

references

Feret et al. (2008), PROSPECT-4 and 5: Advances in the Leaf Optical Properties Model Separating Photosynthetic Pigments, Remote Sensing of Environment

`flim` *Forest Light Interaction Model (FLIM)*

Description

The FLIM model was first described by Rosema et al (1992). In FLIM forests are assumed a discontinous mix of tree crowns and gaps. Reflectance is modelled in terms of the probabilty to observe either a gap (background) or a tree crown. Both gaps and crowns may be shaded.

Usage

```
flim(Rc, Rg, To = NULL, Ts = NULL, params, area = 10000)
```

Arguments

`Rc`	Canopy reflectance at infinite depth
`Rg`	soil/background reflectance
`To`	transmission in viewing direction
`Ts`	transmission in sun direction
`params`	a named vector of parameters: • [1] = D, stand density (confounded with cd) • [2] = cd, crown diameter (confounded with D) • [3] = h, mean crown height • [6] = Solar zenith angle (tts) • [7] = Observer zenith angle (tto) • [8] = Sun-sensor azimuth angle (psi)
`area`	area of stand

Details

Confounded parameters pairs cannot be inversely estimated, one of the pairs should be set to 1.

Value

a list with reflectance, and the fractions of shaded and sunexplosed crowns, shaded and sun exposed open space.

References

Rosema, A., Verhoef, W., Noorbergen, H., Borgesius, J.J. (1992). A new forest light interaction model in support of forest monitoring. Remote Sens. Environ. 42, 23-41.

`foursail` *Optimized R implementation of foursail (4SAIL)*

Description

The foursail (or 4SAIL) radiative transfer model is commonly used to simulate bidirectional reflectance distribution functions within vegetation canopies. Foursail (4SAIL) refers to "Scattering by Arbitrary Inclined Leaves" in a 4-stream model. The four-streams represents the scattering and absorption of upward, downward and two directional radiative fluxes with four linear differential equations in a 1-D canopy. The model was initially developed by Verhoef (1984), who extended work by Suits (1971) 4-steam model.

Usage

```
foursail(rho, tau, bgr, param)
```

Arguments

`rho`	input leaf reflectance from 400-2500nm (can be measured or modeled)
`tau`	input leaf transmittance from 400-2500nm (can be measured or modeled)
`bgr`	background reflectance. Usual input is soil reflectance spectra from 400-2500nm (can be measured or modeled)
`param`	A named vector of SAIL parameter values (note: program ignores case): • [1] = Leaf angle distribution function parameter a (LIDFa) • [2] = Leaf angle distribution function parameter b (LIDFb) • [3] = Leaf angle distribution function type (see ?lidfFun) • [4] = Leaf area index (LAI) • [5] = Hot spot effect parameter (hspot) • [6] = Solar zenith angle (tts) • [7] = Observer zenith angle (tto) • [8] = Sun-sensor azimuth angle (psi)

Value

spectra matrixwith 4 reflectance factors and canopy transmission for wavelengths 400 to 2500nm:

- [1] = bi-hemispherical reflectance (rddt). White-sky albedo: the reflectance of the canopy under diffuse illumination. The BRDF integrated over all viewing and illumination directions.
- [2] = hemispherical directional reflectance (rsdt). Black-sky albedo: reflectance of a surface under direct light without a diffuse component. It is the integral of the BRDF over all viewing directions.
- [3] = directional hemispherical reflectance (rdot). Diffuse reflectance in the vieweing direction.
- [4] = bi-directional reflectance (rsot). The ratio of reflected radiance in the viewing direction to the incoming radiant flux in the solar direction.

- [5] = Canopy transmission of diffuse light through the canopy (taud).
- [6] = transmission of direct light through the canopy (taus).

References

Suits, G.H., 1971. The calculation of the directional reflectance of a vegetative canopy. Remote Sens. Environ. 2, 117-125.

Verhoef, W. (1984). Light scattering by leaf layers with application to canopy reflectance modeling: The SAIL model. Remote Sens. Environ. 16, 125-141.

Examples

```
## lower-level implementation example
## see ?fRTM for the typical mode of simulation
## e.g. fRTM(rho~prospectd+foursail)

## 1) get parameters
params<-getDefaults(rho~prospectd+foursail)
## getDefaults("foursail") will also work
bestpars<-params$foursail$best
## ensure the vector is named
names(bestpars) <- rownames(params$foursail)

## 2) get leaf reflectance and transmission
rt<-fRTM(rho+tau~prospectd)

## 3) get soil reflectance to model background reflectance
data(soil)

## a linear mixture soil model
bgRef<- bestpars["psoil"]*soil[,"drySoil"] + (1-bestpars["psoil"])*soil[,"wetSoil"]

## 4) run 4SAIL
foursail(rt[,"rho"],rt[,"tau"],bgRef,bestpars)
```

---

foursail2 *R implementation of the foursail2 model with 2 canopy layers.*

Description

The foursail2 model is a two layer implementation of the foursail model described in Verhoef and Bach (2007). Layers are assumed identical in particle inclination and hotspot, but may differ in the relative density and types of particles (see foursail2b for a layer specific inclination angle). In comparison to foursail, the background (soil), can now be non-Lambertain, having it own 4-stream BDRF (not implemented here but may be input by the user). There are two types of particles, generalized to primary and secondary (originally termed "green" and "brown" particles). The realtive abundance of the secondary particle in the top canopy is regulated by the dissociation paramerter.The model 4SAIL2 combines with prospect, libery or procosine for the reflectance and transmittance of the particles, and with the the foursail or Hapke elements for the background reflectance. If run alone, these require direct inputs which could be measured leaf reflectance.

Usage

```
foursail2(rhoA, tauA, rhoB = NULL, tauB = NULL, bgr, rsobgr = NULL,
  rdobgr = NULL, rsdbgr = NULL, rddbgr = NULL, param)
```

Arguments

`rhoA`	primary particle reflectance from 400-2500nm (can be measured or modeled)
`tauA`	primary particle transmittance from 400-2500nm (can be measured or modeled)
`rhoB`	secondary particle reflectance from 400-2500nm (can be measured or modeled)
`tauB`	secondary particle reflectance from 400-2500nm (can be measured or modeled)
`bgr`	background reflectance. Usual input is soil reflectance spectra from 400-2500nm (can be measured or modeled)
`rsobgr`	: background bidirectional reflectance (rso)
`rdobgr`	: background directional hemispherical reflectance (rdo)
`rsdbgr`	: background hemispherical directional reflectance (rsd)
`rddbgr`	: background bi-hemispherical diffuse reflectance (rdd)
`param`	A named vector of 4SAIL2 parameter values (note: program ignores case):

- [1] = Leaf angle distribution function parameter a (LIDFa)
- [2] = Leaf angle distribution function parameter b (LIDFb)
- [3] = Leaf angle distribution function type (TypeLidf, see ?lidfFun)
- [4] = Total Leaf Area Index (LAI), including primary and secondary particles (brown and green leafs).
- [5] = fraction secondary particles ("brown leaf fraction", fb)
- [6] = Canopy dissociation factor for secondary particles ("diss")
- [7] = Hot spot effect parameter (hspot). Often defined as the ratio of mean leaf width and canopy height.
- [7] = vertical crown coverage fraction (Cv), models clumping in combination with parameter zeta.
- [7] = tree shape factor (zeta), defined as the ratio of crown diameter and height.
- [6] = Solar zenith angle (tts)
- [7] = Observer zenith angle (tto)
- [8] = Sun-sensor azimuth angle (psi)

Value

spectra matrixwith 4 reflectance factors and canopy transmission for wavelengths 400 to 2500nm:

- [1] = bi-hemispherical reflectance (rddt). White-sky albedo: the reflectance of the canopy under diffuse illumination. The BRDF integrated over all viewing and illumination directions. Diffuse reflectance for diffuse incidence.

- [2] = hemispherical directional reflectance (rsdt). Black-sky albedpo: reflectance of a surface under direct light without a diffuse component. It is the integral of the BRDF over all viewing directions. Diffuse reflectance for direct solar incidence.
- [3] = directional hemispherical reflectance (rdot). Diffuse reflectance in the vieweing direction.
- [4] = bi-directional reflectance (rsot). The ratio of reflected radiance in the viewing direction to the incoming radiant flux in the solar direction.

References

Verhoef, W., Bach, H. (2007). Coupled soil-leaf-canopy and atmosphere radiative transfer modeling to simulate hyperspectral multi-angular surface reflectance and TOA radiance data. Remote Sens. Environ. 109, 166-182.

Examples

```
## see ?foursail for lower-level implementations
fRTM(rho~prospect5+foursail2)
```

`foursail2b` *R implementation of the foursail2 model with 2 canopy layers.*

Description

The foursail2b model is a two layer implementation of the foursail model described in Zhang et al (2005). Layers are assumed identical in hotspot, but may differ in the relative density, inclination and types of particles. In comparison to foursail, the background (soil), can now be non-Lambertain, having it own 4-stream BDRF. There are two types of particles, generalized to primary and secondary (originally termed "green" and "brown" particles). The realtive abundance of the secondary particle in the top canopy is regulated by the dissociation paramerter.The model 4SAIL2 combines with prospect, libery or procosine for the reflectance and transmittance of the particles, and with the the foursail or Hapke elements for the background reflectance. If run alone, these require direct inputs which could be measured leaf reflectance.

Usage

```
foursail2b(rhoA, tauA, rhoB = NULL, tauB = NULL, bgr, rsobgr = NULL,
  rdobgr = NULL, rsdbgr = NULL, rddbgr = NULL, param)
```

Arguments

`rhoA`	primary particle reflectance from 400-2500nm (can be measured or modeled)
`tauA`	primary particle transmittance from 400-2500nm (can be measured or modeled)
`rhoB`	secondary particle reflectance from 400-2500nm (can be measured or modeled)
`tauB`	secondary particle reflectance from 400-2500nm (can be measured or modeled)

- `bgr` background reflectance. Usual input is soil reflectance spectra from 400-2500nm (can be measured or modeled)
- `rsobgr` : background bidirectional reflectance (rso)
- `rdobgr` : background directional hemispherical reflectance (rdo)
- `rsdbgr` : background hemispherical directional reflectance (rsd)
- `rddbgr` : background bi-hemispherical diffuse reflectance (rdd)
- `param` A named vector of 4SAIL2 parameter values (note: program ignores case):
  - [1] = Leaf angle distribution function parameter a (LIDFa)
  - [2] = Leaf angle distribution function parameter b (LIDFb)
  - [3] = Leaf angle distribution function type (TypeLidf, see ?lidfFun)
  - [4] = Total Leaf Area Index (LAI), including primary and secondary particles (brown and green leafs).
  - [5] = fraction secondary particles ("brown leaf fraction", fb)
  - [6] = Canopy dissociation factor for secondary particles ("diss")
  - [7] = Hot spot effect parameter (hspot). Often defined as the ratio of mean leaf width and canopy height.
  - [7] = vertical crown coverage fraction (Cv), models clumping in combination with parameter zeta.
  - [7] = tree shape factor (zeta), defined as the ratio of crown diameter and height.
  - [6] = Solar zenith angle (tts)
  - [7] = Observer zenith angle (tto)
  - [8] = Sun-sensor azimuth angle (psi)

Value

spectra matrixwith 4 reflectance factors and canopy transmission for wavelengths 400 to 2500nm:

- [1] = bi-hemispherical reflectance (rddt). White-sky albedo: the reflectance of the canopy under diffuse illumination. The BRDF integrated over all viewing and illumination directions. Diffuse reflectance for diffuse incidence.
- [2] = hemispherical directional reflectance (rsdt). Black-sky albedpo: reflectance of a surface under direct light without a diffuse component. It is the integral of the BRDF over all viewing directions. Diffuse reflectance for direct solar incidence.
- [3] = directional hemispherical reflectance (rdot). Diffuse reflectance in the vieweing direction.
- [4] = bi-directional reflectance (rsot). The ratio of reflected radiance in the viewing direction to the incoming radiant flux in the solar direction.

References

Zhang, Q., Xiao, X., Braswell, B., Linder, E., Baret, F., Moore, B. (2005). Estimating light absorption by chlorophyll, leaf and canopy in a deciduous broadleaf forest using MODIS data and a radiative transfer model. Remote Sens. Environ. 99, 357-371.

Examples

```
## see ?foursail for lower-level implementations
fRTM(rho~prospectd+foursail2b)
```

---

fRTM *Forward implementation of coupled Radiative Transfer Models.*

Description

Forward implementation of coupled Radiative Transfer Models.

Usage

```
fRTM(fm = rho + tau ~ prospect5 + foursail, pars = NULL,
  wl = 400:2500)
```

Arguments

fm	A formula specifying which rtm to run
pars	a list of _named_ parameter vectors for all models. The parameter list for a model call as rho ~ prospect + foursail therefore contains two named vectors the first with parameters for prospect and the second with parameters for foursail if left empty default parameters are generated
wl	wavelengths (in nm) add only if certain wavelengths are required as output. Input is expected to integers between 400 and 2500, or will be forced to be an integer. Integers outside the 400:2500 range will not be returned.

Value

spectra matrix with reflectance (and transmission, depending on the formula inputs). See seperate model helpfiles for details.

Examples

```
## setup graphics for plots
oldpar<-par()
par(mfrow=c(3,2))

## get reflectance for a leaf
ref <- fRTM(rho~prospect5)
plot(ref,main="Prospect 5")

## get reflectance and transmission for a leaf
reftrans <- fRTM(rho+tau~prospect5)
plot(reftrans,main="Prospect 5")

## get reflectance for a single layered canopy
```

```
ref <- fRTM(rho~prospect5+foursail)
plot(ref,main="Prospect 5 + 4SAIL")

## get reflectance for a 2 layered canopy with two leaf types
ref <- fRTM(rho~prospectd+prospect5+foursail2)
plot(ref,main="Prospect D + Prospect 5  + 4SAIL2")

## edit the parameters: sparse vegatation LAI
parlist<- list(prospect5=NULL,prospectd=NULL,foursail2=c(LAI=0.05))

## update reflectance
ref <- fRTM(rho~prospect5+prospectd+foursail2,parlist)
plot(ref,main="LAI=0.05")

## change leaf area index to dense vegetation
parlist$foursail2["LAI"]<-8.5

## update reflectance
ref <- fRTM(rho~prospect5+prospectd+foursail2,parlist)
plot(ref,main="LAI=8.5")

par(oldpar)
```

`getDefaults` *S3- methods for Generate defaults settings and parameters for all supported models.*

Description

S3- methods for Generate defaults settings and parameters for all supported models.

Usage

```
getDefaults(model = NULL, ...)
```

Arguments

`model`	a ccrtm formula or character vector of modelnames
`\dots`	not used. (e.g. "prospect5")

Value

a data.frame with default model parameters

KLd	*Kullback-Lieber divergence function D(spec1 || spec2) = sum(spec1 * log(spec1 / spec2))*

Description

Kullback-Lieber divergence function D(spec1 || spec2) = sum(spec1 * log(spec1 / spec2))

Usage

```
KLd(spec1, spec2)
```

Arguments

`spec1`	spectral signal 1
`spec2`	spectral signal 2 at identical wavelengths

Value

the KL divergence between the vector inputs

lidf	*Leaf inclination distribution models s3 method for calling leaf models*

Description

Leaf inclination distribution models s3 method for calling leaf models

Usage

```
lidf(pars)
```

Arguments

`pars` a parameter vector with a class lidf.[modelnumber]. Models include:

- [1] = Dlagden distribution (1, lidf.1)
- [2] = Ellipsoid (Campebll) distribution (2, lidf.2)
- [3] = Beta distribution (3, lidf.3)
- [4] = One parameter beta distribution (4, lidf.4)

Models 1 and 2 are the standard models from the SAIL model

Value

a vector of proportions for each leaf angle calculated from each leaf inclination model

plot.rtm.spectra *Plot RTM return spectra vs. wavelength*

Description

Plot RTM return spectra vs. wavelength

Usage

```
## S3 method for class 'rtm.spectra'
plot(x, ...)
```

Arguments

`x`	predictions from an RTM
`...`	additional plot arguments

Value

plots to the device a ccrtm standard spectra plot based on the function call returned from fRTM.

print.rtm.spectra *Plot RTM return spectra vs. wavelength*

Description

Plot RTM return spectra vs. wavelength

Usage

```
## S3 method for class 'rtm.spectra'
print(x, ...)
```

Arguments

`x`	predictions from an RTM
`...`	additional plot arguments

Value

prints the standard information from a simulated ccrtm spectra plot `prospect5` *PROSPECT model version 5 and 5B*

Description

The PROSPECT5(b) leaf reflectance model. The model was implemented based on Jacquemoud and Ustin (2019), and is further described in detail in Feret et al (2008). PROSPECT models use the plate models developed in Allen (1969) and Stokes (1862). Set Cbrown to 0 for prospect version 5.

Usage

```
prospect5(param)
```

Arguments

`param` A named vector of PROSPECT parameters (note: program ignores case):

- [1] = leaf structure parameter (N)
- [2] = chlorophyll a+b content in ug/cm2 (Cab)
- [3] = carotenoids content in ug/cm2 (Car)
- [4] = brown pigments content in arbitrary units (Cbrown)
- [5] = equivalent water thickness in g/cm2 (Cw)
- [6] = leaf dry matter content in g/cm2 - lma - (Cm)

Value

spectra matrix with leaf reflectance and transmission for wavelengths 400 to 2500nm:

- [1] = leaf reflectance (rho)
- [2] = leaf transmission (tau)

References

Jacquemoud, S., and Ustin, S. (2019). Leaf optical properties. Cambridge University Press.

Feret, J.B., Francois, C., Asner, G.P., Gitelson, A.A., Martin, R.E., Bidel, L.P.R., Ustin, S.L., le Maire, G., Jacquemoud, S. (2008), PROSPECT-4 and 5: Advances in the leaf optical properties model separating photosynthetic pigments. Remote Sens. Environ. 112, 3030-3043.

Allen W.A., Gausman H.W., Richardson A.J., Thomas J.R. (1969), Interaction of isotropic ligth with a compact plant leaf, Journal of the Optical Society of American, 59:1376-1379.

Stokes G.G. (1862), On the intensity of the light reflected from or transmitted through a pile of plates, Proceedings of the Royal Society of London, 11:545-556.

`prospectd` *PROSPECT model version D*

Description

The PROSPECTD leaf reflectance model. The model was implemented based on Jacquemoud and Ustin (2019), and is further described in detail in Feret et al (2017). PROSPECT models use the plate models developed in Allen (1969) and Stokes (1862).

Usage

```
prospectd(param)
```

Arguments

`param` A named vector of PROSPECT parameters (note: program ignores case):

- [1] = leaf structure parameter (N)
- [2] = chlorophyll a+b content in ug/cm2 (Cab)
- [3] = carotenoids content in ug/cm2 (Car)
- [4] = Leaf anthocyanin content (ug/cm2) (Canth)
- [5] = brown pigments content in arbitrary units (Cbrown)
- [6] = equivalent water thickness in g/cm2 (Cw)
- [7] = leaf dry matter content in g/cm2 - lma - (Cm)

Value

spectra matrix with leaf reflectance and transmission for wavelengths 400 to 2500nm:

- [1] = leaf reflectance (rho)
- [2] = leaf transmission (tau)

References

Jacquemoud, S., and Ustin, S. (2019). Leaf optical properties. Cambridge University Press.

Feret, J.B., Gitelson, A.A., Noble, S.D., Jacquemoud, S. (2017). PROSPECT-D: Towards modeling leaf optical properties through a complete lifecycle. Remote Sens. Environ. 193, 204-215.

Allen W.A., Gausman H.W., Richardson A.J., Thomas J.R. (1969), Interaction of isotropic ligth with a compact plant leaf, Journal of the Optical Society of American, 59:1376-1379.

Stokes G.G. (1862), On the intensity of the light reflected from or transmitted through a pile of plates, Proceedings of the Royal Society of London, 11:545-556.

`r_foursail` *R implementation of foursail (pure R)*

Description

The pure R version of foursail is included in the package as an easy way to review the code, and to check more optimized versions against. Model originally developed by Wout Verhoef.

Usage

```
r_foursail(rho, tau, bgr, param)
```

Arguments

`rho`	input leaf reflectance from 400-2500nm (can be measured or modeled)
`tau`	input leaf transmittance from 400-2500nm (can be measured or modeled)
`bgr`	background reflectance. Usual input is soil reflectance spectra from 400-2500nm (can be measured or modeled)
`param`	A named vector of SAIL parameter values (note: program ignores case): • [1] = Leaf angle distribution function parameter a (LIDFa) • [2] = Leaf angle distribution function parameter b (LIDFb) • [3] = Leaf angle distribution function type (see ?lidfFun) • [4] = Leaf area index (LAI) • [5] = Hot spot effect parameter (hspot) - The foliage hot spot size parameter is equal to the ratio of the correlation length of leaf projections in the horizontal plane and the canopy height (Verhoef & Bach 2007). • [6] = Solar zenith angle (tts) • [7] = Observer zenith angle (tto) • [8] = Sun-sensor azimuth angle (psi)

Value

spectra matrixwith 4 reflectance factors and canopy transmission for wavelengths 400 to 2500nm:

- [1] = bi-hemispherical reflectance (rddt). White-sky albedo: the reflectance of the canopy under diffuse illumination. The BRDF integrated over all viewing and illumination directions.
- [2] = hemispherical directional reflectance (rsdt). Black-sky albedo: reflectance of a surface under direct light without a diffuse component. It is the integral of the BRDF over all viewing directions.
- [3] = directional hemispherical reflectance (rdot). Diffuse reflectance in the vieweing direction.
- [4] = bi-directional reflectance (rsot). The ratio of reflected radiance in the viewing direction to the incoming radiant flux in the solar direction.
- [5] = Canopy transmission of diffuse light through the canopy (taud).
- [6] = transmission of direct light through the canopy (taus).

Author(s)

Marco D. Visser (R implementation)

`sail_BDRF` *The SAIL BDRF function*

Description

The SAIL BDRF function

Usage

```
sail_BDRF(w, lai, sumint, tsstoo, rsoil, rdd, tdd, tsd, rsd, tdo, rdo, tss,
  too, rsod)
```

Arguments

`w`	goemeric reflectance parameter
`lai`	leaf area index
`sumint`	exp int
`tsstoo`	Bi-directional gap fraction
`rsoil`	background reflectance
`rdd`	Bi-hemispherical reflectance over all in & outgoing directions (white-sky albedo).
`tdd`	Bi-hemispherical transmittance (diffuse transmittance in all directions)
`tsd`	Directional hemispherical transmittance for solar flux
`rsd`	Directional hemispherical reflectance for solar flux (diffuse solar angle)
`tdo`	Directional hemispherical transmittance (diffuse in viewing direction)
`rdo`	Directional hemispherical reflectance in viewing direction
`tss`	Direct transmittance of solar flux
`too`	Direct transmittance in viewing direction
`rsod`	Multi scattering contribution

Value

spectra matrixwith 4 reflectance factors and canopy transmission for wavelengths 400 to 2500nm:

- [1] = bi-hemispherical reflectance (rddt). White-sky albedo: the reflectance of the canopy under diffuse illumination. The BRDF integrated over all viewing and illumination directions.
- [2] = hemispherical directional reflectance (rsdt). Black-sky albedo: reflectance of a surface under direct light without a diffuse component. It is the integral of the BRDF over all viewing directions.
- [3] = directional hemispherical reflectance (rdot). Diffuse reflectance in the vieweing direction.

- [4] = bi-directional reflectance (rsot). The ratio of reflected radiance in the viewing direction to the incoming radiant flux in the solar direction.
- [5] = Canopy transmission of diffuse light through the canopy (taud).
- [6] = transmission of direct light through the canopy (taus).

---

skyl — *Sky light model*

Description

Simple atmospherical model that builds on recommendations from Francois et al. (2002).

Usage

```
skyl(rddt, rsdt, rdot, rsot, Es, Ed, tts, skyl = NULL)
```

Arguments

`rddt`	Bi-hemispherical reflectance
`rsdt`	Directional-hemispherical reflectance for solar incident flux
`rdot`	Hemispherical-directional reflectance in viewing direction
`rsot`	Bi-directional reflectance factor
`Es`	Solar flux
`Ed`	Diffuse flux
`tts`	solar angle
`skyl`	fraction diffuse

Value

a list with hemispherical and directional reflectance. rt<-fRTM(rho~prospect5+foursail) skyl(rt[,"rddt"],rt[,"rsdt"],rt[,"rdot"],r
Es=solar[,1],Ed=solar[,2],tts=45,skyl=NULL)

References

Francois, C., Ottle, C., Olioso, A., Prevot, L., Bruguier, N., Ducros, Y.(2002). Conversion of 400-1100 nm vegetation albedo measurements into total shortwave broadband albedo using a canopy radiative transfer model. Agronomie 22, 611-618.

Examples

```
data(solar)
```

soil — *soil reflectance*

Description

soil reflectance

Usage

```
data(soil)
```

details

****

- [1] = wet soil
- [2] = dry soil

references

Feret et al. (2008), PROSPECT-4 and 5: Advances in the Leaf Optical Properties Model Separating Photosynthetic Pigments, Remote Sensing of Environment

solar — *direct and diffuse light*

Description

direct and diffuse light

Usage

```
data(solar)
```

details

****

- [1] = direct light
- [2] = diffuse light

references

Feret et al. (2008), PROSPECT-4 and 5: Advances in the Leaf Optical Properties Model Separating Photosynthetic Pigments, Remote Sensing of Environment

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