INTRODUCTION TO *solaR*

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03 JUNE 2011

Chapter 1

Introduction

The `solaR` package includes a set of functions which calculate the solar radiation incident on a photovoltaic generator and simulate the performance of several applications of the photovoltaic energy [8]. This package performs the whole calculation from both *daily* and *intra-daily* global horizontal irradiation to the final productivity of grid connected PV systems and water pumping PV systems. Besides, the package includes several visualization methods based on the `lattice` and `latticeExtra` packages, and tools for the statistical analysis of the performance of a large PV plant composed of several systems.

The package is constructed with `S4` classes and methods. The time series are constructed with the `zoo` package [9].

Chapter 2

Solar Geometry

The apparent movement of the Sun is defined with some equations included in the functions `fSolD` and `fSolI`. `fSolD` computes the daily apparent movement of the Sun from the Earth. This movement is mainly described (for the simulation of photovoltaic systems) by the declination angle, the sunset angle and the daily extra-atmospheric irradiation. On the other hand, `fSolI` computes the angles which describe the intra-daily apparent movement of the Sun from the Earth.

The next example shows these calculations for a certain day:

```
> BTd = fBTd(mode = "serie")
> lat = 37.2
> SolD <- fSolD(lat, BTd[100])
> SolI <- fSolI(SolD, sample = "hour", keep.night = FALSE)
> head(SolI)

                        w aman cosThzS     AlS     AzS    Bo0      rd
2011-04-10 06:00:00 -1.5772    1 0.07826 0.07834 -1.6850  106.6 0.01108
2011-04-10 07:00:00 -1.3154    1 0.28265 0.28656 -1.5275  384.9 0.04003
2011-04-10 08:00:00 -1.0535    1 0.47346 0.49321 -1.3576  644.7 0.06706
2011-04-10 09:00:00 -0.7917    1 0.63767 0.69147 -1.1552  868.3 0.09031
2011-04-10 10:00:00 -0.5298    1 0.76409 0.86963 -0.8882 1040.4 0.10822
2011-04-10 11:00:00 -0.2680    1 0.84410 1.00488 -0.5111 1149.4 0.11955
                           rg
2011-04-10 06:00:00 0.007779
2011-04-10 07:00:00 0.032040
2011-04-10 08:00:00 0.059837
2011-04-10 09:00:00 0.087739
2011-04-10 10:00:00 0.111728
2011-04-10 11:00:00 0.128038
```

and for a set of days:

```
> SolD <- fSolD(lat, BTd[c(10, 50, 100)])
> print(SolD)

             decl     eo     ws Bo0d       EoT
2011-01-10 -0.3834 1.0348 -1.260 4521 -0.035464
2011-02-19 -0.1972 1.0238 -1.419 6458 -0.059933
2011-04-10  0.1383 0.9961 -1.677 9614 -0.004637
attr(,"lat")
[1] 37.2
```

With the function `fBTd` it is possible to get time bases with different structures. Thus, the calculations for the so called "average days" need the next piece of code, with the result displayed in the figure 2.1.

```
> lat = 37.2
> SolD <- fSolD(lat, BTd = fBTd(mode = "prom"))
> SolI <- fSolI(SolD, sample = "10 min", keep.night = FALSE)
```

These calculations can also be carried out for the whole year (figure 2.2).

```
> mon = month.abb
> p <- xyplot(r2d(AlS) ~ r2d(AzS), groups = month, data = SolI,
+     type = "l", col = "black", xlab = expression(psi[s]), ylab = expression(gamma[s]))
> plab <- p + glayer({
+     idx <- round(length(x)/2 + 1)
+     panel.text(x[idx], y[idx], mon[group.value], pos = 3, offset = 0.2,
+         cex = 0.8)
+ })
> print(plab)
```

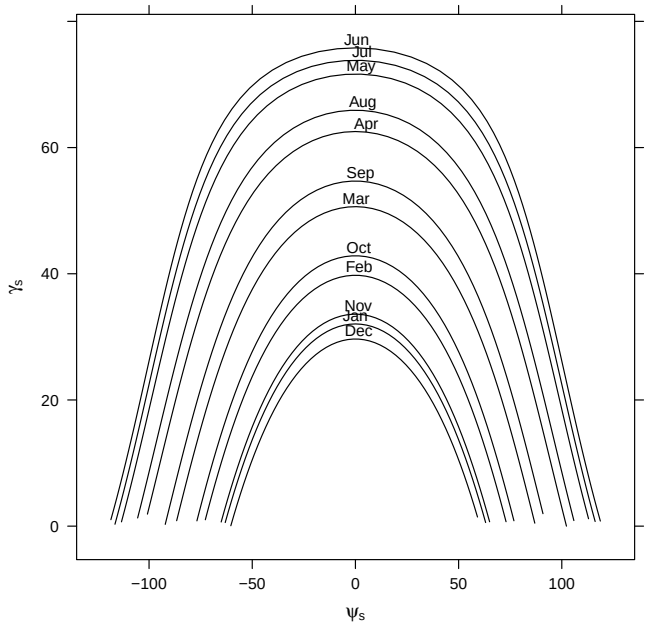

FIGURE 2.1: *Azimuth and height solar angles during the "average days".*

```
> BTd = fBTd(mode = "serie")
> solD <- fSolD(lat, BTd)
> summary(solD)

     Index                 decl                eo               ws
 Min.   :2011-01-01   Min.   :-0.40905   Min.   :0.967   Min.   :-1.91
 1st Qu.:2011-04-02   1st Qu.:-0.27824   1st Qu.:0.976   1st Qu.:-1.80
 Median :2011-07-02   Median : 0.01277   Median :0.999   Median :-1.58
 Mean   :2011-07-02   Mean   : 0.00688   Mean   :1.000   Mean   :-1.58
 3rd Qu.:2011-10-01   3rd Qu.: 0.29171   3rd Qu.:1.024   3rd Qu.:-1.35
 Max.   :2011-12-31   Max.   : 0.40906   Max.   :1.035   Max.   :-1.24
      BoOd             EoT
 Min.   : 4245   Min.   :-6.18e-02
 1st Qu.: 5613   1st Qu.:-2.59e-02
 Median : 8438   Median :-2.48e-03
 Mean   : 8184   Mean   : 1.24e-05
 3rd Qu.:10764   3rd Qu.: 2.16e-02
 Max.   :11604   Max.   : 7.09e-02
```

These two functions are included in a function, `calcSol`. This function constructs an object of class `Sol` containing in its slots the `zoo` objects created by `fSolD` and `fSolI`. This class owns methods for getting and displaying information (for example, `as.zooD, as.zooI, xyplot`).

There are three methods for the sun geometry calculations. These methods are named as 'cooper' (the default in previous versions), 'spencer', 'michalsky' (the default in this version) and 'strous'.

```
> p <- xyplot(solD$decl)
> print(p)
```

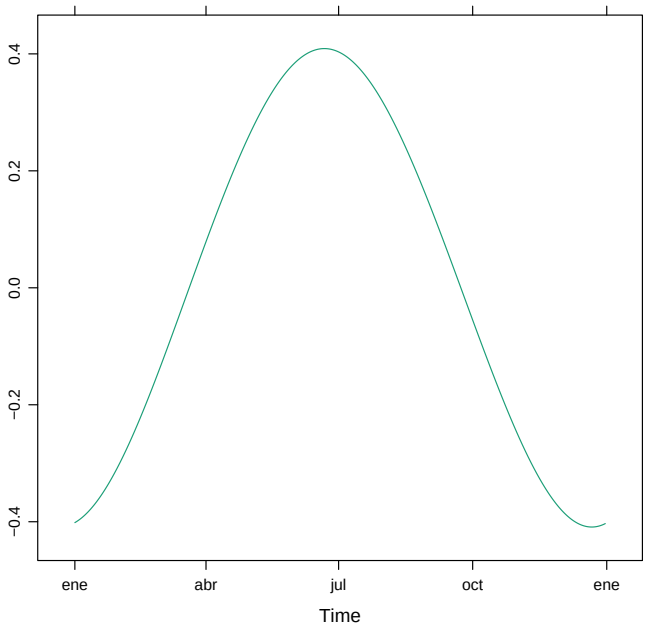

FIGURE 2.2: *Declination throughout the year*

```
> lat = 37.2
> BTd = fBTd(mode = "serie")
> sol = calcSol(lat, BTd[100])
> print(as.zooD(sol))

             decl     eo     ws BoOd       EoT
2011-04-10 0.1383 0.9961 -1.677 9614 -0.004637

> solStrous = calcSol(lat, BTd[100], method = "strous")
> print(as.zooD(solStrous))

            decl     eo     ws BoOd       EoT
2011-04-10 0.137 0.9961 -1.676 9603 -0.004637

> solSpencer = calcSol(lat, BTd[100], method = "spencer")
> print(as.zooD(solSpencer))

             decl     eo     ws BoOd       EoT
2011-04-10 0.1336 0.9961 -1.673 9571 -0.004637

> solCooper = calcSol(lat, BTd[100], method = "cooper")
> print(as.zooD(solCooper))

             decl    eo     ws BoOd       EoT
2011-04-10 0.1315 0.995 -1.671 9541 -0.004637
```

Chapter 3

Solar Radiation

Values of global horizontal irradiation are commonly available either as monthly averages of daily values or as a time series of daily during one or several years. The analysis of the performance of a PV system starts from the transformation of the global horizontal irradiation to global, diffuse and direct horizontal irradiance and irradiation, and then irradiance and irradiation on the generator surface.

3.1 Irradiation and irradiance on the horizontal plane

The function `fCompD` extracts the diffuse and direct components from the daily global irradiation on a horizontal surface by means of regressions between the clearness index and the diffuse fraction parameters. This function need the results from `fSolD`, a set of values of global horizontal irradiation ($^{Wh}/_{m^2}$), and the correlation between the clearness index and the diffuse fraction. The current version of `solaR` includes several correlations (type `help(corrFdKt)` for details). Besides, the user may define a particular correlation through the argument `f`. Once again for a certain day:

```
> BTd = fBTd(mode = "serie")
> SolD <- fSolD(lat, BTd[100])
> SolI <- fSolI(SolD, sample = "hour")
> G0d = zoo(5000, index(SolD))
> fCompD(SolD, G0d, corr = "Page")

               Fd    Ktd  G0d  D0d  B0d
2011-04-10 0.4123 0.5201 5000 2062 2938

> fCompD(SolD, G0d, corr = "CPR")

               Fd    Ktd  G0d  D0d  B0d
2011-04-10 0.5658 0.5201 5000 2829 2171
```

and for the "average days":

```
> lat = 37.2
> G0dm = c(2.766, 3.491, 4.494, 5.912, 6.989, 7.742, 7.919, 7.027,
+     5.369, 3.562, 2.814, 2.179) * 1000
> Rad = readG0dm(G0dm, lat)
> solD <- fSolD(lat, fBTd(mode = "prom"))
> fCompD(solD, Rad, corr = "Page")

               Fd    Ktd  G0d    D0d  B0d
2011-01-17 0.3412 0.5830 2766  943.8 1822
2011-02-14 0.3582 0.5679 3491 1250.6 2240
2011-03-15 0.3677 0.5596 4494 1652.5 2842
2011-04-15 0.3237 0.5985 5912 1914.0 3998
2011-05-15 0.2880 0.6301 6989 2012.8 4976
2011-06-10 0.2438 0.6692 7742 1887.1 5855
2011-07-18 0.2065 0.7022 7919 1635.1 6284
2011-08-18 0.2232 0.6875 7027 1568.1 5459
2011-09-18 0.2912 0.6272 5369 1563.7 3805
2011-10-19 0.3907 0.5392 3562 1391.7 2170
2011-11-18 0.3623 0.5643 2814 1019.6 1794
2011-12-13 0.4265 0.5075 2179  929.3 1250
```

Let's use `corr='user'` to define a function with the correlation of Collares Pereira and Rabl [2]. Obviously, we shall obtain the same result as with `corr='CPR'`.

```
> fKTd = function(x) {
+     (0.99 * (x <= 0.17)) + (x > 0.17) * (1.188 - 2.272 * x +
+         9.473 * x^2 - 21.856 * x^3 + 14.648 * x^4)
+ }
> fCompD(SolD, G0d, corr = "user", f = fKTd)

               Fd    Ktd  G0d  D0d  B0d
2011-04-10 0.5658 0.5201 5000 2829 2171
```

The daily profile of irradiance is obtained with the function `fCompI`. This function needs the information provided by `fCompD` and `fSolI` or `calcSol`. For example, the profiles for the "average days" are obtained with the next code (fig. 3.1).

```
> lat = 37.2
> sol <- calcSol(lat, fBTd(mode = "prom"), sample = "hour", keep.night = FALSE)
> G0dm = c(2.766, 3.491, 4.494, 5.912, 6.989, 7.742, 7.919, 7.027,
+     5.369, 3.562, 2.814, 2.179) * 1000
> Ta = c(10, 14.1, 15.6, 17.2, 19.3, 21.2, 28.4, 29.9, 24.3, 18.2,
+     17.2, 15.2)
> BD <- readG0dm(G0dm = G0dm, Ta = Ta, lat = 37.2)
> compD <- fCompD(sol, BD, corr = "Page")
> compI <- fCompI(sol, compD)
```

3.1.1 Meteorological data

There are several functions to construct a `Meteo` object with radiation and temperature data. For daily data, if it is stored in a local file or a `data.frame`, the functions `readBD` and `df2Meteo` are recommended, while `readG0dm` is indicated when only 12 monthly means are available. For intradaily data the correspondent functions are `readBDi` and `dfI2Meteo`. Besides, `zoo2Meteo` can construct a `Meteo` object from a `zoo` object both for daily and intradaily data.

For example, the `helios` dataset included in the package, obtained from http://helios.ies-def.upm.es, can be converted to a `Meteo` object with the next code:

```
> p <- xyplot(G0 + B0 + D0 ~ w | month, data = compI, type = "l",
+     auto.key = list(space = "right"))
> print(p)
```

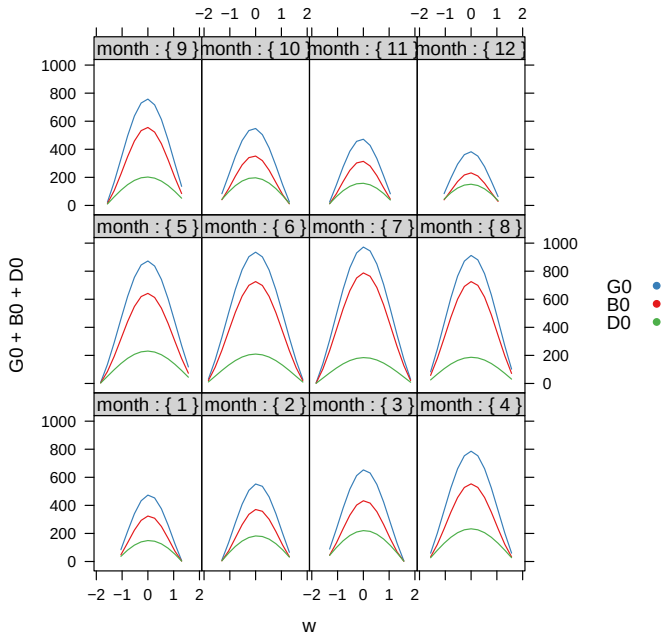

FIGURE 3.1: *Global, diffuse, and direct irradiance during the "average days".*

```
> data(helios)
> names(helios) = c("date", "G0", "TempMax", "TempMin")
> bd = df2Meteo(helios, dates.col = "date", lat = 41, source = "helios-IES",
+     format = "%Y/%m/%d")
> summary(getData(bd))

     Index                          G0           TempMax         TempMin
 Min.   :2009-01-01 00:00:00   Min.   :  326   Min.   : 1.41   Min.   :-37.50
 1st Qu.:2009-04-08 12:00:00   1st Qu.: 2523   1st Qu.:14.41   1st Qu.:  1.95
 Median :2009-07-07 00:00:00   Median : 4746   Median :23.16   Median :  7.91
 Mean   :2009-07-04 21:29:54   Mean   : 4812   Mean   :22.59   Mean   :  5.32
 3rd Qu.:2009-10-03 12:00:00   3rd Qu.: 7140   3rd Qu.:31.06   3rd Qu.: 15.11
 Max.   :2009-12-31 00:00:00   Max.   :11254   Max.   :38.04   Max.   : 24.80
```

On the other hand, the function `readSIAR` is able to download the meteorological data available at www.marm.es/siar. This webpage provides daily measurements from a set of agroclimatic stations located in Spain. This function needs the code of the station and its province, and the start and end date. The codes of stations and provinces are stored at the dataset `RedEstaciones`. For example, there are several stations in Madrid:

```
> data(RedEstaciones)
> Madrid <- subset(RedEstaciones, NomProv == "Madrid")
> print(Madrid)

     Provincia Estacion NomProv                    NomEst
P209        28        1  Madrid Center:_Finca_experimental
P210        28        2  Madrid                  Arganda
P211        28        3  Madrid                 Aranjuez
P212        28        4  Madrid       Fuentiduena_de_Tajo
P213        28        5  Madrid     San_Martin_de_la_Vega
P214        28        6  Madrid                 Chinchon
P215        28      102  Madrid           Villa_del_Prado
```

`readSIAR` constructs an object of class `Meteo`. The data is obtained with the method `getData`. If only the irradiation series is needed, the method `getG0` is recommended.

For example, let's obtain the 2009 data from the station at Aranjuez (fig. 3.2). It is important to note that the radiation measurements available at the webpage are in $^{MJ}/_{m^2}$, but `readSIAR` converts the values to $^{Wh}/_{m^2}$:

```
> Aranjuez <- readSIAR(28, 3, "01/01/2009", "31/12/2009")

Downloading data from www.marm.es/siar...
```

```
> p = xyplot(G0 ~ TempMedia | month, data = Aranjuez, type = c("p",
+     "r"))
> print(p)
```

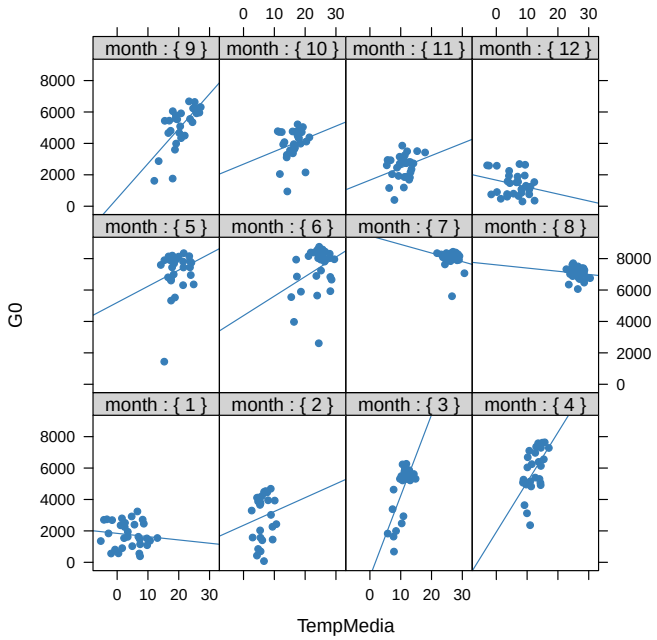

FIGURE 3.2: *Daily irradiation and mean temperature in the station of Aranjuez.*

This database includes information of maximum and minimum values of temperature. The function `fTemp` calculates a profile of the ambient temperature with this information following the method proposed in [3]. The evolution of this synthetic temperature during March is displayed in the figure 3.3.

```
> lat = 41
> sol = calcSol(lat, BTd = indexD(Aranjuez), sample = "hour")
> Temp <- fTemp(sol, Aranjuez)
```

3.1.2 The function `calcGO`

The previous steps are included in the function `calcGO`. For example, with the next code, the components of horizontal irradiation and irradiance are obtained from the measurements of the meteorological station of Aranjuez (figure 3.4).

```
> wTemp = window(Temp, start = as.POSIXct("2009-03-01"), end = as.POSIXct("2009-03-31"))
> p = xyplot(wTemp, col = "black", ylab = "T") + layer_(panel.xblocks(x,
+     DoY, col = c("lightgray", "white")))
> print(p)
```

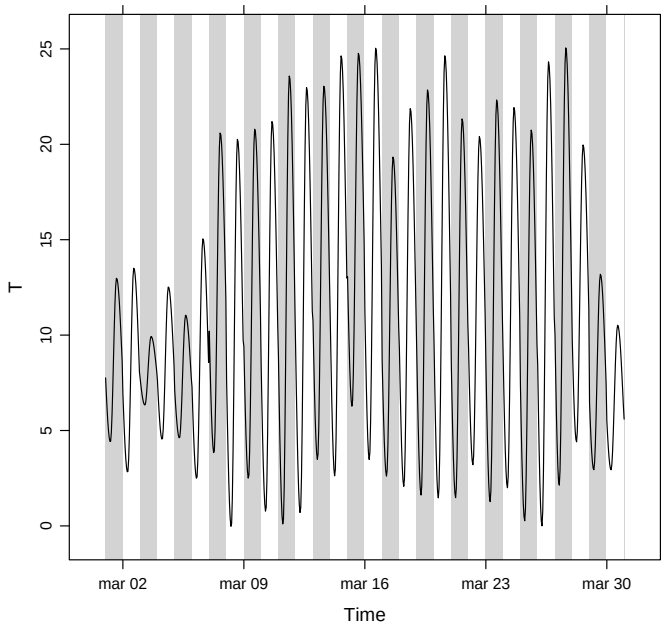

FIGURE 3.3: *Evolution of the ambiente temperature during March 2009 in Aranjuez.*

```
> g0 <- calcG0(lat = 37.2, modeRad = "siar", dataRad = list(prov = 28,
+     est = 3, start = "01/01/2009", end = "31/12/2009"))

Downloading data from www.marm.es/siar...

> print(g0)

Object of class  G0

Source of meteorological information: mapa-Est: 3 Prov: 28

Latitude of source:  37.2 degrees
Latitude for calculations:  37.2 degrees

Monthly averages:
          G0d    D0d    B0d
ene 2009 1.764 1.1624 0.6014
feb 2009 2.916 1.3542 1.5618
mar 2009 4.725 1.6523 3.0726
abr 2009 5.819 2.3287 3.4905
may 2009 7.198 2.2613 4.9372
jun 2009 7.354 2.4532 4.9006
jul 2009 8.002 2.0391 5.9632
ago 2009 7.061 1.9468 5.1137
sep 2009 5.168 1.9351 3.2328
oct 2009 3.993 1.5492 2.4437
nov 2009 2.510 1.3632 1.1464
dic 2009 1.397 0.9823 0.4142

Yearly values:
      G0d   D0d  B0d
2009 1730 625.4 1104
```

`solaR` accepts intradaily irradiation data sources. For example, the Measurement and Instrumentation Data Center of the NREL (NREL-MIDC) provides meteorological data from a variety of stations. We will try the *La Ola - Lanai* station at Hawaii (http://www.nrel.gov/midc/la_ola_lanai/).

```
> file = "http://www.nrel.gov/midc/apps/plot.pl?site=LANAI&start=20090722&edy=19&emo=11&eyr=2010&zenloc=19&year=2010&month=11&day=1&endyear=2010&
> dat <- read.table(file, header = TRUE, sep = ",")
> lat = 20.77
> lon = -156.9339
```

First, we have to change the names of the columns and calculate the horizontal direct irradiation, since only the normal direct irradiation is included in the file.

```
> p = xyplot(g0)
> print(p)
```

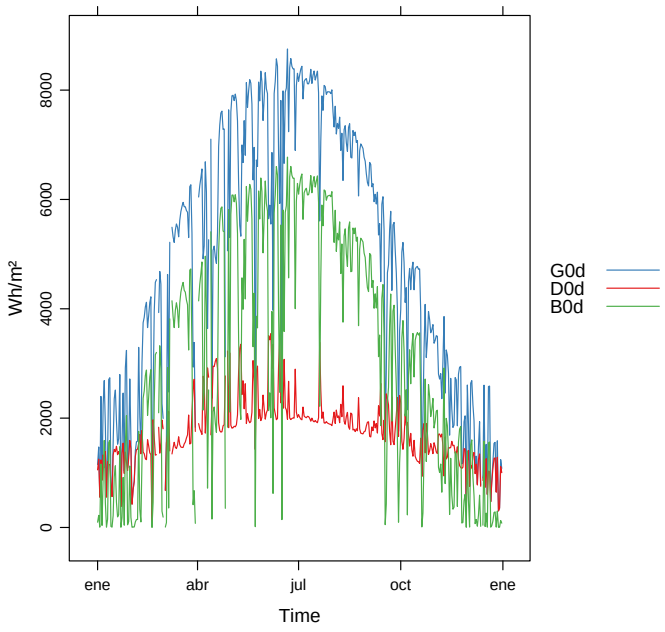

FIGURE 3.4: *Components of horizontal irradiation calculated with* `calcG0`.

```
> names(dat) <- c("date", "hour", "G0", "B", "D0", "Ta")
> dat$B0 <- dat$G0 - dat$D0
```

The datalogger program runs using Greenwich Mean Time (GMT), and data is converted to Hawaiian Standard Time (HST) after data collection. With `local2Solar` we can calculate the Mean Solar Time of the index.

```
> idxLocal <- with(dat, as.POSIXct(paste(date, hour), format = "%m/%d/%Y %H:%M",
+     tz = "HST"))
> idx <- local2Solar(idxLocal, lon = lon)
```

Therefore, the object `Meteo` is obtained with (figure 3.5):

```
> z <- zoo(dat[, c("G0", "D0", "B0", "Ta")], idx)
> NRELMeteo <- zoo2Meteo(z, lat = lat)
```

With this data, a `G0` object can be calculated. First, the direct and diffuse components of the data are used (`corr='none'`):

```
> g0NREL <- calcG0(lat = lat, modeRad = "bdI", dataRad = NRELMeteo,
+     corr = "none")
```

If these components were not available, a fd-kt hourly correlation is needed (figure **??**). For example:

```
> g0BRL <- calcG0(lat = lat, modeRad = "bdI", dataRad = NRELMeteo,
+     corr = "BRL")
```

3.2 Irradiation and irradiance on the generator plane

The solar irradiance incident on an inclined surface can be calculated from the direct and diffuse irradiance on a horizontal surface, and from the evolution of the angles of the Sun and the surface. The transformation of the direct radiation is straightforward since only geometric considerations are needed. However, the treatment of the diffuse irradiance is more complex since it involves the modelling of the atmosphere. There are several models for the estimation of diffuse irradiance on an inclined surface. The one which combines simplicity and acceptable results is the proposal of Hay and McKay. This model divides the diffuse component in isotropic and anisotropic whose values depends on a anisotropy index. On the other hand, the effective irradiance, the fraction of the incident irradiance that reaches the cells inside a PV module, is calculated with the losses due to the angle of incidence and dirtiness.

```
> p <- xyplot(NRELMeteo)
> print(p)
```

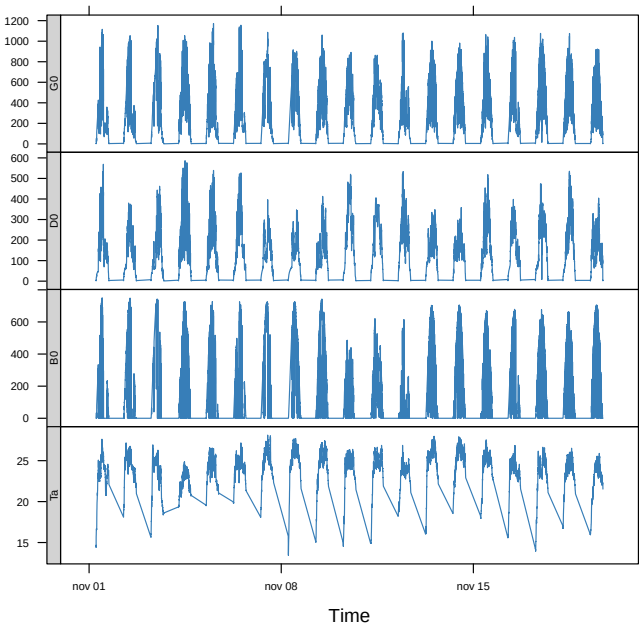

FIGURE 3.5: *1-min irradiation data from NREL-MIDC*

This behaviour can be simulated with a model proposed by Martin and Ruiz requiring information about the angles of the surface and the level of dirtiness [4].

The orientation, azimuth and incidence angle are calculated from the results of `fSolI` or `calcSol` with the functions `fTheta` and `fInclin`. These functions can calculate the movement and irradiance for fixed systems, and two-axis and horizontal N-S trackers. Besides, the movement of a horizontal NS tracker due to the backtracking strategy [5] can be calculated with information about the tracker and the distance between the trackers included in the system.

Both functions are integrated in `calcGef`, which construct an object of class `Gef`. Once again, this class owns methods for obtaining and displaying information.

For example, with the previous results, we can calculate the irradiance and irradiation on a fixed surface. The figure 3.6 shows the relation between the effective and incident irradiance versus the cosine of the angle of incidence for this system.

```
> gef <- calcGef(lat = 37.2, modeRad = "prev", dataRad = g0, beta = 30)
> print(gef)

Object of class  Gef

Source of meteorological information: mapa-Est: 3 Prov: 28

Latitude of source:  37.2 degrees
Latitude for calculations:  37.2 degrees

Monthly averages:
            Bod   Bnd    Gd     Dd     Bd  Gefd   Defd  Befd
ene 2009  8.898 1.489 2.332 1.2326 1.0763 2.188 1.1421 1.029
feb 2009  9.779 3.209 3.741 1.4250 2.2778 3.521 1.3252 2.168
mar 2009 10.349 5.045 5.160 1.5820 3.5207 4.868 1.4751 3.352
abr 2009 10.442 5.017 5.501 2.0635 3.3670 5.174 1.9179 3.206
may 2009 10.226 7.589 6.905 2.1383 4.6704 6.480 1.9888 4.423
jun 2009 10.026 7.526 6.735 2.2673 4.3687 6.299 2.1032 4.126
jul 2009 10.070 9.280 7.465 1.8975 5.4599 7.005 1.7677 5.161
ago 2009 10.257 8.019 7.215 1.9116 5.2089 6.798 1.7849 4.945
sep 2009 10.277 5.598 5.877 1.9924 3.8149 5.541 1.8568 3.635
oct 2009  9.888 4.917 5.292 1.7286 3.5100 4.995 1.6131 3.343
nov 2009  9.127 2.719 3.498 1.5113 1.9527 3.294 1.4056 1.865
dic 2009  8.501 1.047 1.767 0.9936 0.7548 1.654 0.9194 0.722

Yearly values:
      Bod  Bnd   Gd    Dd   Bd Gefd Defd Befd
2009 3584 1875 1873 630.9 1219 1762  587 1158
-----------------
Mode of tracking:  fixed
    Inclination:  30
    Orientation:  0
```

The next lines of code calculate the movement of a N-S horizontal axis tracker with *backtracking* (`modeShd='bt'`) and whose inclination angle is limited to 60° (`betaLim=60`). The evolution of the inclination angle is displayed in the figure 3.7. The meaning of the `distances` and `struct` arguments will be detailed in the 4.2 section.

```
> structHoriz = list(L = 4.83)
> distHoriz = data.frame(Lew = structHoriz$L * 4, H = 0)
> gefBT = calcGef(lat = 37.2, dataRad = prom, sample = "10 min",
+     modeTrk = "horiz", modeShd = "bt", betaLim = 60, distances = distHoriz,
+     struct = structHoriz)
```

```
> p <- xyplot(Gef/G ~ cosTheta | month, data = gef, type = c("p",
+     "smooth"), cex = 0.4, alpha = 0.5)
> print(p)
```

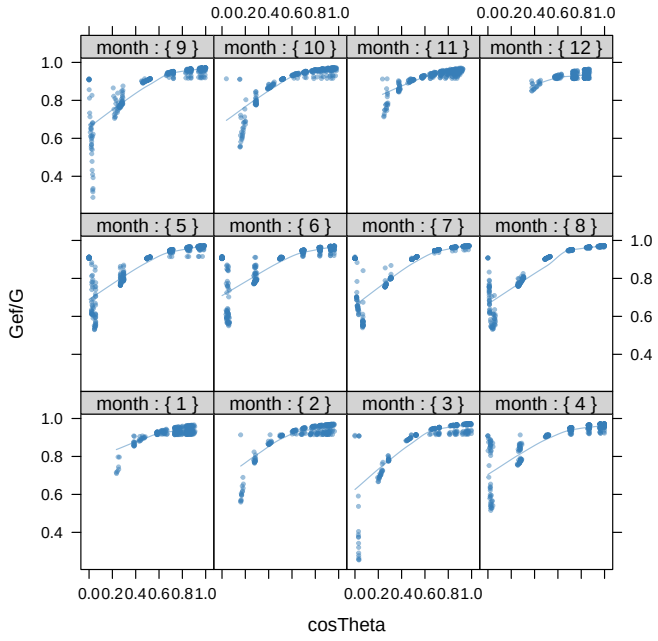

FIGURE 3.6: *Relation between the effective and incident irradiance versus the cosine of the angle of incidence for a fixed system.*

```
> p <- xyplot(r2d(Beta) ~ r2d(w), data = gefBT, type = "l", xlab = expression(omega),
+     ylab = expression(beta))
> print(p)
```

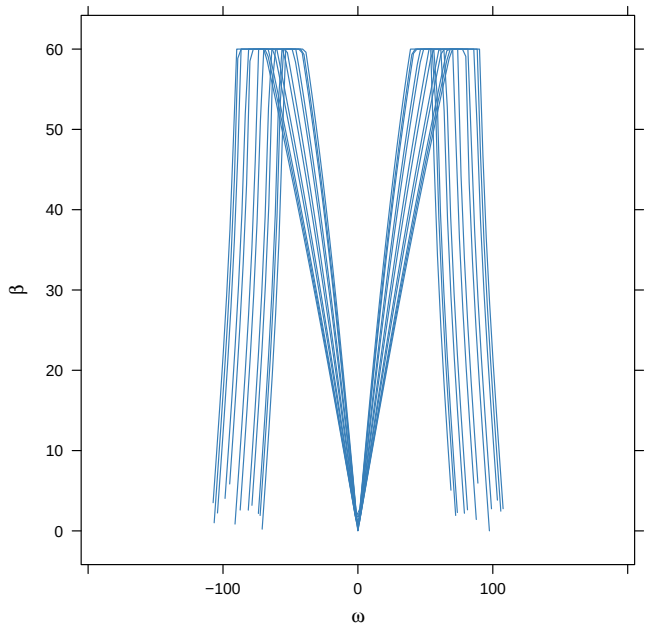

FIGURE 3.7: *Evolution of the angle of inclination of a NS horizontal axis tracker with* backtracking *and limitation of angle.*

Chapter 4

Productivity of a Grid Connected PV System

From the previous irradiance calculations, the function `fProd` simulates the performance of a Grid Connected PV (GCPV) system paying attention to some parameters of the system (characteristics of the PV module and the inverter, the electrical arrangement of the PV generator, and the losses of the system).

For example, the electrical power, voltage and current of a certain PV system is calculated below.

```
> inclin = data.frame(Gef = c(200, 400, 600, 800, 1000), Ta = 25)
> fProd(inclin)

   Gef Ta    Tc   Voc   Isc  Vmpp   Impp   Vdc    Idc   Pac   Pdc   EffI
1  200 25 31.75 673.3 10.34 533.1  9.586 533.1  9.586  4212  4737 0.9164
2  400 25 38.50 655.4 20.68 516.3 19.090 516.3 19.090  8275  9137 0.9334
3  600 25 45.25 637.5 31.02 499.6 28.506 499.6 28.506 11972 13202 0.9346
4  800 25 52.00 619.7 41.36 483.0 37.824 483.0 37.824 15323 16936 0.9325
5 1000 25 58.75 601.8 51.70 466.5 47.037 466.5 47.037 18342 20342 0.9293
```

First, `fProd` computes the Maximum Power Point (MPP) of the generator (`Vmpp` and `Impp`) at the irradiance and ambient temperature conditions contained in `Inclin`. Next, it checks that this point is inside the MPP window of the inverter, as defined by `inverter$Vmin` and `inverter$Vmax`. If the MPP value is outside this range, the function asigns the limit value to the voltage, and calculates the correspondent current value with a warning.

Anyway, the inverter input voltage and current are `Vdc` e `Idc`. With the next piece of code, the `Vdc` value is set to `Vmin` (the minimum value of the MPP window of the inverter), 420 V, since `Vmpp` is below this value.

```
> inclin = data.frame(Gef = 800, Ta = 30)
> gen1 = list(Nms = 10, Nmp = 11)
> inv1 = list(Ki = c(0.01, 0.025, 0.05), Pinv = 25000, Vmin = 420,
+     Vmax = 750, Gumb = 20)
> prod = fProd(inclin, generator = gen1, inverter = inv1)
> print(prod)

  Gef Ta Tc   Voc   Isc  Vmpp  Impp Vdc   Idc   Pac   Pdc   EffI
1 800 30 57 505.3 41.36 392.3 37.68 420 33.83 11943 13169 0.9346
```

For this configuration, the losses due to the voltage limitation are:

```
> with(prod, Vdc * Idc/(Vmpp * Impp))

[1] 0.961
```

The function `prodGCPV` integrates the calculation procedure of irradiation, irradiance and simulation of the GCPV system. It constructs an object of class `ProdGCPV`.

The next code computes the productivity of the previous GCPV system working as fixed, NS horizontal axis tracking and two-axis tracking systems. The parameters of the generator, module, inverter and rest of the system are those by default in `prodGCPV`. The comparative of the intradaily power time series is shown at the figure 4.1. Later on, the `compare` and `compareLosses` methods will be shown. They are useful for comparisons of *yearly* values.

```
> ProdFixed <- prodGCPV(lat = lat, dataRad = prom, keep.night = FALSE)
> Prod2x <- prodGCPV(lat = lat, dataRad = prom, modeTrk = "two",
+     keep.night = FALSE)
> ProdHoriz <- prodGCPV(lat = lat, dataRad = prom, modeTrk = "horiz",
+     keep.night = FALSE)
```

```
> ComparePac <- CBIND(two = as.zooI(Prod2x)$Pac, horiz = as.zooI(ProdHoriz)$Pac,
+     fixed = as.zooI(ProdFixed)$Pac)
> AngSol = as.zooI(as(ProdFixed, "Sol"))
> ComparePac = CBIND(AngSol, ComparePac)
> mon = month(index(ComparePac))
> p = xyplot(two + horiz + fixed ~ AzS | mon, data = ComparePac,
+     type = "l", auto.key = list(space = "right", lines = TRUE,
+         points = FALSE), ylab = "Pac")
> print(p)
```

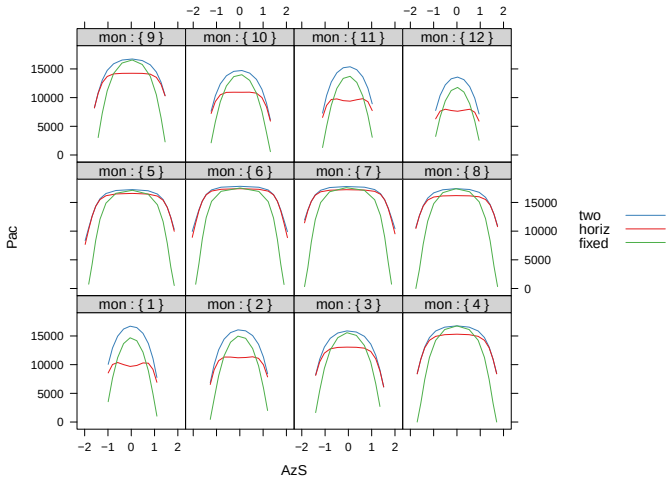

FIGURE 4.1: *Comparative of intradaily power between tracker strategies.*

4.1 Using `mergesolaR`

The `mergesolaR` method is designed to merge *daily* time series of several `solaR` objects.

For example, we can obtain the daily irradiation of the whole set of meteorological stations of Madrid (Spain) and use this information to calculate the productivity of a grid connected PV system. It is possible to complete this process with the `lapply` function. Therefore we obtain a list of `ProdGCPV` objects:

```
> EstMadrid <- subset(RedEstaciones, NomProv == "Madrid")
> nEstMadrid <- nrow(EstMadrid)
> namesMadrid <- EstMadrid$NomEst
> prodMadrid <- lapply(1:nEstMadrid, function(x) {
+     try(prodGCPV(lat = 41, modeRad = "siar", dataRad = list(prov = 28,
+         est = x, start = "01/01/2009", end = "31/12/2010")))
+ })

Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...
Downloading data from www.marm.es/siar...

> names(prodMadrid) <- namesMadrid
> okMadrid <- lapply(prodMadrid, class) != "try-error"
> prodMadrid <- prodMadrid[okMadrid]
```

In order to prevent from the erroneous behaviour of some stations, the code includes the use of `try`. Now it's time for `mergesolaR`. Since we have a list of objects, `do.call` can solve the problem:

```
> YfMadrid <- do.call(mergesolaR, prodMadrid)
> summary(YfMadrid)

     Index                       Center:_Finca_experimental    Arganda
 Min.   :2009-01-01 00:00:00   Min.   :0.00               Min.   :0.00
 1st Qu.:2009-07-02 06:00:00   1st Qu.:2.56               1st Qu.:2.80
 Median :2009-12-31 12:00:00   Median :4.42               Median :4.59
 Mean   :2009-12-31 12:00:00   Mean   :3.81               Mean   :3.90
 3rd Qu.:2010-07-01 18:00:00   3rd Qu.:5.10               3rd Qu.:5.16
 Max.   :2010-12-31 00:00:00   Max.   :6.02               Max.   :5.86
                               NA's   :3.00               NA's   :3.00
    Aranjuez    Fuentiduena_de_Tajo San_Martin_de_la_Vega    Chinchon
 Min.   :0.00   Min.   :0.00        Min.   :0.00          Min.   :0.00
 1st Qu.:2.59   1st Qu.:2.82        1st Qu.:2.68          1st Qu.:2.70
 Median :4.43   Median :4.58        Median :4.45          Median :4.64
 Mean   :3.79   Mean   :3.93        Mean   :3.83          Mean   :3.94
 3rd Qu.:5.07   3rd Qu.:5.19        3rd Qu.:5.17          3rd Qu.:5.25
 Max.   :5.99   Max.   :5.98        Max.   :6.07          Max.   :5.98
 NA's   :3.00   NA's   :3.00        NA's   :3.00          NA's   :3.00
```

The `mergesolaR` for a set of `ProdGCPV` objects merges the daily time series of the `Yf` variable of each object. The result is a multivariate `zoo` object where each column is the daily productivity with the radiation data of each meteorological station. It can be displayed (for example) with the `horizonplot` function (figure 4.2). This result will be revisited with the `Target Diagram` tool (figure 6.3).

4.2 Shadows

The shadows on PV generators alter the performance of the PV generators and reduce their productivity [6]. This package includes functions for the estimation of mutual shadows between generators from a same system. `fSombra2X`, `fSombraHoriz`, `fSombraEst`, calculate the shadows in two-axis, horizontal axis and fixed systems, respectively. The function `fSombra6` is indicated for groups of 6 two-axis trackers. Finally, `fSombra` is a wrapper to the previous functions.

For example, the shadows factor of a tracker surrounded by five trackers is calculated in the next code box. The dimensions of the tracker structure and the configuration (rows and columns) of the plant are defined by `struct`, while the distances between the trackers are defined by `distances`. The figure 4.3 shows the evolution of the shadows factor during the day (X axis) and year (Y axis).

```
> print(horizonplot(YfMadrid - rowMeans(YfMadrid), origin = 0,
+     scales = list(y = list(relation = "same")), colorkey = TRUE))
```

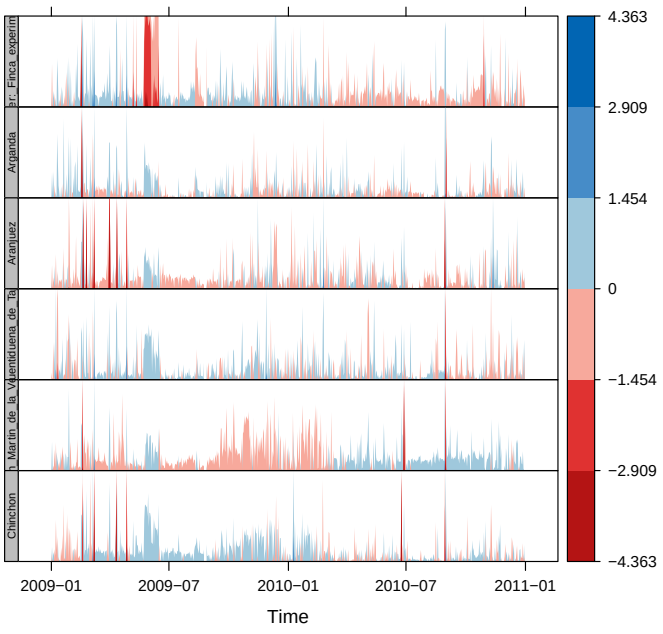

FIGURE 4.2: *`Horizonplot` of the result of a `mergesolaR` call. Previously, the row mean is substracted from each column in order to show the deviation of each meteorological station from the daily mean of the set.*

```
> sol <- calcSol(lat = 37.2, fBTd(mode = "serie"), sample = "10 min",
+     EoT = FALSE, keep.night = FALSE, method = "spencer")
> angGen <- fTheta(sol, beta = 35)
> Angles = CBIND(as.zooI(sol), angGen)
> distances = data.frame(Lew = 40, Lns = 30, H = 0)
> struct = list(W = 23.11, L = 9.8, Nrow = 2, Ncol = 8)
> ShdFactor <- fSombra6(Angles, distances, struct, prom = FALSE)
> Angles$FS = ShdFactor
```

Since the `data.frame` `distances` does only have one row, the function `fSombra6` builds a symmetric grid around the point (0,0,0), which is the affected tracker. This grid can also be constructed with:

```
> distances = data.frame(Lew = c(-40, 0, 40, -40, 40), Lns = c(30,
+     30, 30, 0, 0), H = 0)
> ShdFactor2 <- fSombra6(Angles, distances, struct, prom = FALSE)
> identical(coredata(ShdFactor), coredata(ShdFactor2))

[1] TRUE
```

Besides, `distances` can define a irregular grid around the affected tracker. Since this tracker is situated at (0,0,0), `distances` must have five rows. When `prom=TRUE`, `fSombra6` provides a weighted averaged of the shadows in the whole set of trackers, whose distribution in the PV plant is defined by `Nrow` and `Ncol`.

These functions are integrated in `calcShd`, `calcGef` and `prodGCPV`, as these examples show.

First, a two-axis tracking system.

```
> struct2x = list(W = 23.11, L = 9.8, Nrow = 2, Ncol = 8)
> dist2x = data.frame(Lew = 40, Lns = 30, H = 0)
> prod2xShd <- prodGCPV(lat = lat, dataRad = prom, modeTrk = "two",
+     modeShd = "area", struct = struct2x, distances = dist2x)
```

Then, a N-S horizontal axis tracking system without backtracking,

```
> structHoriz = list(L = 4.83)
> distHoriz = data.frame(Lew = structHoriz$L * 4, H = 0)
> prodHorizShd <- prodGCPV(lat = lat, dataRad = prom, sample = "10 min",
+     modeTrk = "horiz", modeShd = "area", betaLim = 60, distances = distHoriz,
+     struct = structHoriz)
```

and a N-S horizontal axis tracking system with backtracking,

```
> p <- levelplot(FS ~ w * day, data = Angles, par.settings = custom.theme(region = brewer.pal("YlOrBr",
+     n = 9)))
> print(p)
```

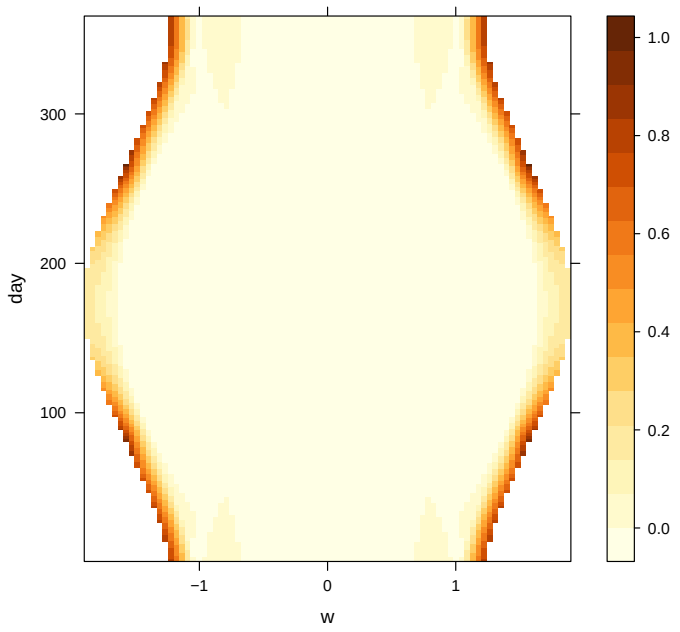

FIGURE 4.3: *Shadows in a PV plant with two-axis trackers.*

```
> prodHorizBT <- prodGCPV(lat = lat, dataRad = prom, sample = "10 min",
+     modeTrk = "horiz", modeShd = "bt", betaLim = 60, distances = distHoriz,
+     struct = structHoriz)
```

Finally, we can compare the *yearly* performance of these systems with the method `compare` (fig. 4.4), and calculate and compare their *yearly* losses with the methods `losses` and `compareLosses` (fig. 4.5), respectively.

4.3 Position of trackers in a PV plant

The optimum distance between trackers or static structures of a PV grid connected plant depends on two main factors: the ground requirement ratio (defined as the ratio of the total ground area to the PV generator area), and the productivity of the system including shadow losses. Therefore, the optimum separation may be the one which achieves the highest productivity with the lowest ground requirement ratio (GRR). However, this definition is not complete since the terrain characteristics and the costs of wiring or civil works could alter the decision.

The function `optimShd` is a help for choosing this distance: it computes the productivity for a set of combinations of distances between the elements of the plant [6]. The designer should adopt the decision from these results with the adequate economical translations.

Let's analyse the configuration of a PV plant with NS horizontal axis trackers, without *backtracking*, and a height of 4,83 m. We are interested in a range of separations of 2 and 5 times this dimension. Besides, the analysis will be carried out with a limitation in the angle of inclination:

```
> structHoriz = list(L = 4.83)
> distHoriz = list(Lew = structHoriz$L * c(2, 5))
> Shd12Horiz <- optimShd(lat = lat, dataRad = prom, modeTrk = "horiz",
+     betaLim = 60, distances = distHoriz, res = 2, struct = structHoriz,
+     modeShd = "area", prog = FALSE)
```

The function `optimShd` constructs an object of class `Shade` This class owns a S4 method of `plot` for displaying the results (figure 4.6).

Now, for a fixed system (figure 4.7):

```
> structFixed = list(L = 5)
> distFixed = list(D = structFixed$L * c(1, 3))
> Shd12Fixed <- optimShd(lat = lat, dataRad = prom, modeTrk = "fixed",
+     distances = distFixed, res = 1, struct = structFixed, modeShd = "area",
+     prog = FALSE)
```

Last, we are interested in a two-axis tracker whose dimensions are 23,11 m width and 9,8 m height. We will try to design a PV plant with a grid of trackers of 2 rows and 8 columns.

```
> struct2x = list(W = 23.11, L = 9.8, Nrow = 2, Ncol = 8)
```

We will try the separations between 30 m and 50 m for the E-O direction and between 20 m and 50 m for the N-S direction.

```
> dist2x = list(Lew = c(30, 50), Lns = c(20, 50))
```

`optimShd` constructs a sequence from the minimum to the maximum value of `distances`, with `res` as the increment, in meters, of the sequence. In this example, `res=5`.

```
> ShdM2x <- optimShd(lat = lat, dataRad = prom, modeTrk = "two",
+     modeShd = c("area", "prom"), distances = dist2x, struct = struct2x,
+     res = 5, prog = FALSE)
```

Besides, the `Shade` object includes the local fitting of the sequence of `Yf` and `FS` values (slots named `Yf.loess` and `FS.loess`). The `predict` method is used with these `loess` slots inside the `shadeplot` method of the `Shade` class (figure 4.8).

```
> comp <- compare(ProdFixed, Prod2x, ProdHoriz, prod2xShd, prodHorizShd,
+     prodHorizBT)
> head(comp)

  values  ind      name
1   1836  G0d ProdFixed
2   1969 Gefd ProdFixed
3   1506   Yf ProdFixed
4   1836  G0d    Prod2x
5   2961 Gefd    Prod2x
6   2235   Yf    Prod2x
```

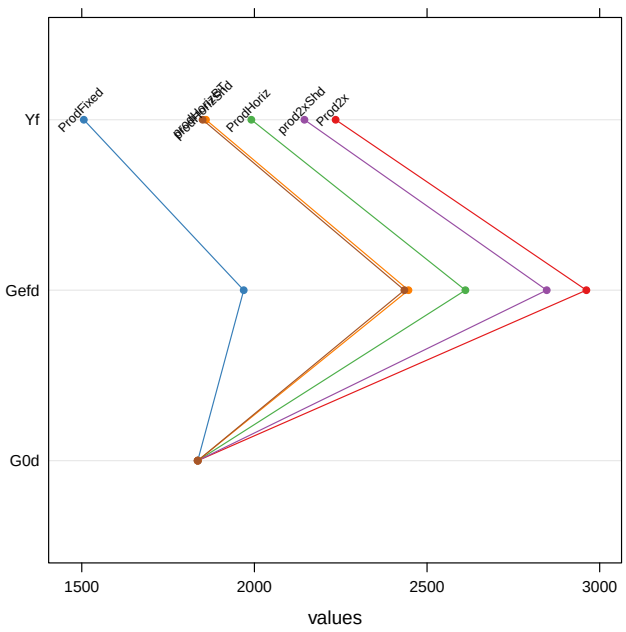

FIGURE 4.4: *Comparison of several* `ProdGCPV` *objects.*

```
> compL <- compareLosses(ProdFixed, Prod2x, ProdHoriz, prod2xShd,
+     prodHorizShd, prodHorizBT)
> head(compL)

         id  values      name
1   Shadows 0.00000 ProdFixed
2       AoI 0.05894 ProdFixed
3 Generator 0.08392 ProdFixed
4        DC 0.07441 ProdFixed
5  Inverter 0.07038 ProdFixed
6        AC 0.02973 ProdFixed
```

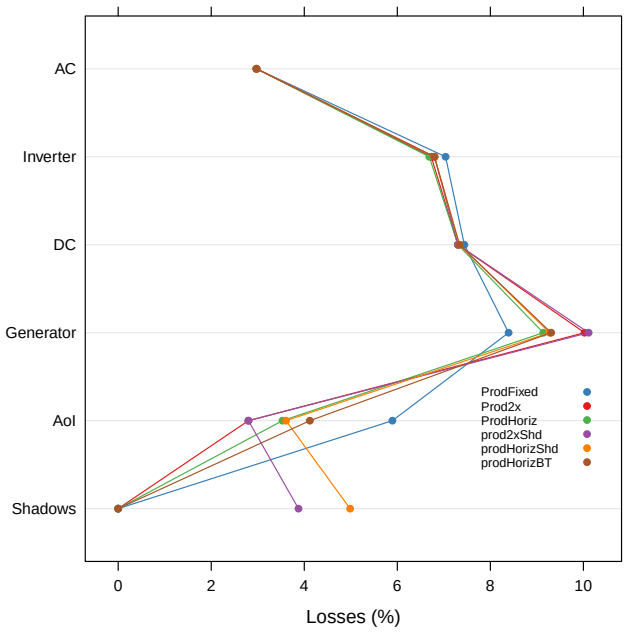

FIGURE 4.5: *Comparison of the losses of several* `ProdGCPV` *objects.*

```
> shadeplot(Shd12Horiz)
```

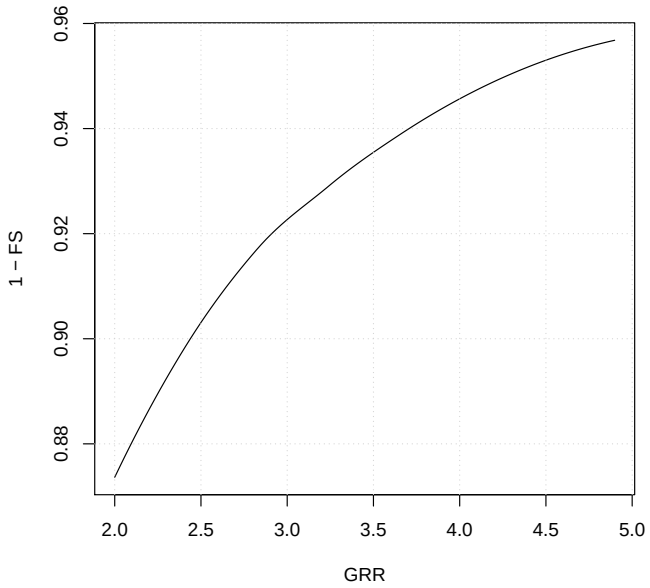

FIGURE 4.6: *Mutual shadows in a NS horizontal axis tracking PV system.*

```
> shadeplot(Shd12Fixed)
```

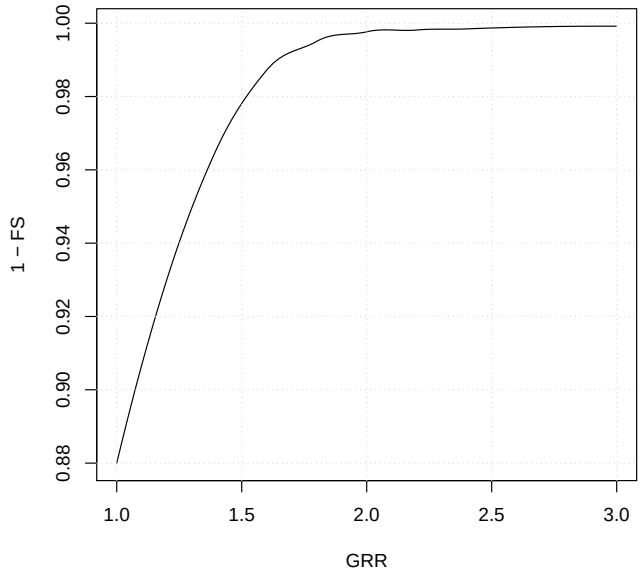

FIGURE 4.7: *Mutual shadows in a PV plant with fixed structures.*

```
> shadeplot(ShdM2x)
```

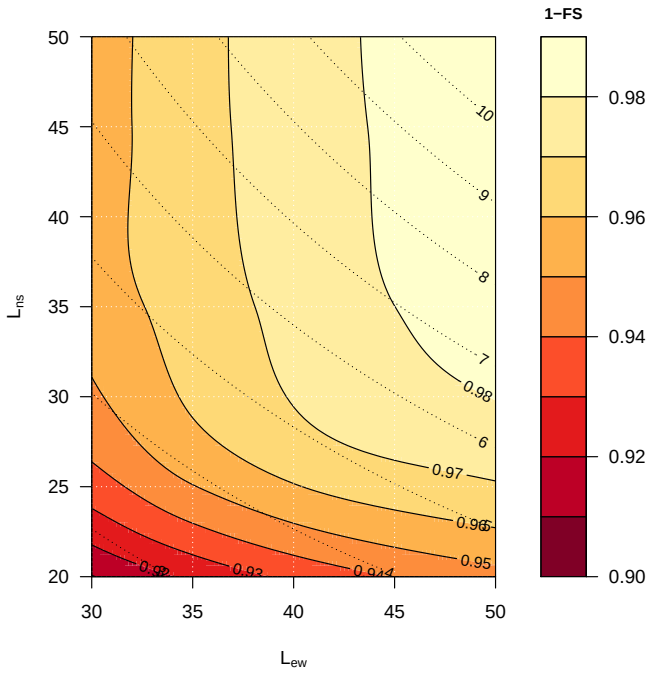

FIGURE 4.8: *Mutual shadows in a two-axis tracking PV system for a combination of separations between trackers.*

Chapter 5

PV pumping systems

5.1 Simulation of centrifugal pumps

The first step for the simulation of the performance of a PV pumping system (PVPS) is the characterization of the pump under the supposition of constant manometric height [1]. The function `fPump` computes the performance of the different parts of a centrifugal pump fed by a frequency converter following the affinity laws.

For example, we can characterize the performance of the SP8A44 pump (http://net.grundfos.com/Appl/WebCAPS/InitCtrl?mode=1) working with $H = 40$ m. The information of this pump is stored in the dataset `pumpCoef`.

```
> data(pumpCoef)
> CoefSP8A44 <- subset(pumpCoef, Qn == 8 & stages == 44)
> fSP8A44 <- fPump(pump = CoefSP8A44, H = 40)
```

The result of `fPump` is a set of functions which relate the electrical power and the flow, hydraulical and mechanical power, and frequency. These functions allow the calculation of the performance for any electrical power inside the range of the pump (figures 5.1 and 5.2):

```
> SP8A44 = with(fSP8A44, {
+     Pac = seq(lim[1], lim[2], by = 100)
+     Pb = fPb(Pac)
+     etam = Pb/Pac
+     Ph = fPh(Pac)
+     etab = Ph/Pb
+     f = fFreq(Pac)
+     Q = fQ(Pac)
+     result = data.frame(Q, Pac, Pb, Ph, etam, etab, f)
+ })
> SP8A44$etamb = with(SP8A44, etab * etam)
```

5.2 Nomograms of PVPS

The international standard IEC 61725 is of common usage in public licitations of PVPS. This standard proposes a equation of the irradiance profile with several parameters such as the length of the day, the daily irradiation and the maximum value of the irradiance. With this profile, the performance of a PVPS can be calculated for several manometric heights and nominal PV power values. A nomogram can display the set of combinations. This graphical tool can help to choose the best combination of pump and PV generator for certain conditions of irradiation and height [1].

This kind of graphics is provided by the function `NmgPVPS`. For example, the figure 5.3 is a nomogram for the SP8A44 pump working in a range of heights from 50 to 80 meters, with different PV generators. The peculiar shape of the curve of 50 meters shows that this pump does not work correctly with this height.

5.3 Productivity of PVPS

A different approach is to simulate the performance of the PVPS following the same procedure as the one described for the GCPV systems. The function `prodPVPS` is the equivalent to the function `prodGCPV`. The inputs are very similar between them, although there are some changes due to the different composition of the system. This function does not allow for the calculation of shadows.

```
> lab = c(expression(eta[motor]), expression(eta[pump]), expression(eta[mp]))
> p <- xyplot(etam + etab + etamb ~ Pac, data = SP8A44, type = "l",
+     ylab = "Eficiencia")
> print(p + glayer(panel.text(x[1], y[1], lab[group.number], pos = 3)))
```

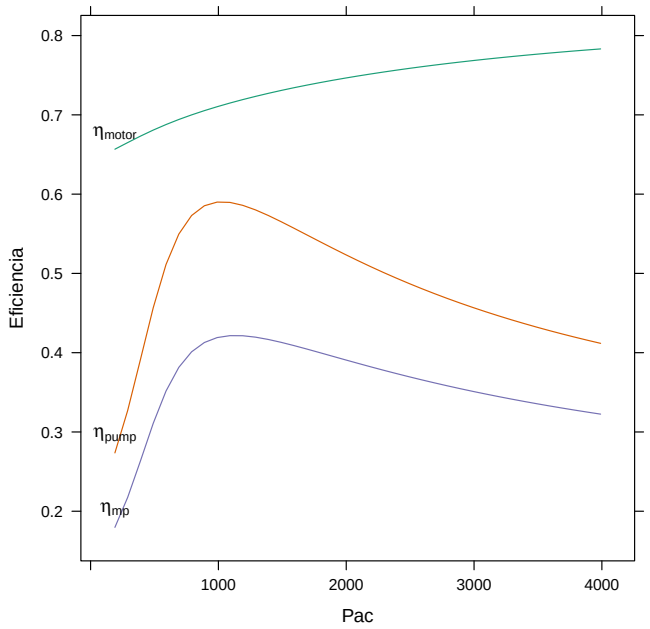

FIGURE 5.1: *Efficiency of the motor and pump for several values of electrical power of a SP8A44 pump with* $H = 40\,\mathrm{m}$

```
> lab = c(expression(P[pump]), expression(P[hyd]))
> p <- xyplot(Pb + Ph ~ Pac, data = SP8A44, type = "l", ylab = "Power (W)",
+     xlab = "AC power (W)")
> print(p + glayer(panel.text(x[length(x)], y[length(x)], lab[group.number],
+     pos = 3)))
```

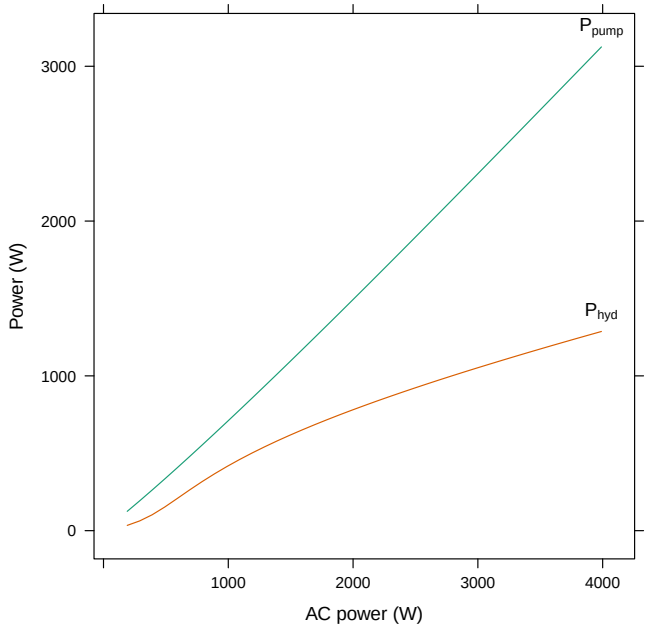

FIGURE 5.2: *Mechanical and hydraulical power versus electrical power of a SP8A44 pump with* $H = 40\,\mathrm{m}$.

```
> Pg = seq(3000, 5500, by = 500)
> H = seq(50, 80, by = 5)
> NmgSP8A44 <- NmgPVPS(pump = CoefSP8A44, Pg = Pg, H = H, Gd = 6000,
+     title = "Selection of Pumps", theme = custom.theme())
> print(NmgSP8A44$plot)
```

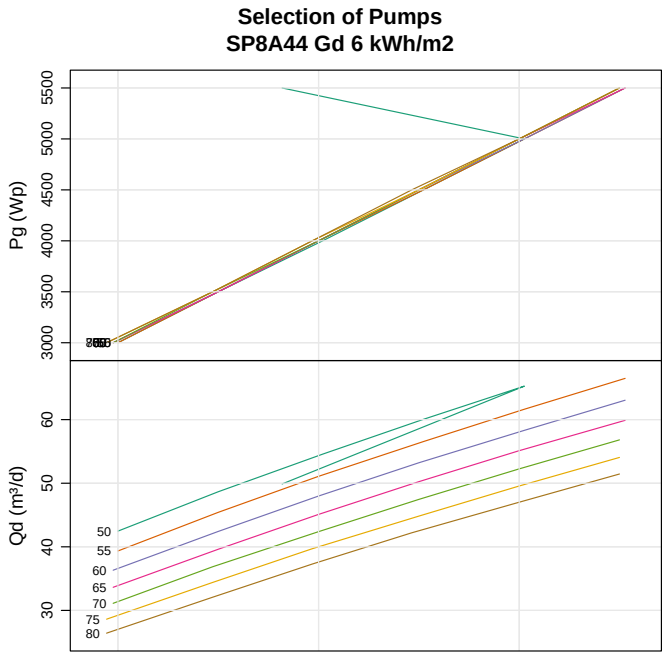

FIGURE 5.3: *Nomogram for the SP8A44 pump working in a range of heights from 50 to 80 meters, with different PV generators.*

Once again with the SP8A44 pump, we compute the flow to be produced by this pump with a PV generator of 5500 Wp and a manometric height of 50 meters. The relation between flow and effective irradiance is displayed in the figure 5.4.

```
> prodSP8A44 <- prodPVPS(lat = 41, modeRad = "siar", dataRad = list(prov = 28,
+     est = 3, start = "01/01/2009", end = "31/12/2009"), pump = CoefSP8A44,
+     Pg = 5500, H = 50)

Downloading data from www.marm.es/siar...

> as.zooY(prodSP8A44)

      Eac    Qd   Yf
2009 7931 22533 1442
```

Let's try to obtain more water with this pump using a larger PV generator of 7000 Wp. However, we can check that this is not a correct decision since the productivity has decreased. The figure 5.5 shows that during the central months of the year, during the maximum irradiance periods, the pump reaches its limits of flow and frequency, and so the frequency converter stops the system. Finally, the figure 5.6 shows the evolution of the daily productivity of these two configurations.

```
> prodSP8A44Lim <- prodPVPS(lat, modeRad = "prev", dataRad = prodSP8A44,
+     pump = CoefSP8A44, H = 50, Pg = 7000)
> as.zooY(prodSP8A44Lim)

      Eac    Qd   Yf
2009 7951 22103 1136
```

```
> p = xyplot(Q ~ Gef | month, data = prodSP8A44, cex = 0.5, type = c("p",
+     "smooth"), col.symbol = "gray", col.line = "black")
> print(p)
```

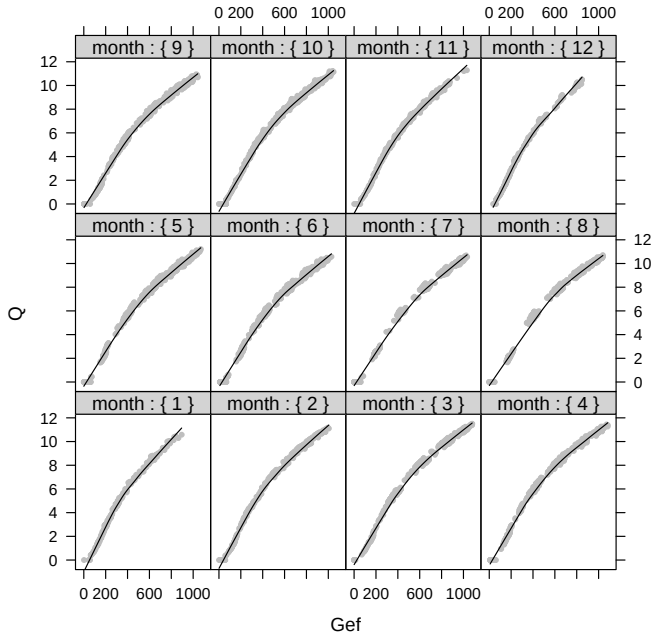

FIGURE 5.4: *Flow versus irradiance of a PVPS with a SP8A44 pump and a PV generator with a nominal power of* 5500 Wp *and a manometric height of 50 meters.*

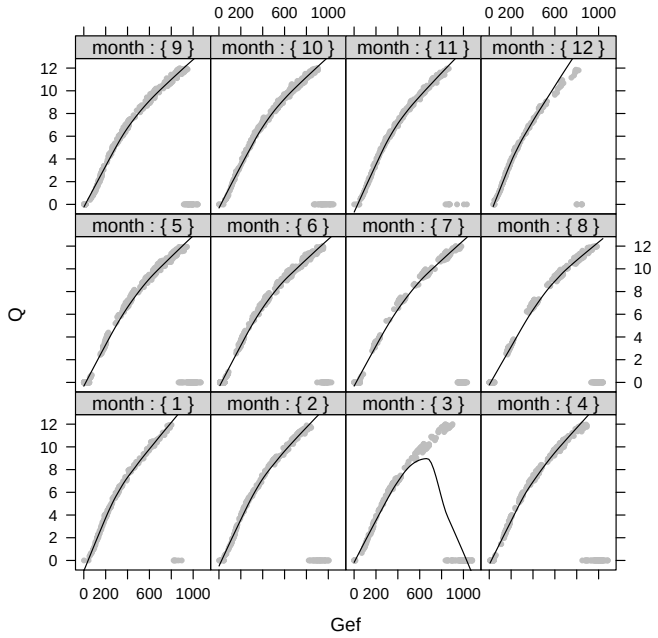

FIGURE 5.5: *Water flow versus irradiance of a PVPS system with a SP8A44 pump and a generator of* 7000 Wp *with a manometric height of 50 meters.*

```
> compPVPS <- mergesolaR(prodSP8A44, prodSP8A44Lim)
> print(xyplot(compPVPS, superpose = TRUE, ylab = "Yf"))
```

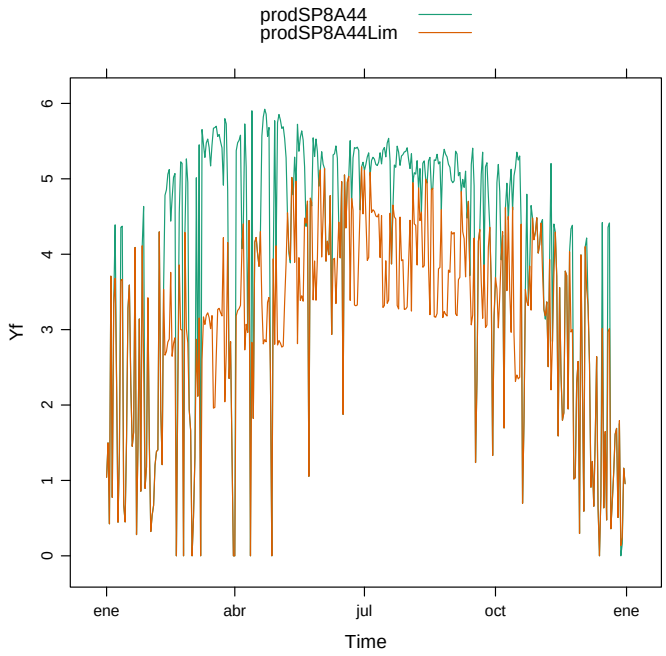

FIGURE 5.6: *Comparison of the daily productivity of two pumping PV systems.*

Chapter 6

Statistical analysis of PV plants

In a PV plant, the individual systems are theoretically identical and their performance along the time should be the same. Due to their practical differences –power tolerance, dispersion losses, dust–, the individual performance of each system will deviate from the average behaviour. However, when a system is performing correctly, these deviations are constrained inside a range and should not be regarded as a sign of malfunctioning.

If these common deviations are assumed as a random process, a statistical analysis of the performance of the whole set of systems can identify a faulty system as the one that departs significantly from the mean behaviour.

The functions `analyzeData` and `Target Diagram` compare the daily performance of each system with a reference (for example, the median of the whole set) during a time period of N days preceding the current day. They calculate a set of statistics of the performance of the PV plant as a whole, and another set of the comparison with the reference. This statistical analysis can be summarised with a graphical tool named "Target Diagram", which plots together the root mean square difference, the average difference and the standard deviation of the difference. Besides, this diagram includes the sign of the difference of the standard deviations of the system and the reference [7].

The next example uses a dataset of productivity from a PV plant composed of 22 systems (`data(prodEx)`). It is clear that the system no.20 is not working correctly during these periods (horizonplot of figure 6.1 and target diagram of figure 6.2).

```
> data(prodEx)
> prodStat <- analyzeData(prodEx)
```

Let's remember the example devoted to `mergesolaR`, with the result displayed in the figure 4.2. The function `TargetDiagram` is an alternative tool to show the behaviour of the set of meteorological stations (figure 6.3).

```
> dif <- prodEx - prodStat$stat$Median
> day = as.Date("2008-8-29")
> p <- horizonplot(window(dif, start = day - 60, end = day), origin = 0,
+     layout = c(1, 22), colorkey = TRUE, colorkey.digits = 1,
+     scales = list(y = list(relation = "same")))
> print(p)
```

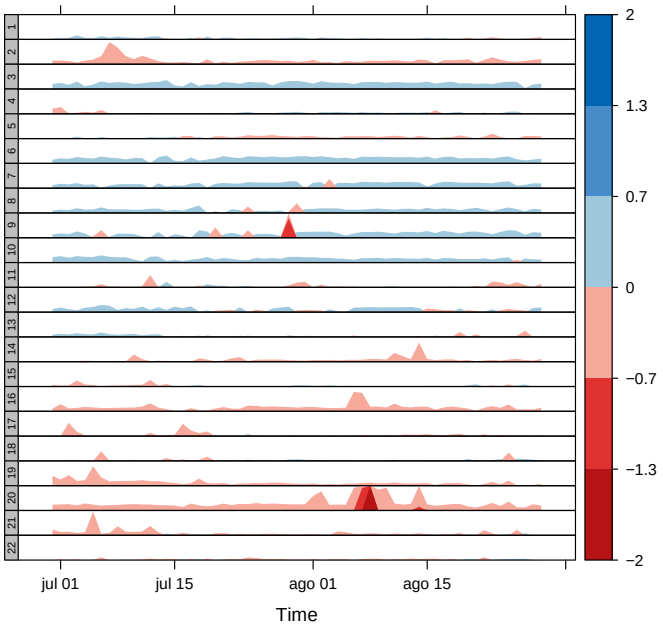

FIGURE 6.1: *Horizonplot of the differences of productivity of a set of 22 PV systems.*

```
> ndays = c(5, 10, 15, 20)
> palette = brewer.pal(n = length(ndays), name = "Set1")
> TDColor <- TargetDiagram(prodEx, end = day, ndays = ndays, color = palette)
> print(TDColor$plot)
```

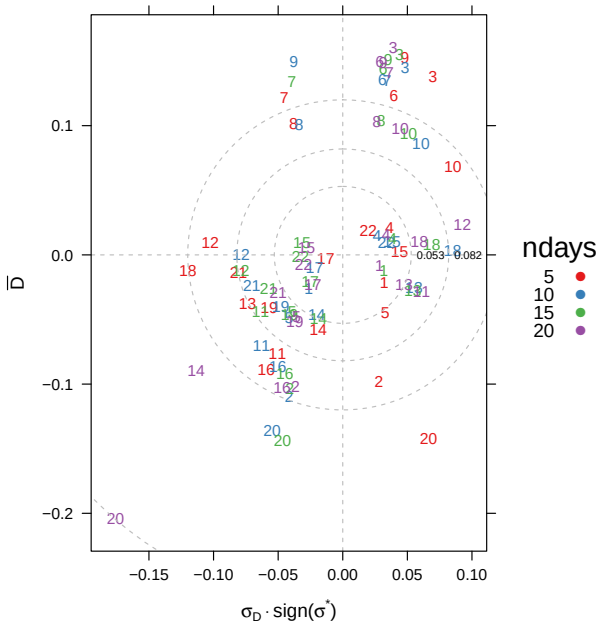

FIGURE 6.2: *"Target Diagram" of the statistical analysis of a set of 22 systems during various time periods.*

```
> TDMadrid <- TargetDiagram(YfMadrid, end = as.POSIXct("2010-12-31"),
+     ndays = c(10, 20, 30, 40, 50, 60), cex = 0.5)
> print(TDMadrid$plot)
```

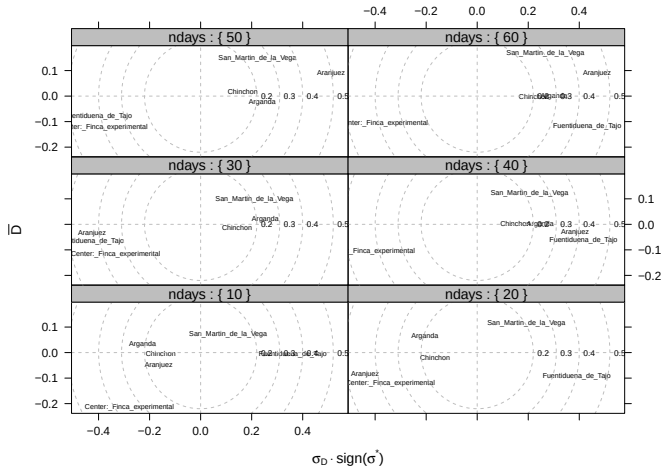

FIGURE 6.3: *Target Diagram of the result of the mergesolaR example*

Chapter 7

Changes

solaR 0.23

- A bug in `fInclin` when `horizBright=FALSE` has been corrected. See help(calcGef).
- Four sun-geometry methods are now available in `fSolD, fSolI, calcSol`.
- `ThzS, AlS and AzS` are not set to NA outside sunrise-sunset period (suggested by Joerg Trentmann)
- `fInclin` and `calcGef` gain a new argument, `HCPV` (suggested by Álvaro Segovia)
- A bug in `fSolI` and `fTheta` when `lat=0` has been corrected (suggested by Alberto Soria)
- `h2d` and `d2h` small functions added.

solaR 0.22

- A new `mergesolaR` method has been defined for merging `solaR` objects.
- The calculation of the sunset time has been improved.
- The voltage dependency of the efficiency curve of the inverter is now included in `fProd` and `calcGCPV`.
- The default values of the `module`, `generator` and `inverter` of both `fProd`, `calcGCPV` and `optimShd` is now documented.
- The help page of optimShd now explains correctly the concept of GRR.
- The plot method for Shade has been renamed to shadeplot.
- The `as.data.frame` method of the `Shade` class is now exported.

solaR 0.21

solaR is now able to calculate from both daily and sub-daily irradiation values. Besides,

- `calcSol` and `fSolI` gain a `"BTi"` argument for intradaily time bases.
- `fCompI` gains a `"G0I"` argument for intradaily irradiation series.
- `fCompI` gains both `"corr"` and `"f"`.
- `calcG0, calcGef, prodGCPV` and `prodPVPS` gain a new `"bdI"` argument for intradaily irradiation, and the `"corr", "f"` arguments.
- The `"bd"` (and the new `"bdI"`) argument of `"calcG0"` can be now a `"Meteo"` object. The `"file"` component of this argument can be now a `"zoo"` object.
- New methods (`"losses"`, `"compareLosses"` and `"compare"`) are available for `"Gef"` and `"ProdGCPV"` classes.

- The "corr" argument of "fCompD" (and "fCompI") can be now "corr=none".
- The correlations between the diffuse fraction and the clearness index are now coded outside "fCompD" as separate functions. Several new correlations have been included, both for monthly/daily values and for intradaily values.
- New small functions for difftime objects have been included.

solaR 0.20

- The package is now almost entirely designed with S4 classes and methods.
- The time series object are constructed with the 'zoo' package.
- Most of the functions and arguments have been renamed in order to ease the understanding by international users.
- Two new functions have been included for the statistical analysis of a PV plant composed of several systems.
- The package dependencies have been optimized.
- Several new small functions for date-time calculations are now available.

Bibliography

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