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1 A new methodology to analyse and optimize territorial
2 compensations of solar radiation intermittency: a case
3 study in Corsica Island (France)

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10 **Abstract**

Territorial compensations of variability are a lever for smoothing the global photovoltaic production. They may allow a higher penetration rate of photovoltaic production in an energy mix, especially for non-interconnected islands. The aim of this paper is to analyse and optimise the smoothing effects of solar resource on a territory. In that view a novel typological classification-based methodology is proposed: intervals from highly intermittent episodes to ones with few fluctuations are discriminated. Then, the potential for compensation is demonstrated through the transformation from classes of high to low variability when summing solar radiation over several sites instead of one alone. The methodology is applied to Corsica. Solar radiation measured at 1 Hz on 8 sites which criss-crosses the island, when summed, demonstrates a reduction in the set of most intense variations compared to individual basis: they represent 5.5 % to 15.5 % of the studied period for the sites taken individually against only 1.7 % for the cumulated radiation. Optimisation of the territorial compensation strategy leads to a near-disappearance of intense variations, with this class representing only 0.13 % of the period. Finally, the optimized dispersion map of solar capacities results from this optimisation.

11 *Keywords:* Solar radiation, Classification, Variability, Territorial
12 compensations, Smoothing effect, Optimization

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Nomenclature		II	Interval	
		b	Classification thresholds	[s]
$inter$	Inter-interval	C	Class	
$intra$	Intra-interval	d	Distances between sites	[km]
S_i	Refers to site S_i	F	Objective function	[s]
t_{tot}	Refers to t_{tot} , the studied period	G	Global horizontal radiation	[W m ⁻²]
t_{var}	Refers to t_{var}	k_b	Direct fraction	
tot	Refers to total (or cumulated)	k_t	Clarity index	
var	Variable	k_{cls}	Clear sky index	
		N	Number (sites, instants)	
β	Weight coefficient	P_N	Relative total number of intervals	[%]
λ	Longitude	[°]		
φ	Latitude	[°]		
		P_t	Relative cumulated interval duration	[%]
		r	Pearson correlation coefficients	[-]
δG	Relative variation of radiation			
	[s]	S	Site	
δt	Variation scale	[s]	t	Time [s]

13 1. Introduction

14 Multicriteria selection of potential photovoltaic (PV) plants in Corsica re-
15 vealed the challenges associated to the territorial concentration of grid-connected
16 plants [1, 2]. Of primary concern is the abrupt loss in energy generation arising
17 from localized heavy cloud cover. The issue is part of the broader challenge of
18 resource intermittency, which has been extensively studied for the electricity in-
19 frastructures with a high penetration of photovoltaic technology [3, 4, 5, 6]. The
20 risk of grid instability has resulting in a limit being set on the amount of installed
21 capacity that can be based on intermittent renewable sources. This limit can
22 be highly constraining particularly for small grids such as non-interconnected
23 islands. For instance, for the islands of La réunion and Corsica (France), this
24 limit was set to 35 % of total electrical power by decrees [7, 8].

25 Today this regulatory constraint is a significant limiting factor for the tran-
26 sition to renewable energy technologies such as photovoltaic facilities, which
27 may only progress if the technical feasibility of safely exceeding the limit can
28 be proven. Small grids in non-interconnected zones such as on islands are es-
29 pecially impacted by this limit. In this context, the intermittence of the solar
30 resource, its territorial variations and its predictability stand as major issues for
31 the energy utility operator. A good knowledge of the solar resource variation
32 over a territory would enable territorial compensation strategies to smooth pho-
33 tovoltaic generation as suggested by [9] and thereby allow the limit on renewable
34 integration to be increased.

35 The spatial variability of solar radiation is typically shown through the anal-
36 ysis of inter-sites Pearson correlation coefficients r presented as a function of the
37 distances between the studied sites [10, 11, 12, 13, 14]. A more advanced treat-
38 ment was introduced by [15] and [16] who defined the discorrelation distance
39 as the distance for which r drops below 0.5. Other authors have proposed sta-
40 tistical indices with which to compare fluctuations of solar radiation at various
41 sites. For instance, [12] studied the standard deviation of hourly clearsky k_{cls}
42 between 2 sites, obtained with satellite data. [10] discussed the solar radiation

43 difference between two sites by comparing the difference to the mean daily value
44 of solar radiation. [17] compared solar radiation power spectra of several sites,
45 and focused particularly on the linear best fit line for time scales less than 1 h.

46 The spatial variability of solar radiation demonstrated though the dis-corre-
47 lation between sites induces shifts in temporal fluctuations from a site to other.
48 Thus for a given period, statistical compensations of variations can be expected
49 on a territory. These spatial compensations are exposed and analysed in various
50 studies. [17] examined the average smoothing effect of solar radiation received
51 by 4 sites separated by several tens of kilometres (20 km to 180 km), at different
52 time scales. The ramp rate analysis of the average revealed a significant decrease
53 in their mean and maximum magnitude, standard deviation, and kurtosis com-
54 pared to each site individually. Also, probability distribution functions and
55 cumulative distribution functions of ramp rates indicated that the average of all
56 four sites is less likely to have large fluctuations than each of the other sites indi-
57 vidually. Similarly, [15] compared boxplots of 1 Hz measurements at 7 isolated
58 sites on the island of La Réunion to their aggregated radiation. The averaged ra-
59 diation variability showed narrower distributions than individual stations, with
60 less hour-to-hour variability. The spatial smoothing of the solar potential was
61 shown to exist for a small geographic site in Japan by [18]. In that work, the
62 mean value of a network of 9 pyranometers covering a 4 km by 4 km area was
63 found to fluctuate to a significantly lesser degree than the individual readings
64 of each sensor.

65 Spatial compensations on solar radiation smooth the PV generation that
66 allows a better integration in the energy mix. At PV plants scale first, [19]
67 analysed the PV output of 6 plants of different sizes, from 0.2 ha to 52 ha,
68 scattered over a 1000 km² area in the south of Navarra (Spain). Smoothing
69 of power fluctuations has demonstrated for large PV plants, and this effect is
70 particularly noticeable for small time steps. At larger scale, [20] performed
71 a multi-objective optimization, maximizing energy and minimizing variability,
72 to allocate 2 MW PV among four sites, with differing amounts at each site,
73 on the island of Lanai, Hawaii. For the optimal allotment, the variability in

74 the form of ramp rates, were reduced by 50 %, whereas energy was reduced
75 by only 3 % over the maximum production case. [21] have shown that the
76 dispersal of PV installations over a wide territory can enable a higher degree of
77 penetration of PV systems without jeopardizing grid stability, from 1.3 % for
78 a fully centralized facility to 37 % for a distributed system covering 1000 km².
79 Also, [22] studied how geographic dispersion of PV installations may minimize
80 electricity supply uncertainty in Virginia (USA). They showed the probabilities
81 of generation shortfalls was lowered for decentralized configurations, since the
82 variability of the production are less variable.

83 Thus, the smoothing effects on solar radiation over a territory, when it is
84 demonstrated, is a lever to limit the intermittence of the global photovoltaic
85 production. Consequently, the territorial compensations of solar radiation offer
86 a mean to increase the deployment of renewable energy technologies. These
87 compensations are already analysed with statistical tools at different scales and
88 territories in the literature. However no method has been proposed neither to
89 quantify the smoothing effect of the solar radiation, nor to build a roadmap
90 for an optimal dispersion of PV installation over a wide territory.

91 This paper addresses these two issues through a novel methodology for the
92 analysis and optimization of the territorial compensations of radiation variabil-
93 ity. The methodology is based on the classification of solar radiation variability
94 and the quantification of durations of intermittent classes. The optimization
95 consists then in finding the dispersion of PV capacity that minimizes the dura-
96 tion of the most intermittent class. To treat these issues, the main novelties of
97 the paper are the following :

- 98 • A new typological classification methodology of solar radiation variations
- 99 • The use of a typological classification for studying the temporal variability
100 of solar resource over measurement sites
- 101 • The application of the typological classification for analysing and quanti-
102 fying the smoothing effects on solar radiation over a territory

- 103 • The optimization of the smoothing effect for minimizing the intermittence
104 of PV production

105 The paper is structured with four sections: the overall methodology, based
106 on typological classification and optimisation of territorial compensations of
107 variation, is introduced in section 2. A case study comprising several different
108 sites is described in section 3. Finally, results of the methodology applied to the
109 case study are presented in section 4. Solar resource variations of individual
110 sites, as well as considering them altogether are qualified and classified. Finally,
111 the presence of territorial compensations is demonstrated and then these are
112 optimised for the dataset.

113 2. Methodology

114 2.1. Classification methodology

115 If source intermittency is well understood, periods of deficient solar energy
116 can be mitigated by managing the various energy generation plants at the dis-
117 posal of the utility operator. As a first step towards developing effective strate-
118 gies to overcome intermittency, it is important to develop a means to characterise
119 the feature in a rigorous manner using data with a sampling time short enough
120 to capture rapid fluctuations in radiation intensity.

121 Temporal fluctuation of solar resource is usually characterized by the analysis
122 of statistics on timeseries of solar radiation or photovoltaic generation data.
123 [12] calculated standard deviation of PV production measured at various times
124 steps. [15] used boxplots of k_{cls} to describe distributions of this index via
125 their median, 1st and 3rd quartiles. [13] applied autocorrelation coefficients
126 presented as a function of different temporal lags. Moreover, ramp rates are also
127 analysed through their probability densities, cumulative probabilities functions
128 [17], power spectral analysis [23, 17] and counting of ramp rates occurrences
129 over a given threshold [19].

130 Irradiance measurements for multiple sites spanning a sufficient period with a
131 high sampling frequency leads to a significant volume of data to analyse. Rather

132 than conventional statistical tools, typological classifications can prove advan-
133 tageous. Within this framework, a classification methodology was developed to
134 identify and describe the nature of variations in solar radiation for individual
135 sites in order to demonstrate the spatial compensations phenomenon.

136 The typological classification of solar radiation per day or instantaneously
137 has been previously studied for satellite image processing [24, 25], the decom-
138 position of total radiation into its direct and diffuse components [26] or the
139 calculation of radiation incident on an inclined plane. Typically, within such
140 studies, periods are classified into intervals of clear sky, partial cloud or over-
141 cast conditions, so that different models can be applied to each scenario. The
142 segregation of a data into two or three intervals using instantaneous indicators
143 of cloud cover or sky clarity provides a first means of classification. Thanks
144 to its simplicity, this approach has been widely implemented in previous works
145 [27, 28, 26, 24, 25]. However, since it evokes a static measure of daily cloudy
146 conditions, the method is incapable of retaining dynamic information such as
147 the degree of variability of cloud cover. Hence, a highly variable day can be
148 attributed the same indicator of mean clarity as an overcast day.

149 Other typological methods allow the dynamics of passing clouds to be taken
150 into account: the categorization by the mean clarity index k_t was complemented
151 by mathematical quantities to quantify the roughness of the signal such as the
152 fractal dimension [29, 30] or the Dirichlet coefficients [31] or wavelet decompo-
153 sition coefficients [32]. [33] classified the daily distribution of direct fraction k_b
154 time series at reduced time-step. The methodology consists in combining three
155 data mining methods: principal component analysis (PCA), K-means cluster-
156 ing methods and Ward hierarchical method to determine five typical days at
157 La Réunion Island. [34] used a set of discrimination parameters derived from
158 hourly clarity index k_t to define three types of day in Corsica, applying Ward
159 hierarchical method. The dynamics of solar radiation were taken into account
160 through an integral of the square of the second derivative of k_t . Similarly, [15]
161 identified five different solar radiation regimes at La Réunion, using k-means
162 clustering analysis. They considered the irradiance level with the daily clear

163 sky index and the variability through two parameters:

- 164 1. a Total Relative Change (TRC) of the clear sky index between 10 h and
165 16 h
- 166 2. a Random Absolute Relative Change (RARC) index that represents the
167 sum of short-term variability, excluding the variability trend of the day.

168 These recent methods, less trivial and more satisfactory represent neverthe-
169 less the limitation of classifying days by averaging over instantaneous indicators,
170 despite the fact that even within a single day it is possible to observe periods
171 of different weather conditions. Once again, the characteristics of each weather
172 phenomenon becomes smoothed and attenuated and, consequently distinctly
173 different days may become embroiled together. Therefore, the categories repre-
174 sent a large number of different radiation profiles. An additional shortcoming is
175 their limitation to the classification of complete days rather than short intervals.
176 In this respect, these methods are inadequate for the electricity utility operator
177 who must be able to forecast the intra-day conditions for energy generation.
178 To break away from this limitation, days may instead be considered as succes-
179 sions of sunlight regimes to be identified by a suitable classification algorithm.
180 The typological classification method of solar radiation variability by interval,
181 mentioned in [35] is presented in a comprehensive manner in this paper.

182 *2.1.1. Variation scale*

183 Regimes in solar radiation distinguish themselves in particular by the form
184 of the variations in irradiance that are observed, which can be characterized by
185 two criteria: their duration and amplitude. The objective of this work is to
186 develop a classification method of the regimes according to these properties.

187 The variation scale refers to the duration of time intervals for which the
188 variation of solar radiation is evaluated. It is duration between two consecutive
189 instants for which the relative variation δG is calculated, ignoring the variations
190 present in the interval, following the relation:

$$\delta G(t) = \left| \frac{G(t) - G(t - \delta t)}{G(t - \delta t)} \right| \quad (1)$$

191 *2.1.2. Categories of variations*

192 Different solar radiation variation dynamics are discriminated by the varia-
 193 tion scales. In effect, variations that are too slow to be perceived for a given δt
 194 can be revealed for larger time intervals (Fig. 1).

195 For a given day, if the data points with a variation greater than 10 % are
 196 selected, one observes that four discontinuous and relatively short groups are
 197 revealed for a variation scale of $\delta t = 1$ s, corresponding to times when the
 198 solar radiation fluctuates considerably. A large set of points is identified for
 199 a variation scale of $\delta t = 300$ s, and indeed it is observed that low frequency
 200 variations occurring between 3:00 pm – 5:00 pm are particularly considered.
 201 Finally, nearly all points in the interval 12:45 – 5:20 pm are recovered when
 202 $\delta t = 1200$ s . The scales of variation therefore render visible and quantifiable
 203 the intensity of the variability following the rule according to which, the smaller
 204 the δt beyond which the variations become visible, the stronger and tighter the
 205 variations.

206 It is therefore possible to construct a typology on the basis of scales of vari-
 207 ations according to the following procedure: considering the scales retained,
 208 calculate and compare the variations for a threshold in variability. The varia-
 209 tions superior to this threshold are associated to the equivalent class, which can
 210 be semantically defined as a class of “variations visible at such a scale”. Two
 211 distinct scales δt_1 and δt_2 give rise to three classifications, including the class
 212 of negligible variations. It is useful to choose scales that are separated by sev-
 213 eral orders of magnitude, in order to categorize qualitatively different variation
 214 profiles.

215 *2.1.3. Delimitation of intervals*

216 For most cases, even within a highly active cloudy regime, variations of so-
 217 lar radiation are found to only occasionally exceed the fixed threshold. The

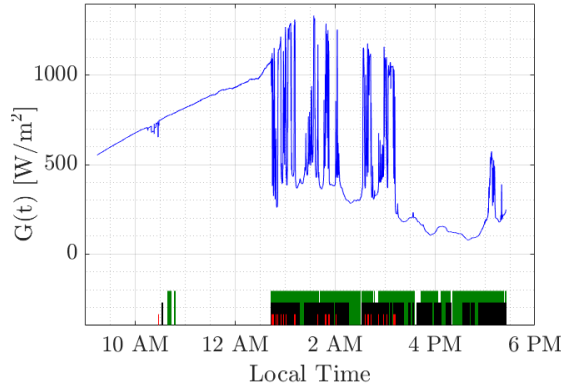


Figure 1: Variations revealed by different values of variations scales : $\delta t = 1$ s in red, $\delta t = 300$ s in black and $\delta t = 1200$ s in green

218 categorization condition therefore generates a large number of instants of dif-
 219 ferent classes that pass in rapid succession. On the other hand, an isolated and
 220 punctual variation, as may arise from a single passing cloud for example, may
 221 generated an isolated micro-interval. It seems therefore important to regroup
 222 these micro-intervals into large interval. The definition of criteria with which
 223 to regroup the data is therefore needed in order to limit the number of entities,
 224 whilst respecting the similarity of variation profiles that have been regrouped.

225 The two filters have been introduced following this rational. The first thresh-
 226 old represented the maximum duration between two variations so that they are
 227 regrouped into the same interval. Labelled b_{intra} , it is the intra-interval thresh-
 228 old. The second threshold compares to a minimum duration of intervals: it
 229 is the inter-interval threshold b_{inter} . Using these two thresholds, the following
 230 four-steps sequential procedure (Fig.2)

1. Variable instants t_{var} are identified as instants for which the variations of solar radiation exceed the threshold of variability b_{var} (Step 0 & 1):

$$t_{var} = \{t \text{ s.t. } \delta G(t) \geq b_{var}\} \quad (2)$$

231

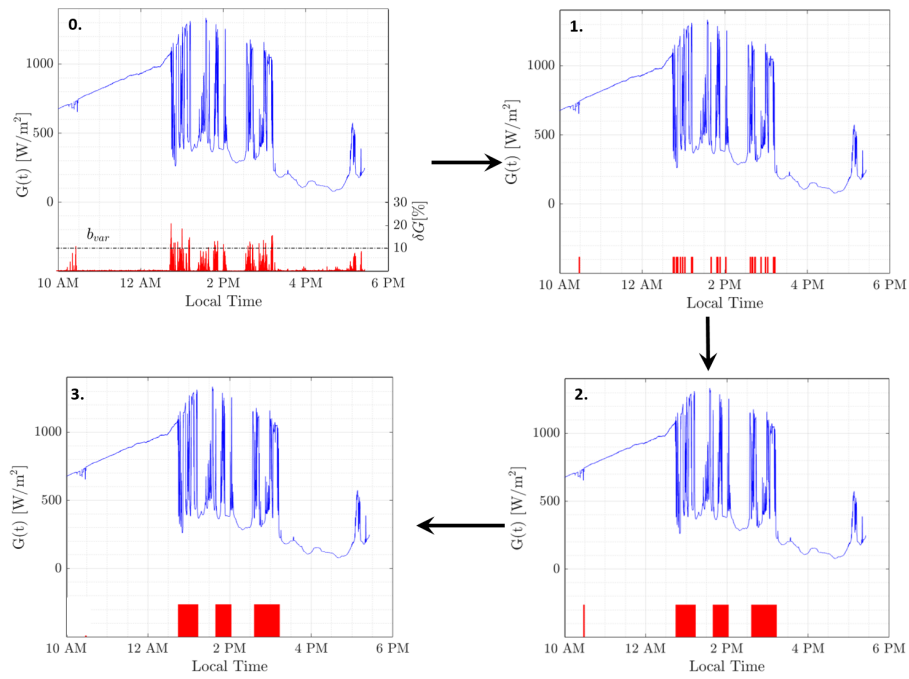


Figure 2: Diagram of the method : 0.&1. Identification of variations ($b_{var} = 0.1$) ; 2. Intra-interval grouping step ($b_{intra} = 900$ s) and 3. inter-interval grouping step ($b_{intra} = 900$ s) (measured irradiance at Corte, 24th May 2010)

2. Times between two distinct variations separated by an interval which duration do not exceed the threshold b_{intra} are in turn considered : this step comprises the inter-interval regrouping, or the homogenisation during which the set of fluctuating irradiance intervals \mathbb{I}_{var} is determined (Step 2) :

$$\mathbb{I}_{var,i} = \mathbb{I}_{var,i} \cup \{t_{var,i+1}\} \quad \text{if } t_{var,i+1} - \max_{t \in \mathbb{I}_{var,i}}(t) \leq b_{intra} \quad (3)$$

232

3. Any intervals that are too short are integrated into adjacent intervals in the inter-interval regrouping step (step 3) :

$$\mathbb{I}_{var,i+1} = \mathbb{I}_{var,i} \cup \mathbb{I}_{var,i+1} \text{ or } \mathbb{I}_{var,i-1} = \mathbb{I}_{var,i} \cup \mathbb{I}_{var,i-1} \quad \text{if } \max_{t \in \mathbb{I}_{var,i}}(t) - \min_{t \in \mathbb{I}_{var,i}}(t) \leq b_{inter} \quad (4)$$

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In the case of adjacent intervals being of different classes, the inter-interval regrouping proceeds depending on its class: if the given interval is of the maximal class, it will be concatenated to the nearest neighbouring inferior class, otherwise it will be added automatically to the nearest superior class interval. These conditions are valid because, from the perspective of the utility operator, it is more convenient to choose the less favourable case in order to limit risks. However, in the first case where up-classing is impossible, the marginality or short duration of fluctuations are assumed to dominate their intensity and the interval is downgraded.

242

2.2. Optimisation of spatial compensation of solar radiation variations

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247

The phenomenon of spatial compensation of solar radiation variations represents an original alternative to smoothing photovoltaic generation without the need for additional technologies. To this end, optimization of the phenomenon could serve to attenuate variations and provide a relatively stable photovoltaic energy supply over the whole territory.

248 The optimization problem shall be to find the set of coefficients $(\beta_{S_i})_{i \in [1, N]}$,
 249 with $\forall i \in [1, N]$, $\beta_{S_i} \geq 0$ and $\sum_{i=1}^N \beta_{S_i} = 1$ that minimizes $P_{t, G_{tot}}(C_M)$ the
 250 relative cumulated duration of most important variations C_M in the weight sum
 251 of global irradiance G_{tot} over all the N sites :

$$G_{tot}(t) = \sum_{i=1}^N \beta_{S_i} \cdot G_{S_i}(t) \quad (5)$$

252 .

253 So, objective function $F((\beta_{S_i})_{i \in [1, N]})$ is :

$$F((\beta_{S_i})_{i \in [1, N]}) = \min(P_{t, G_{tot}}(C_M)) \quad (6)$$

254 The coefficients corresponding to the minimum of the cost function indi-
 255 cate the optimal deployment of photovoltaic capacity at the sites included in
 256 the study for a minimum of C_j variations and hence the smoothest possible
 257 generation curve.

258 In order to determine the optimal set of coefficients β_{S_i} an efficient optimi-
 259 sation tool is needed to limit the number of necessary calculations. Ultimately,
 260 all combinations $(\beta_{S_i})_{i \in [1, N]}$ should be tested to find the optimal set: for a coef-
 261 ficient precision of 1×10^{-1} , this would entail 9^N tests. Rather than pursuing this
 262 tedious approach, a genetic algorithm (GA) [36, 37] was employed to accelerate
 263 the search.

264 3. Case study

265 The methodology developed in section 2 is applied to Corsica Island as it
 266 presents characteristics of an good illustrative case study. Indeed, the island can
 267 be considered as a non-interconnected zone, since the importation of electricity
 268 from the continental grid represents only a fifth of the total grid capacity. As
 269 a consequence, the regulatory limit (35 %) of renewable integration in Corsica
 270 was reached in 2012 when all existing PV plants were connected to the local
 271 grid [38]. The objective of the present work is to highlight and optimize the ter-
 272 ritorial compensation of solar resource variation as an effective strategy in order

273 to exceed the regulatory integration limit for intermittent renewables without
274 impacting on the grid. To this end, the spatial and temporal behaviour of solar
275 radiation in Corsica was analysed, using ground-based measurements at a small
276 number of weather stations.

277 *3.1. Geography of the studied territory*

278 Corsica is a Mediterranean island lying in the golf of Genova. From north
279 to south the landmass spans 183 km, from latitude N 41°20'2" to N 43°1'31".
280 The island is 83.5 km wide from east to west, covering longitudes E 8°32'30"
281 to E 9°33'38". With a surface area of 8722 km², Corsica is the fourth largest
282 island in the Mediterranean after Sardinia, Sicily and Cyprus. The island is
283 classed as a "mountain in the sea", with relief above 600 m accounting for 39
284 % of its surface and an average elevation above sea level of 568 m. Some 120
285 peaks exceed 2000 m altitude (Rome and Giorgetti, 2007). The coastal regions
286 enjoy a Mediterranean climate characterized by warm, dry summers and mild,
287 humid winters, which translates into a higher solar resource potential than most
288 of metropolitan France. In contrast, in the mountains the climate is strongly
289 affected by the altitude. At the highest altitudes Corsica exhibits an alpine
290 climate. Inland, summers are hot and sunny, but in winter conditions are more
291 unstable with a high degree of precipitation (about 700 mm yr⁻¹). The geo-
292 graphical distribution of the solar potential across the island is therefore par-
293 ticularly heterogeneous and microclimates are present in the region, correlated
294 with elevation as illustrated by the map of daily average radiation in 2005 ob-
295 tained with processed Meteosat8 satellite images [39].

296 The geographical dispersion of the studied sites is essential, in order to ensure
297 a representative and coherent dataset for solar radiation across the territory.
298 The positions of the weather stations were therefore carefully chosen taking
299 into account the microclimate zones on the island. The north-eastern and south-
300 western parts of the island do not experience variations in solar radiation at the
301 same time. A line of separation exists, running north-west to south-east due to
302 the orientation of the mountain range in the centre of the island. Coastal areas

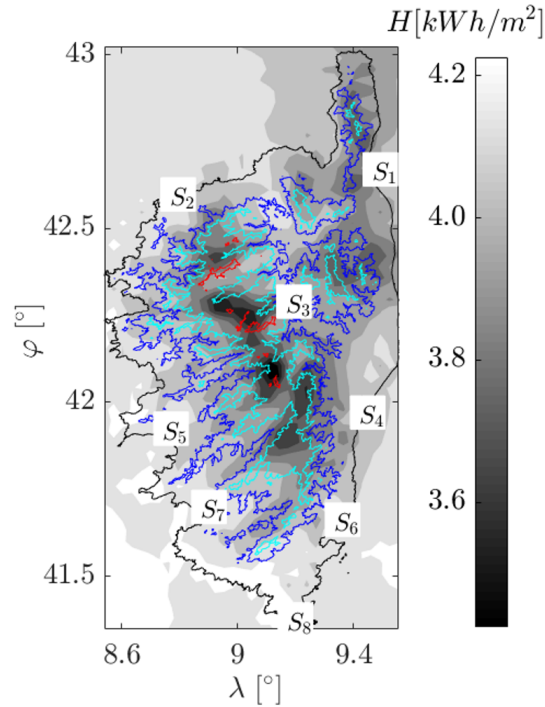


Figure 3: Geographic localisation of measurement stations S_i , micro-climates and elevation contours in Corsica. The greyscale indicates daily irradiation intensity in 2005 over the island. Cyan, blue and red contours highlight the elevation levels at 530 m, 1060 m and 2120 m respectively.

303 of the north-east and south-west, which represent equivalent microclimates, do
 304 not however experience the same weather. It is therefore convenient to install
 305 weather stations in both areas. The measurement sites were thus deployed
 306 at EDF net interconnection sites, taking into account the above mentioned
 307 constraints (Fig. 3), with altitude and geographical coordinates detailed in
 308 table 1.

309 3.2. Dataset

310 3.2.1. Instrumentation

311 The apparatus used, SP Lite 2 Kipp & Zonen pyranometers, are equipped
 312 with a silicon photodiode of sensitivity 60 to 100 $\mu\text{V W}^{-1} \text{m}^{-2}$. Their rapid

Table 1: Geographical coordinates of measures sites

Code	Site	Latitude (φ)	Longitude (λ)	Altitude	N ^{er} days
S_1	Lucciana	42°39'49''	9°25'28''	60 m	456
S_2	Calvi	42°33'38''	8°44'48''	31 m	416
S_3	Corte	42°18'4''	9°9'57''	381 m	445
S_4	Ghisonaccia	42°3'54''	9°22'14''	65 m	451
S_5	Ajaccio	41°55'49''	8°45'23''	2 m	355
S_6	Sainte Lucie	41°41'59''	9°20'12''	66 m	405
S_7	Propriano	41°39'43''	8°55'2''	17 m	407
S_8	Bonifacio	41°22'17''	9°12'10''	46 m	450

313 response time to 95 % signal strength within 1 s allowed for the second-wise
 314 measurements undertaken in the current study. This time step was chosen in
 315 order to allow a thorough study of short term variations in solar radiation.

316 3.2.2. Measurement period

317 The data span a period of 18 months, starting the 24th May 2010 for the sta-
 318 tions at Corte and Ajaccio, and a few days later for the other installations. Data
 319 acquisition was stopped on the 2nd October 2011. Over the period, occasional
 320 service interruptions lasting from a few hours to a few days were experienced.
 321 Consequently,

- 322 • Some days contain several data gaps, rendering them unusable for the
 323 analysis. Those days with more than 10 % missing or unusable data were
 324 eliminated from the analysis
- 325 • The number and distribution of useable days of data in the dataset vary
 326 between sites (Table 1)

327 Applying the requirement that data from all stations were available (neces-
 328 sary for a comparative analysis), a subset of 152 days was kept for the present
 329 analysis. This constraint plus the heterogeneous distribution of the useable
 330 dates across the seasons represent serious limiting factors for this type of study.
 331 Indeed, the present dataset comprised 62 days in winter, 63 in spring, 21 in
 332 summer and only 6 days in autumn. The set of overlapping dates therefore con-

333 tains a seasonal imbalance, which introduces a statistical bias when comparing
334 sites.

335 Around the hours of sunrise and sunset the effect of nearby obstructions
336 and airmass result in low radiation intensities. Moreover, these phenomena are
337 deterministic whereas the study is focused on stochastic variation due to cloudy
338 cover. It was therefore necessary to define a so-called energy interval, represent-
339 ing 80 % of the solar energy of the day (at clear sky condition), symmetrical
340 about solar noon and excluding the start and end of each day [40].

341 *3.2.3. Parametrisation of the classification method*

342 The development of the classification method as well as the definition of
343 intervals of variability and of regimes of solar radiation require the determination
344 of four parameters:

- 345 1. A variability threshold b_{var} beyond which the conditions are considered
346 fluctuant
- 347 2. The values of the variation scales δt used to discriminate the different
348 regimes of solar radiation
- 349 3. The thresholds of intra- and inter-intervals regrouping, designated respec-
350 tively b_{intra} and b_{inter} , which set the limits of the different intervals.

351 The variability threshold was defined by the french grid operator in Corsica,
352 EDF, which judges a variation to be important when it exceeds 10 % of the
353 radiation received during 5 minutes. It was therefore decided to generalize this
354 10 % threshold for all of the variability scales to be considered.

355 The scales of variability δt serve to discriminate variations with different
356 features. It suffices to adopt variation scales that are separated by orders of
357 magnitude in order to discriminate different variation dynamics. Those of order
358 a few seconds may be used to identify deep and narrow variations whereas
359 those of a few minutes, as well as intense variations, recover slow and shallower
360 variations.

361 Consider $N_{t_{var}}$ the number of instants t_{var} identified, for a given variability
362 scale δt , by the first step of the classification procedure (Fig. 2). Let's define

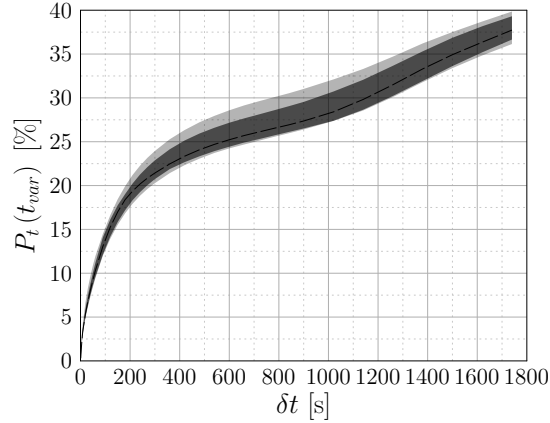


Figure 4: Statistics of $P_t(t_{var})$ as a function of the scale of variability δt for the 8 sites on all the study period. The light grey area depicts the range between the 10th and the 90th percentiles, dark grey depicts range between the 25th and the 75th percentiles and dashed line is the median

363 $P_t(t_{var}) = N_{t_{var}}/N_{t_{tot}} * 100$ the ratio of number of variable instants to the total
 364 sample of the measurement period $N_{t_{tot}}$. $P_t(t_{var})$ can be seen as the cumulative
 365 time variable on the whole sample.

366 On figure 4, we can observe that the ranges between 25th and the 75th
 367 of $P_t(t_{var})$ and its derivative drawn a thick envelope curves. It shows that
 368 whatever the site, $P_t(t_{var})$ has the same shape: $P_t(t_{var})$ increases with the
 369 scale of variations δt considered. More precisely, $P_t(t_{var})$ rises rapidly up until
 370 an inflexion of the envelop, for $\delta t = 300$ s. Very fewer variable instants are found
 371 for $\delta t = 1$ s than for $\delta t = 300$ s. These points reflect different types of variations
 372 to those observed for $\delta t = 300$ s : large variation scales can be used to identify
 373 slow variations in addition to deep and fast found with small scales. Then, we
 374 can see $P_t(t_{var})$ increases slowly for $\delta t \geq 300$ s and $\delta t \leq 1200$ s: nearly the same
 375 instants are considered variable when δt is set in this intervale of values. Finaly,
 376 more variations identified at $\delta t > 1200$ s. These additionalvariations are not
 377 directly associated to meteorological instabilities, but rather may arise from the
 378 variation in solar radiation under clear sky conditions.

379 From this analysis of figure 4, it appears appropriate to undertake an analysis
380 considering two variation scales, $\delta t_1 = 1$ s and $\delta t_2 = 300$ s, used to define three
381 classes:

- 382 • Class 0 (C_0): stable conditions, with no visible variations for $\delta t = 1$ s or
383 $\delta t = 300$ s;
- 384 • Class 1 (C_1): slow and shallow variations perceptible only for $\delta t = 300$ s;
- 385 • Class 2 (C_2): narrow and deep variations present for both scales, $\delta t = 1$ s
386 and $\delta t = 300$ s.

387 The roles of b_{intra} and b_{inter} are equivalent: b_{intra} can be interpreted as a
388 maximal time interval between two variations, and therefore the minimum size
389 of stable intervals; whereas the b_{inter} designates the minimum size of variable
390 intervals. These thresholds therefore represent the minimal sizes of intervals,
391 stable or otherwise, and hence it is appropriate to consider identical values for
392 the two parameters.

393 Figure 5 presents intervals delimited for different regrouping thresholds,
394 which are observed to as significant an impact on the data as the configura-
395 tions, when the thresholds are varied from $b_{intra} = b_{inter} = 1$ s to $b_{intra} =$
396 $b_{inter} = 300$ s, $b_{intra} = b_{inter} = 900$ s and finally to $b_{intra} = b_{inter} = 1800$ s.

397 As was previously expected, without regrouping ($b_{intra} = b_{inter} = 1$ s) a large
398 number of small discontinuous intervals are observed (Fig.5(a)). The application
399 of these thresholds serves to eliminate marginal variations. Thus, all unstable
400 points classified as C_1 observed between 10:28 and 10:33 (Fig.5(a)) change to
401 C_0 when regrouping is applied (Fig.5(b), 5(c) et 5(d)). The intervals generated
402 by the instabilities during these times do not exceed the threshold S_{inter} , and
403 are therefore declassified.

404 These thresholds are responsible for a considerable restructuring of the vari-
405 ation intervals. Therefore,

- 406 • Data belonging to C_2 between 1:40 pm and 2:00 pm before regrouping are
407 too spaced out to be regrouped into an interval when $b_{intra} = b_{inter} =$

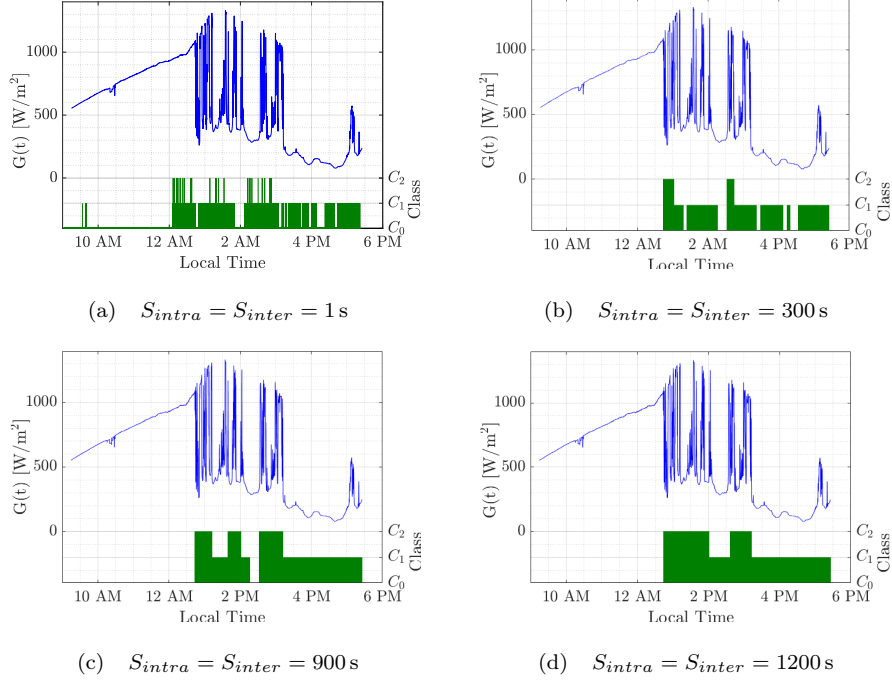


Figure 5: Intervals revealed for a variability threshold of 10 %, $dt_1 = 1 \text{ s}$ and $dt_2 = 300 \text{ s}$ and different values of intra and inter – interval grouping thresholds

408 300 s, and are thus declassified (Fig.5(b)). In contrast, the same points are
 409 regrouped into an interval of class C_2 for $b_{intra} = b_{inter} = 900 \text{ s}$ (Fig.5(c)).
 410 Finally, they integrate class C_2 interval between 12:25 pm and 1:12 pm
 411 when $b_{intra} = b_{inter} = 900 \text{ s}$ (Fig.5(d)).

- 412 • Points classed as C_2 for the range 2:36 pm to 2:43 pm are retained in
 413 this class when $b_{intra} = b_{inter} = 300 \text{ s}$, because the subsequent points
 414 are two spread out to be included. These points are retained within this
 415 interval when the thresholds are raised to $b_{intra} = b_{inter} = 900 \text{ s}$ and
 416 $b_{intra} = b_{inter} = 1800 \text{ s}$.

417 We can observe a total of 14 intervals were identified for $b_{intra} = b_{inter} =$
 418 300 s (Fig. 5(b)), of which 6 persist less than 15 minutes. For $b_{intra} = b_{inter} =$
 419 900 s (Fig. 5(c)), 8 intervals are recovered, whereas 5 are found for regrouping

420 thresholds of 1800 s (Fig. 5(d)). It should be noted that a period in which
421 N intervals are identified for $b_{intra} = b_{inter} = 300$ s, including M intervals
422 of durations shorter than 900 s, will not be split into $N - M$ intervals when
423 considering $b_{intra} = b_{inter} = 900$ s.

424 Overall, the smaller the thresholds, the larger the degree of segmentation
425 of days and the smaller the intervals that will be obtained (Fig. 4). With this
426 in mind, and in the absence of any objective criterion for the determination of
427 these thresholds, they should rather be set according to the specific applica-
428 tion under study, the subsequent analysis, and the desired temporal resolution
429 needed for that application.

430 4. Results and discussion

431 4.1. Characterisation of fluctuations observed at each site

432 The method introduced in section 2 was implemented to characterise the
433 fluctuations observed at the 8 sites, considering a variability threshold of b_{var}
434 = 10 %, and two scales of variations $\delta t_1 = 1$ s and $\delta t_2 = 300$ s to allow the
435 evaluation of the three classes defined above. The thresholds intra- and inter-
436 regrouping were set to $b_{intra} = b_{inter} = 900$ s, affording a good compromise
437 between temporal resolution for intervals and the number of intervals to be
438 defined. This comparative assessment was undertaken using the 152 days of
439 overlapping data.

440 The results of this comparative analysis of intervals are shown in figure 6,
441 where each class C_j is presented with its associated weight in terms of

- 442 1. relative cumulated durations $P_t(C_j)$ of intervals, obtained by evaluating
443 the number of measurements associated to each class relative to the sample
444 size.
- 445 2. relative number of intervals $P_N(C_j)$, obtained by counting the amount of
446 interval of each class normalized by the total amount of intervals.

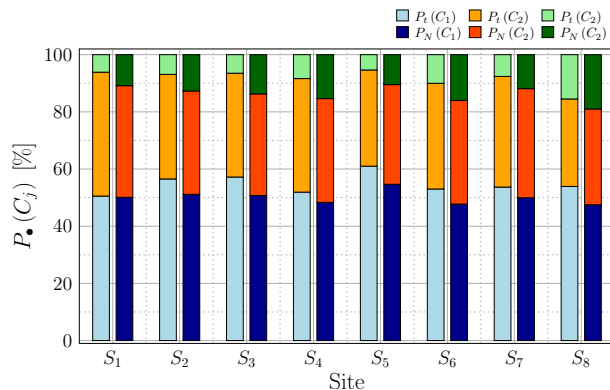


Figure 6: Histograms of relative numbers of intervals $P_N(C_j)$ and relative cumulated durations $P_t(C_j)$ of variation class C_j for the studied sites S_i

447 The fluctuations of all stations exhibit $P_t(C_0) > P_N(C_0)$, and with the
 448 exception of Ajaccio (S_5) and Bonifacio (S_8), $P_t(C_1) > P_N(C_1)$. These obser-
 449 vations show that the intervals of classes C_0 and C_1 tend to be relatively long.
 450 For example, 50 % of the intervals of class C_0 at Propriano (S_7) represent some
 451 53.7 % of the measurement time; similarly, 36.3 % of the intervals classed C_1 at
 452 Ghisonaccia (S_4) occupy 39.7 % of the time. In contrast, $P_t(C_2) < P_N(C_2)$ in-
 453 dicates that the intervals of class C_2 tend to be of short duration. One observes
 454 that at the Lucciana site (S_1) for example, 10.9 % of the intervals represent 6.13
 455 % of the measurement time.

456 Ajaccio (S_5) appears to be meteorologically the most stable of the 8 sites,
 457 with the most intervals of class C_0 and the fewest of class C_2 which is confirmed
 458 in terms of the cumulated time: variations of class C_0 represent 61 % of the
 459 period whereas class C_2 covers only 5.36 % (Fig.6). At the other extreme,
 460 Bonifacio (S_8) experiences the least stable conditions with a larger frequency of
 461 C_2 variations, representing 19 % of intervals and 15.5 % of cumulated time.

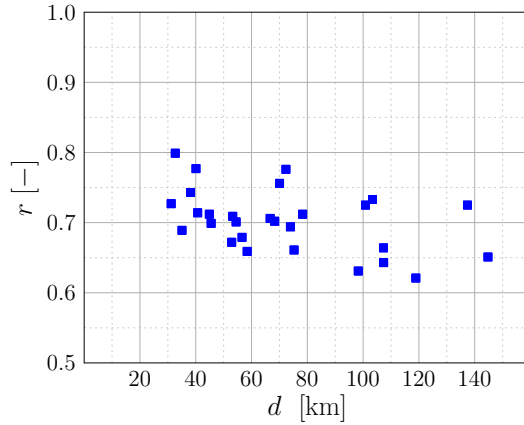


Figure 7: Variogram of the irradiance data per paire of sites: standard variations between irradiances measured over paire of sites as a function of distances

462 *4.2. Characterising the spatial compensation of the solar resource in Corsica*

463 *4.2.1. Evidence for the phenomenon*

464 The subset of data corresponding to daylight hours was retained for the
 465 comparative analysis. Pair-wise linear correlation coefficients were evaluated
 466 for the 152 days of overlapping data for each weather stations and the seven
 467 other sites. As can be seen in figure 7, the correlation factor between sites
 468 was found to not exceed 0.8 for the available data, indicating that the sites
 469 are not strongly correlated. The data exhibit phase differences between the
 470 variations observed from one site to the next, which therefore may be exploited
 471 to smooth the effects of intermittence and hence take advantage of the spatial
 472 compensations of the solar resource.

473 With the aid of the present data analysis, it has been possible to draw
 474 certain observations of the spatial compensation of the solar resource that are
 475 nevertheless indicative of the presence of the phenomenon for Corsica.

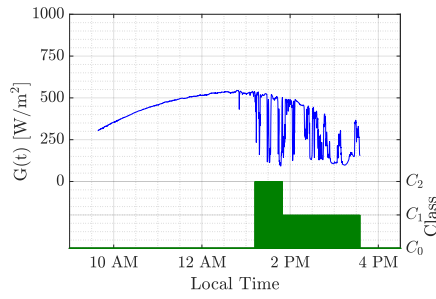
- 476 • Distinct variations in meteorological conditions recorded as a function of
- 477 geographical position;
- 478 • correlation coefficients not exceeding 0.8 between sites (Fig.7), arising from

479 phase shifts in cloud phenomena;

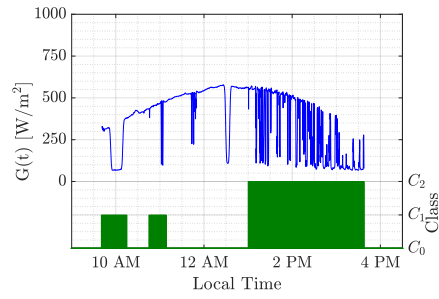
- 480 • Different fluctuations observed by the classification method, indicating
481 different climate and weather from one site to another.

482 Also, we can observe that the degree of fluctuation observed for individual
483 sites (Fig. 8(a), 8(b), 8(c), 8(d), 8(e), 8(f), 8(g), 8(h)) is attenuated when
484 the solar radiation is integrated over all sites (Fig. 8(i)). For instance, some
485 sites exhibit significant variations in solar radiation during the afternoon: such
486 variations of class C_2 were observed in Lucciana (S_1), Calvi (S_2) and Bonifacio
487 (S_8). These variations are attenuated when considering the average, and none
488 of them are of class C_1 . These observations are consistent with earlier evidence.

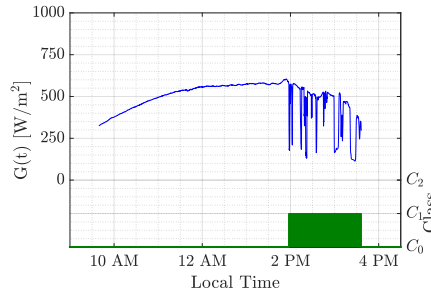
489 The distribution of solar radiation over the island is therefore favourable
490 to the concept of territorial smoothing of the solar resource, although it remains
491 necessary to develop a more general proof for all days and also a method to
492 quantify the level of compensation achieved. Conventional statistical methods
493 such as histograms of variations are inadequate for the current study. Indeed, we
494 have not found any suitable data representation tool to visualise and quantify
495 the variations. The use of variation classes could serve to prove the existence
496 of the phenomenon, by presenting the class distribution for individual sites and
497 the cumulated signal.



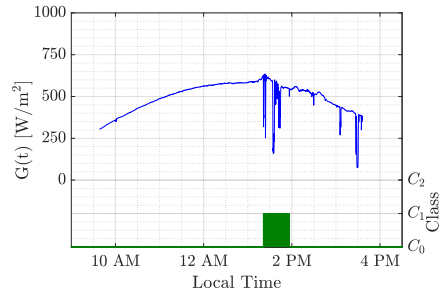
(a) S_1 : Lucciana



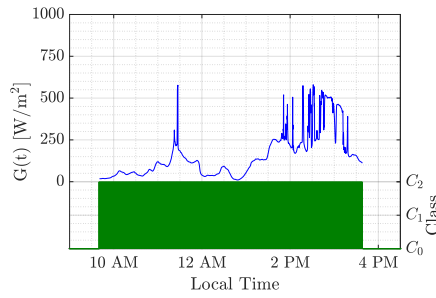
(b) S_2 : Calvi



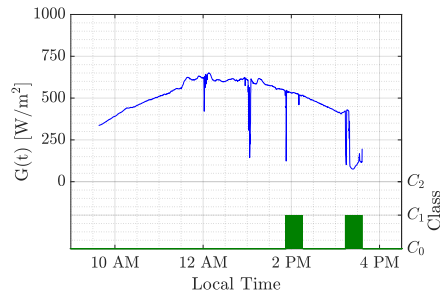
(c) S_3 : Corte



(d) S_4 : Ghisonaccia



(e) S_5 : Ajaccio



(f) S_6 : Sainte Lucie

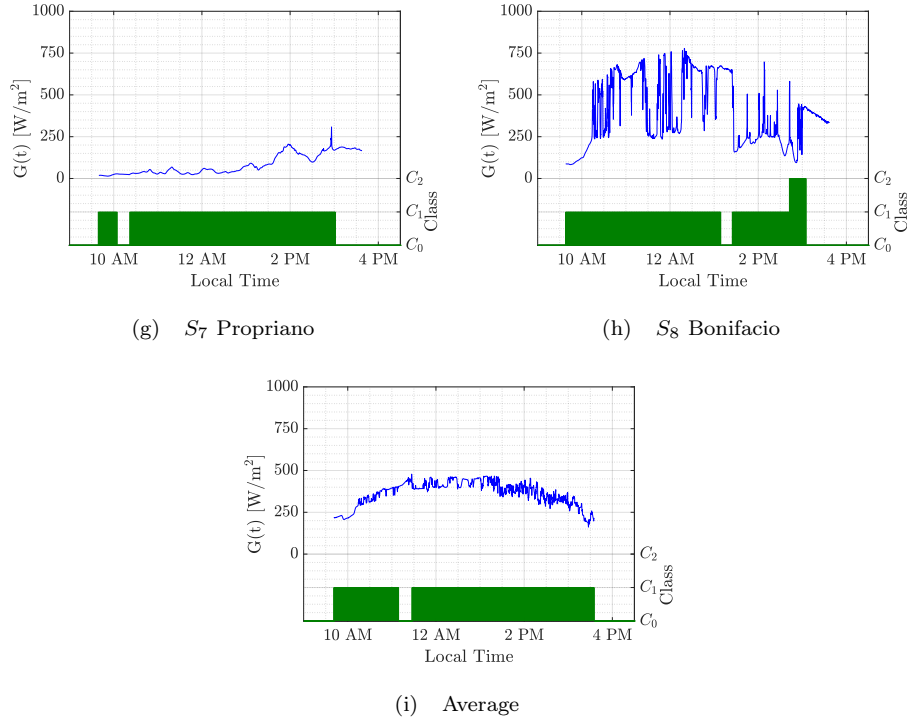


Figure 8: Irradiances and variations classes ($b_{var} = 10\%$, $\delta t_1 = 1$ s, $\delta t_2 = 300$ s, and $b_{intra} = b_{inter} = 900$ s) over the sites and average, on 13th February 2011

498 *4.2.2. Quantification of spatial compensation*

499 In the present work, the durations of intervals associated to the various
500 classes has been used to characterize the phenomenon of territorial smoothing,
501 by classifying the solar radiation at each site and then studying the cumulated
502 duration of each class. The integrated radiation over all sites can be analysed
503 following the same procedure. This method was applied to the 152 days of
504 overlapping data for the 8 sites, using the same parameters as the analysis of
505 individual sites: $b_{var} = 10\%$, $\delta t_1 = 1$ s, $\delta t_2 = 300$ s, and $b_{intra} = b_{inter} = 900$ s,
506 and hence the same three class descriptions. Recall that, for all sites, the class
507 C_0 variations are the most frequent, representing some 50 – 60 % of the study
508 period, whereas class C_1 variations account for 30 – 40 %. Class C_2 variations
509 are the least common, covering only 5 – 15 % of the measurement time (Fig.

510 6). When the data are cumulated over all sites, class C_1 variations increase at
 511 the expense of the other classes (Fig. 9).

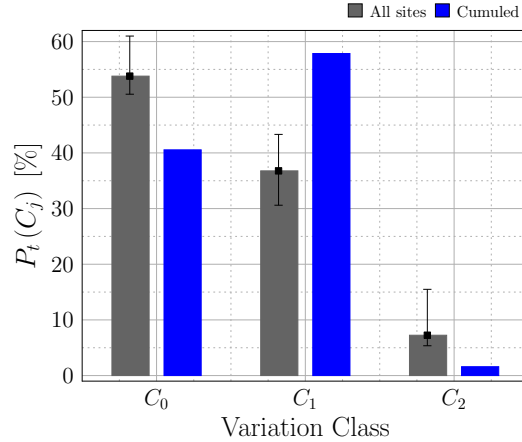


Figure 9: Relative cumulated durations of intervals $P_t(C_j)$ of each class C_j considering the individual sites in gray histograms (the errorbar depicts the minimal and maximal values all sites considered) and the accumulation of the global radiation over all the sites, illustrating territorial compensation in blue histograms

512 This result shows firstly that C_2 variations are smoothed and become less
 513 frequent when radiation is integrated over several sites : only 1.7 % of the
 514 cumulated dataset is associated to class C_2 compared to 5.36 % for the most
 515 favourable site. Else, an increase of cumulated duration of C_1 intervals is ob-
 516 served, whereas C_0 intervals duration decreases slightly. This undesired growth
 517 of C_1 interval cumumated time can be explained by considering that C_2 varia-
 518 tions may be smoothed through the summation of either C_2 variations that are
 519 out of phase, or C_0 variations that attenuate the relative fluctuations. For the
 520 latter case, C_0 variation are transformed to C_1 . Despite this, the overall effect
 521 is to smooth the radiation trend.

522 4.2.3. Optimisation results

523 A simple GA was implemented to determine the coefficients $(\beta_{S_i})_{i \in [1,8]}$ for
 524 a range of tests, which converged after 70 to 75 generations of 20 individuals.
 525 The obtained coefficients are summarized in table 2. They are the result of 8

526 applications of the GA on the scale of the study, the calculations being reiterated
 527 in order to test the sensitivity of the coefficients and thus exclude the hypothesis
 528 of a given solution corresponding to a local minimum.

Table 2: β_i coefficients for each site S_i , with their uncertainties obtained with GA optimization ran 8 times

Code	Sites	β_{S_i} [%]
S_1	Lucciana	26.04 ± 1.80 %
S_2	Calvi	11.71 ± 0.65 %
S_3	Corte	16.20 ± 2.47 %
S_4	Ghisonaccia	8.40 ± 0.73 %
S_5	Ajaccio	16.51 ± 2.01 %
S_6	Sainte Lucie	5.29 ± 0.33 %
S_7	Propriano	12.55 ± 0.57 %
S_8	Bonifacio	2.81 ± 0.47 %

529 Operationnally, the β_i coefficients can be translated as rates of the total PV
 530 capacity installed on the territory to be implemented at around each site. Thus,
 531 a map of the optimal dispersion of PV installations is shown in figure 10.

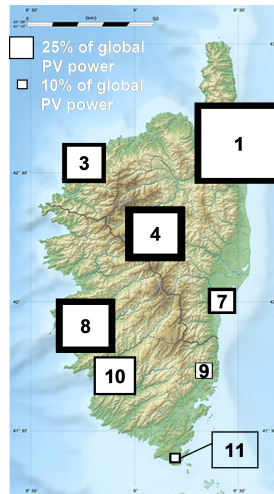


Figure 10: Territorial redistribution of solar electricity generation for an optimal compensation of variations. The sizes of the squares denote the optimal rate of PV global capacity on the site zone and the thickness of the edges represent the uncertainties of the optimization

532 Those sites with the least C_2 variations are found to carry the greatest

533 weight: the Lucciana and Ajaccio sites, with C_2 variations covering 6.13 % and
 534 5.29 % of time respectively, have weights of 26.04 ± 1.80 % and 16.51 ± 2.01
 535 %. Reciprocally the most unstable site, Bonifacio, was designated the smallest
 536 coefficient of 2.81 ± 0.47 %. The optimization process had two positive outcomes
 537 (Fig. 11):

- 538 • The near total suppression of C_2 variations, which after optimisation ac-
 539 count for only 0.13% of the measurement period of 6600 s;
- 540 • A reduction in the growth in frequency of C_1 variations. The occurrence
 541 of this class of variation was limited to a level comparable to the site with
 542 the highest frequency of C_1 variations.

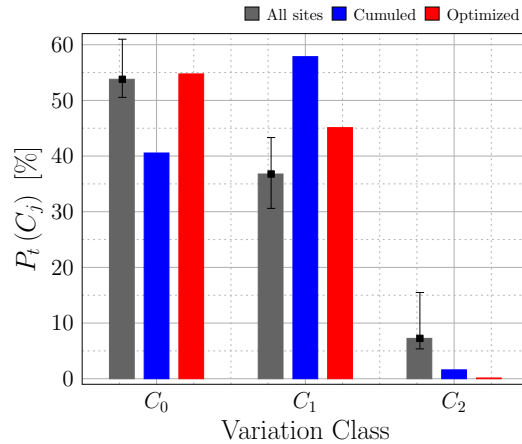
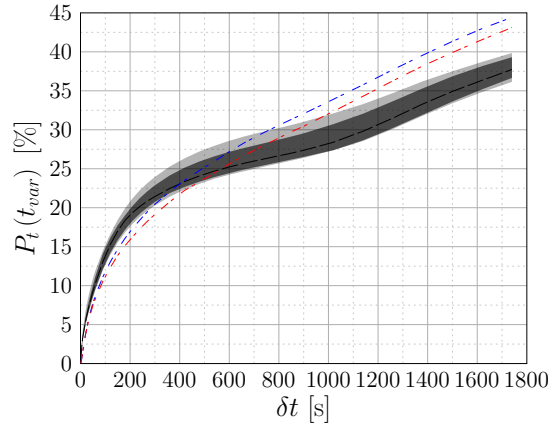


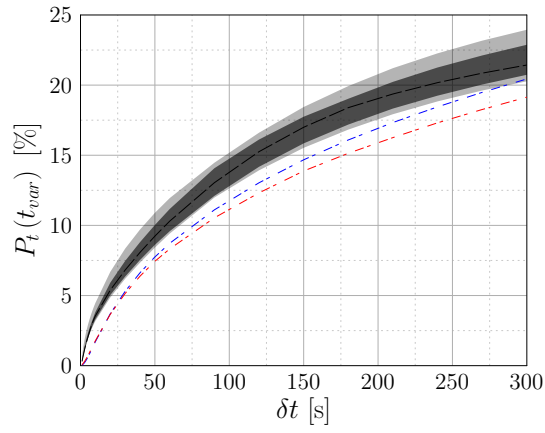
Figure 11: Relative cumulated durations of intervals $P_t(C_j)$ of each class C_j considering the individual sites in gray histograms (the errorbar depicts the minimal and maximal values all sites considered) ; the accumulation of the global radiation over all the sites, illustrating territorial compensation in blue histograms and the compensations phenomenon optimization in red histograms

543 The ratios of points considered unstable relative to the number of data, for
 544 the sample of 152 days, are for any interval in the range $dt \in [1; 1800]$ less for the
 545 spatially compensated combinations than for the individual sites (Fig.12(a)).

546 The optimization improves on the simple sum of irradiances by reducing



(a) $1 \leq dt \leq 1800$ s



(b) $1 \leq dt \leq 60$ s

Figure 12: Proportion of unstable periods to the total data sample for the 8 sites; for the territorial variation compensations (blue) and the optimized case (red)

547 the number of strong variations for scales from 1 to 20 s. Smaller variations, for
548 scales greater than 20 s, are less impacted by the optimization search (Fig.12(b)).
549 This is explained by the fact that the optimization processes is focused more
550 towards the larger variations because the criterion to minimize is the number
551 of variations observable at 1 s. In general, the smoothing afforded for this type
552 of variation can only be partial, hence strong variations are downgraded to
553 moderate ones, which are observable for larger scales and thus the ratio for
554 these scales increases.

555 5. Conclusion

556 We have presented in this paper a new typological classification method for
557 solar radiation, in which the principle innovation resides in the decomposition
558 of days into intervals of different classes according the regime of solar radiation
559 and its variability.

560 This classification method has been applied to the meteorological character-
561 ization of sites across the territory of Corsica, and in order to demonstrate the
562 phenomenon of spatial compensation through an understanding of variations:
563 the collection of events for which the variations were sufficiently important to
564 be classified “strong variations” is limited when radiation is integrated across
565 several sites. Therefore, the observable fluctuations at the scale of 1 s, classed
566 C_2 , represent between 5.5 and 15.5 % of the measured time for individual sites
567 whereas they represent 1.7 % for the cumulated intensity.

568 A genetic algorithm was subsequently implemented in order to optimise the
569 compensation afforded by spatially distributed radiation, and was found able
570 to practically eliminate intervals of strong variation. Variations of class C_2
571 represented only 0.13 % after optimization.

572 However, even once optimised, the compensation is not complete for the
573 set of sites under consideration, and some variations were found to persist.
574 Therefore in the case of a high degree of penetration of intermittent renewable
575 energy resources in Corsica, the utility operator will always need to manage the

576 variations and thus overcome the intermittence of energy generation in order to
577 ensure the stability of the grid supply and guaranty the electricity service.

578 **References**

- 579 [1] P. Haurant, P. Oberti, M. Muselli, Multicriteria selection aiding related to
580 photovoltaic plants on farming fields on Corsica island: A real case study
581 using the ELECTRE outranking framework, *Energy Policy* 39 (2) (2011)
582 676–688. doi:10.1016/j.enpol.2010.10.040.
583 URL [http://linkinghub.elsevier.com/retrieve/pii/
584 S0301421510007913](http://linkinghub.elsevier.com/retrieve/pii/S0301421510007913)
- 585 [2] P. Oberti, M. Muselli, P. Haurant, Photovoltaic Plants Selection on an
586 Insular Grid Using Multicriteria Outranking Tools: Application in Corsica
587 Island (France), in: F. Cavallaro (Ed.), *Assessment and Simulation Tools
588 for Sustainable Energy Systems*, Vol. 129, Springer London, London, 2013,
589 pp. 27–54.
- 590 [3] A. Woyte, V. V. Thong, R. Belmans, J. Nijs, Voltage fluctuations on distri-
591 bution level introduced by photovoltaic systems, *IEEE Transactions on En-
592 ergy Conversion* 21 (1) (2006) 202–209. doi:10.1109/TEC.2005.845454.
- 593 [4] P. Denholm, R. M. Margolis, Evaluating the limits of solar photovoltaics
594 (PV) in traditional electric power systems, *Energy Policy* 35 (5) (2007)
595 2852 – 2861. doi:<https://doi.org/10.1016/j.enpol.2006.10.014>.
596 URL [http://www.sciencedirect.com/science/article/pii/
597 S0301421506003740](http://www.sciencedirect.com/science/article/pii/S0301421506003740)
- 598 [5] J. Paatero, P. Lund, Effects of large-scale photovoltaic power integration
599 on electricity distribution networks, *Renewable Energy* 32 (2) (2007)
600 216–234. doi:10.1016/j.renene.2006.01.005.
601 URL [https://linkinghub.elsevier.com/retrieve/pii/
602 S0960148106000425](https://linkinghub.elsevier.com/retrieve/pii/S0960148106000425)
- 603 [6] M. Eltawil, Z. Zhao, Grid-connected photovoltaic power systems: Techni-
604 cal and potential problems—A review, *Renewable and Sustainable Energy
605 Reviews* 14 (1) (2010) 112–129. doi:10.1016/j.rser.2009.07.015.

- 606 URL [https://linkinghub.elsevier.com/retrieve/pii/](https://linkinghub.elsevier.com/retrieve/pii/S1364032109001749)
607 S1364032109001749
- 608 [7] J.O, Décret n° 2015-1697 du 18 décembre 2015 relatif à la programmation
609 pluriannuelle de l'énergie de Corse (Dec. 2015).
- 610 [8] J.O, Décret n° 2017-530 du 12 avril 2017 relatif à la programmation pluri-
611 annuelle de l'énergie de la réunion (Apr. 2017).
- 612 [9] R. Perez, M. David, T. E. Hoff, M. Jamaly, S. Kivalov, J. Kleissl, P. Lau-
613 ret, M. Perez, Spatial and temporal variability of solar energy, *Foundations and Trends® in Renewable Energy* 1 (1) (2016) 1–44. doi:
614 10.1561/27000000006.
615 URL <http://dx.doi.org/10.1561/27000000006>
616
- 617 [10] H. Gallegos, R. Lopardo, Spatial variability of the global solar radiation
618 obtained by the solarimetric network in the Argentine Pampa Humeda, *Solar Energy* 40 (5) (1988) 397–404. doi:10.1016/0038-092X(88)90094-1.
619 URL [https://linkinghub.elsevier.com/retrieve/pii/](https://linkinghub.elsevier.com/retrieve/pii/0038092X88900941)
620 0038092X88900941
621
- 622 [11] C. Gueymard, S. Wilcox, Assessment of spatial and temporal variability
623 in the US solar resource from radiometric measurements and predictions
624 from models using ground-based or satellite data, *Solar Energy* 85 (5)
625 (2011) 1068–1084. doi:10.1016/j.solener.2011.02.030.
626 URL [http://linkinghub.elsevier.com/retrieve/pii/](http://linkinghub.elsevier.com/retrieve/pii/S0038092X11000855)
627 S0038092X11000855
- 628 [12] M. David, F. Andriamasomanana, O. Liandrat, Spatial and Temporal Vari-
629 ability of PV Output in an Insular Grid: Case of Reunion Island, *Energy Procedia* 57 (2014) 1275–1282. doi:10.1016/j.egypro.2014.10.117.
630 URL [http://linkinghub.elsevier.com/retrieve/pii/](http://linkinghub.elsevier.com/retrieve/pii/S1876610214014842)
631 S1876610214014842
632

- 633 [13] C. Glasbey, R. Graham, A. Hunter, Spatio-temporal variability of solar
634 energy across a region : statistical modelling approach, *Solar Energy* 70 (4)
635 (2001) 373–381.
- 636 [14] R. Perez, S. Kivalov, T. Hoff, Spatial & Temporal Characteristics of Solar
637 Radiation Variability, in: *Proceedings of the ISES Solar World Congress*
638 2011, International Solar Energy Society, Kassel, Germany, 2011, pp. 1–11.
639 doi:10.18086/swc.2011.24.23.
640 URL <http://proceedings.ises.org/citation?doi=swc.2011.24.23>
- 641 [15] J. Badosa, M. Haeffelin, H. Chepfer, Scales of spatial and temporal
642 variation of solar irradiance on Reunion tropical island, *Solar Energy* 88
643 (2013) 42–56. doi:10.1016/j.solener.2012.11.007.
644 URL [https://linkinghub.elsevier.com/retrieve/pii/
645 S0038092X12003982](https://linkinghub.elsevier.com/retrieve/pii/S0038092X12003982)
- 646 [16] T. E. Hoff, R. Perez, Quantifying PV power Output Variability, *Solar*
647 *Energy* 84 (10) (2010) 1782–1793. doi:10.1016/j.solener.2010.07.003.
648 URL [https://linkinghub.elsevier.com/retrieve/pii/
649 S0038092X10002380](https://linkinghub.elsevier.com/retrieve/pii/S0038092X10002380)
- 650 [17] M. Lave, J. Kleissl, Solar variability of four sites across the
651 state of Colorado, *Renewable Energy* 35 (12) (2010) 2867–2873.
652 doi:10.1016/j.renene.2010.05.013.
653 URL [https://linkinghub.elsevier.com/retrieve/pii/
654 S0960148110002314](https://linkinghub.elsevier.com/retrieve/pii/S0960148110002314)
- 655 [18] K. Otani, J. Minowa, K. Kurokawa, Study on areal solar irra-
656 diance for analyzing areally-totalized PV systems, *Solar Energy*
657 *Materials and Solar Cells* 47 (1) (1997) 281 – 288. doi:[https:
658 //doi.org/10.1016/S0927-0248\(97\)00050-0](https://doi.org/10.1016/S0927-0248(97)00050-0).
659 URL [http://www.sciencedirect.com/science/article/pii/
660 S0927024897000500](http://www.sciencedirect.com/science/article/pii/S0927024897000500)

- 661 [19] J. Marcos, L. Marroyo, E. Lorenzo, D. Alvira, E. Izco, Power output fluctua-
662 tions in large scale pv plants: One year observations with one second
663 resolution and a derived analytic model, *Progress in Photovoltaics: Re-*
664 *search and Applications* 19 (2) (2011) 218–227. doi:10.1002/pip.1016.
665 URL <http://doi.wiley.com/10.1002/pip.1016>
- 666 [20] B. Urquhart, M. Sengupta, J. Keller, Optimizing Geographic Allotment
667 of Photovoltaic Capacity in a Distributed Generation Setting, in: 27th
668 European Photovoltaic Solar Energy Conference and Exhibition, Frankfurt,
669 Germany, 2012.
- 670 [21] W. T. Jewell, T. D. Unruh, Limits on cloud-induced fluctuation in photo-
671 voltaic generation, *IEEE Transactions on Energy Conversion* 5 (1) (1990)
672 8–14. doi:10.1109/60.50805.
- 673 [22] R. Collins, K. Crowther, Systems-based modeling of generation vari-
674 ability under alternate geographic configurations of photovoltaic (PV)
675 installations in Virginia, *Energy Policy* 39 (10) (2011) 6262–6270.
676 doi:10.1016/j.enpol.2011.07.025.
677 URL [https://linkinghub.elsevier.com/retrieve/pii/](https://linkinghub.elsevier.com/retrieve/pii/S0301421511005490)
678 [S0301421511005490](https://linkinghub.elsevier.com/retrieve/pii/S0301421511005490)
- 679 [23] J. Marcos, I. de la Parra, M. García, L. Marroyo, Simulating the variability
680 of dispersed large PV plants: Simulating the variability of dispersed large
681 PV plants, *Progress in Photovoltaics: Research and Applications* 24 (5)
682 (2016) 680–691. doi:10.1002/pip.2719.
683 URL <http://doi.wiley.com/10.1002/pip.2719>
- 684 [24] C. Rigollier, M. Lefèvre, L. Wald, The method Heliosat-2 for deriving
685 shortwave solar radiation from satellite images, *Solar Energy* 77 (2) (2004)
686 159–169. doi:10.1016/j.solener.2004.04.017.
687 URL [http://www.sciencedirect.com/science/article/](http://www.sciencedirect.com/science/article/B6V50-4CMHKPM-1/2/9eee0d4079bad5382ff4287b96487a2a)
688 [B6V50-4CMHKPM-1/2/9eee0d4079bad5382ff4287b96487a2a](http://www.sciencedirect.com/science/article/B6V50-4CMHKPM-1/2/9eee0d4079bad5382ff4287b96487a2a)

- 689 [25] A. Mefti, A. Adane, M. Bouroubi, Satellite approach based on cloud cover
690 classification: Estimation of hourly global solar radiation from meteosat
691 images, *Energy Conversion and Management* 49 (4) (2008) 652–659.
692 doi:10.1016/j.enconman.2007.07.041.
693 URL [http://www.sciencedirect.com/science/article/
694 B6V2P-4PMYX8X-3/2/e19170e0fc0ff16cdbaff933e20d500a](http://www.sciencedirect.com/science/article/B6V2P-4PMYX8X-3/2/e19170e0fc0ff16cdbaff933e20d500a)
- 695 [26] G. Notton, C. Cristofari, M. Muselli, P. Poggi, Calculation on an hourly
696 basis of solar diffuse irradiations from global data for horizontal surfaces in
697 Ajaccio, *Energy Conversion and Management* 45 (18-19) (2004) 2849–2866.
698 doi:10.1016/j.enconman.2004.01.003.
699 URL [http://www.sciencedirect.com/science/article/
700 B6V2P-4BVRNP6-1/2/e92520f0e770a9b1d8713881b48ce66e](http://www.sciencedirect.com/science/article/B6V2P-4BVRNP6-1/2/e92520f0e770a9b1d8713881b48ce66e)
- 701 [27] A. de Miguel, J. Bilbao, R. Aguiar, H. Kambezidis, E. Negro, Diffuse solar
702 irradiation model evaluation in the North Mediterranean Belt area, *Solar*
703 *Energy* 70 (2) (2001) 143–153. doi:16/S0038-092X(00)00135-3.
704 URL [http://www.sciencedirect.com/science/article/pii/
705 S0038092X00001353](http://www.sciencedirect.com/science/article/pii/S0038092X00001353)
- 706 [28] D. Li, J. Lam, An analysis of climatic parameters and sky condition
707 classification, *Building and Environment* 36 (4) (2001) 435 – 445.
708 doi:https://doi.org/10.1016/S0360-1323(00)00027-5.
709 URL [http://www.sciencedirect.com/science/article/pii/
710 S0360132300000275](http://www.sciencedirect.com/science/article/pii/S0360132300000275)
- 711 [29] A. Maafi, S. Harrouni, Preliminary results of the fractal classifica-
712 tion of daily solar irradiances, *Solar Energy* 75 (1) (2003) 53 – 61.
713 doi:https://doi.org/10.1016/S0038-092X(03)00192-0.
714 URL [http://www.sciencedirect.com/science/article/pii/
715 S0038092X03001920](http://www.sciencedirect.com/science/article/pii/S0038092X03001920)
- 716 [30] S. Harrouni, A. Guessoum, A. Maafi, Classification of daily solar irra-
717 diation by fractional analysis of 10-min-means of solar irradiance, *The-*

- 718 oretical and Applied Climatology 80 (1) (2005) 27–36. doi:10.1007/
719 s00704-004-0085-0.
720 URL <https://doi.org/10.1007/s00704-004-0085-0>
- 721 [31] T. Soubdhan, R. Emilion, R. Calif, Classification of daily solar radiation
722 distributions using a mixture of Dirichlet distributions, Solar Energy
723 83 (7) (2009) 1056–1063. doi:10.1016/j.solener.2009.01.010.
724 URL [https://linkinghub.elsevier.com/retrieve/pii/
725 S0038092X09000073](https://linkinghub.elsevier.com/retrieve/pii/S0038092X09000073)
- 726 [32] A. Woyte, R. Belmans, J. Nijs, Fluctuations in instantaneous clearness
727 index: Analysis and statistics, Solar Energy 81 (2) (2007) 195 – 206.
728 doi:<https://doi.org/10.1016/j.solener.2006.03.001>.
729 URL [http://www.sciencedirect.com/science/article/pii/
730 S0038092X0600079X](http://www.sciencedirect.com/science/article/pii/S0038092X0600079X)
- 731 [33] P. Jeanty, M. Delsaut, H. Ralambondrainy, J. Lan-Sun-Luk, M. Dessafy,
732 P. Charton, J. Chabriat, Clustering daily solar radiation from Reunion Is-
733 land using data analysis methods, in: Renewable Energy and Power Qual-
734 ity Journal, Renewable Energy and Power Quality Journal, Bilbao, Spain,
735 2013, p. 6.
- 736 [34] M. Muselli, P. Poggi, G. Notton, A. Louche, Classification of typical meteo-
737 rological days from global irradiation records and comparison between two
738 Mediterranean coastal sites in Corsica Island, Energy Conversion 41 (10)
739 (2000) 1043–1063.
- 740 [35] P. Haurant, A. Rodler, G.-A. Faggianelli, M. Muselli, P. Poggi, Intermit-
741 tence forecasting of the solar resource in Corsica, International Solar Energy
742 Society, Daegu, 2015, pp. 1–11. doi:10.18086/swc.2015.07.03.
743 URL <http://proceedings.ises.org/citation?doi=swc.2015.07.03>
- 744 [36] J. Holland, Adaptation in Natural and Artificial Systems, MIT Press, Cam-
745 bridge, MA, USA, 1975.

- 746 [37] D. Goldberg, Genetic algorithms in search, Optimization, and Machine-
747 Learning (1989).
748 URL <https://ci.nii.ac.jp/naid/10000038763/en/>
- 749 [38] EDF, Bilan prévisionnel de l'équilibre offre/demande d'électricité corse,
750 Tech. rep., EDF SEI (2011).
- 751 [39] P. Haurant, M. Muselli, B. Pillot, P. Oberti, Disaggregation of
752 satellite derived irradiance maps: Evaluation of the process and
753 application to Corsica, Solar Energy 86 (11) (2012) 3168–3182.
754 doi:10.1016/j.solener.2012.08.010.
755 URL [http://www.sciencedirect.com/science/article/pii/
756 S0038092X12003015](http://www.sciencedirect.com/science/article/pii/S0038092X12003015)
- 757 [40] P. Haurant, De la sélection multicritère de parcs photovoltaïques à la car-
758 tographie et l'étude de l'intermittence de la ressource : modélisations ap-
759 pliquées à l'île de Corse, Ph.D. thesis, Université de Corse Pascal Paoli,
760 Ajaccio (2012).