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Cloud Transient Characterization in Different Time Steps

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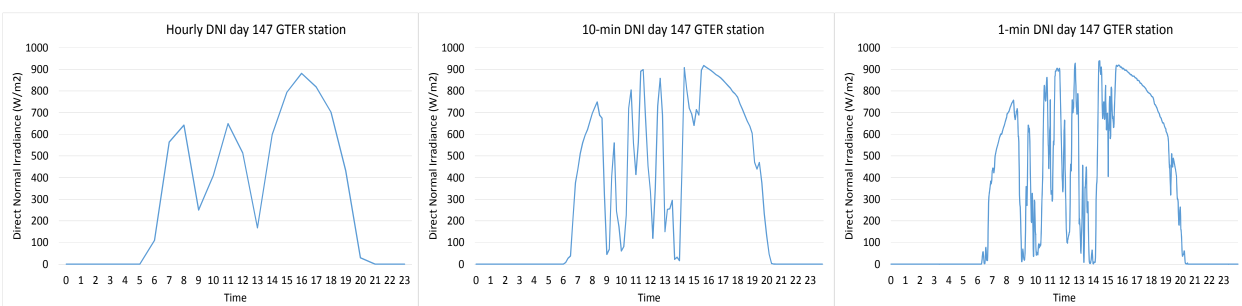
Abstract. In this paper we evaluate the cloud transients by analyzing the dynamics of the direct fraction index k_b for one year of solar radiation data in different time steps. We use instant 5-sec data integrated data and compare the number and percentage of occurrences of the different defined sky conditions. We find that the most common situation is a progressive transient and that the average transient lasts between one and 5 minutes. We also perform a cloud transient duration analysis observing that the denser clouds have greater persistence.

INTRODUCTION

The passage of clouds involves a decrease in the solar radiation that depends on the density of the clouds, implying disturbances in the production of solar thermal systems [1]. When forecasting the solar radiation, the common practice is to predict the cloud shape, base height and position and afterwards estimate its corresponding attenuation [2] generally in an hourly time step. But the cloud passages may last from seconds to hours, therefore this resolution may not be sufficient to simulate transient processes [3]. Figure 1 illustrates the same daily profile but in different resolutions, hourly, 10-min, and 1-min.



(a) (b) (c)

FIGURE 1. Same daily profile but in different resolutions: hourly (a), 10-min (b) and 1-min (c).

DATABASE

The data set used for this study corresponds to measurements of Direct Normal Insolation (DNI) for the year 2014 at the location of Seville (Spain). The measurements were taken with a sampling and storing frequency of 0.2

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Hz with a first class Eppley NIP pyrheliometer coupled to a sun tracker Kipp&Zonen 2AP. The devices are located at the meteorological station of the Group of Thermodynamics and Renewable Energy of the University of Seville. Data has been subjected to quality-control procedures following the Baseline Surface Radiation Network (BSRN) recommendations. Besides the instant data, we use six temporal resolutions calculated as the integration of the 5-seg measurements. 1-min, 5-min, 10-min, 15-min, 30-min and 1-h to assess the cloud transients. Data recorded at the sun´s altitude lower than 6º has been removed from the database to avoid the noise that would cause the horizon obstacles.

METHODOLOGY

We calculate the direct fraction index (k_b) in each of the selected time steps dividing the observed DNI by the clear-sky DNI. The focus of our analysis is on the dynamics of the solar radiation and not in the atmospheric turbidity, for this reason, the clear-sky DNI is calculated for each day by empirically fitting a clear sky model -in this case the AB model [4]. The sky condition (related to cloudiness or cloud type) is defined by means of the levels of attenuation of the direct solar radiation reaching the earth surface. Based on [5] we can generalize the type of clouds into 5 groups. The k_b threshold selected for performing this classification are presented in table 1.

TABLE 1. Classification of sky conditions.

Group	kb Value
G1	$k_b \leq 0.2$
G2	$0.2 < k_b \leq 0.4$
G3	$0.4 < k_b \leq 0.6$
G4	$0.6 < k_b \leq 0.8$
G5	$k_b > 0.8$

To quantify the cloud transients, we count the number of times that kb varies from a sky condition to another state defined by the threshold values specified in Table 1. We also quantify the duration of the transient by counting the time that the sky condition remains inside those threshold values. The analysis of the results is performed for the 7 posed time resolutions evaluating the differences that entails the use of DNI data in different frequencies.

RESULTS

For the assessment of the results we present the transition matrices [6]. Each value represent the transition from an initial sky condition (column) to a final sky condition (row). In this manner, values in the diagonal represent the persistence, values over the diagonal represent the entrance of clouds and values above the diagonal represent the exit of clouds. We divide the tables into number of occurrences, and percentage of occurrences where we omit the persistence in order to quantify only the cloud transients. Tables 2-8 present the transition matrixes for the seven evaluated resolutions.

TABLE 2. Transition matrix for the instant 5-sec resolution.

		5-sec									
		Number of occurrences-Entrance of clouds					Percentage of occurrences-Entrance of clouds				
		Group					Group				
		G1	G2	G3	G4	G5	G1	G2	G3	G4	G5
Exit of clouds	G1	741107	8903	1363	451	246		11%	2%	1%	0%
	G2	8919	71218	7352	1503	696	11%		9%	2%	1%
	G3	1355	7482	83901	7503	1644	2%	10%		10%	2%
	G4	529	1511	7726	143184	9167	1%	2%	10%		12%
	G5	209	576	1538	9466	1762772	0%	1%	2%	12%	

TABLE 3. Transition matrix for the integrated 1-min resolution.

		1-min									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	57613	1630	76	22	9		11%	1%	0%	0%
	G2	1666	6416	1632	100	10	12%		11%	1%	0%
	G3	99	1650	7167	1700	98	1%	11%		12%	1%
	G4	17	129	1748	11932	1789	0%	1%	12%		12%
	G5	11	20	101	1861	142635	0%	0%	1%	13%	

TABLE 4. Transition matrix for the integrated 5-min resolution.

		5-min									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	10686	641	228	95	52		10%	3%	1%	1%
	G2	643	724	396	215	123	10%		6%	3%	2%
	G3	246	404	877	469	239	4%	6%		7%	4%
	G4	164	228	481	1644	741	2%	3%	7%		11%
	G5	57	129	264	828	27450	1%	2%	4%	12%	

TABLE 5. Transition matrix for the integrated 10-min resolution.

		10-min									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	5104	350	190	85	47		8%	4%	2%	1%
	G2	415	277	202	131	73	10%		5%	3%	2%
	G3	216	226	377	257	173	5%	5%		6%	4%
	G4	100	142	299	708	436	2%	3%	7%		10%
	G5	88	109	191	515	13296	2%	3%	4%	12%	

TABLE 6. Transition matrix for the integrated 15-min resolution.

		15-min									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	3309	254	117	81	38		8%	4%	2%	1%
	G2	327	163	154	85	56	10%		5%	3%	2%
	G3	179	175	240	176	123	6%	5%		5%	4%
	G4	96	122	234	441	306	3%	4%	7%		9%
	G5	63	90	158	414	8622	2%	3%	5%	13%	

TABLE 7. Transition matrix for the integrated 30-min resolution.

		30-min									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	1568	144	64	34	24		7%	3%	2%	1%
	G2	206	89	71	59	40	10%		4%	3%	2%
	G3	156	77	123	107	55	8%	4%		5%	3%
	G4	106	90	121	194	159	5%	4%	6%		8%
	G5	33	80	131	249	4027	2%	4%	7%	12%	

TABLE 8. Transition matrix for the integrated hourly resolution.

		1-h									
		Number of occurrences-Entrance of clouds					**Percentage of occurrences-Entrance of clouds**				
		Group					**Group**				
		G1	**G2**	**G3**	**G4**	**G5**	**G1**	**G2**	**G3**	**G4**	**G5**
Exit of clouds	**G1**	688	70	49	18	11		6%	4%	2%	1%
	G2	100	44	39	42	22	8%		3%	4%	2%
	G3	79	51	64	57	48	7%	4%		5%	4%
	G4	57	41	67	90	101	5%	3%	6%		8%
	G5	80	42	90	128	1923	7%	4%	8%	11%	

Certain symmetry between values above and below the diagonal is observed. The values closer to the diagonal are the most repeated, i.e., transitions are progressive. As the time step increases, this trend is reduced. In figure 2 we present the number of occurrences of progressive transitions versus de time step.

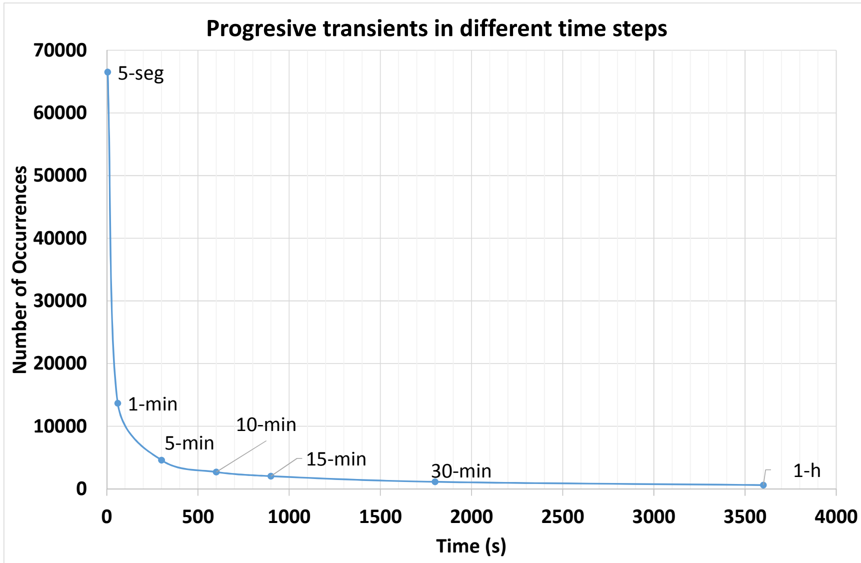


FIGURE 2. Number of occurrences of the progressive transients depending on the time step.

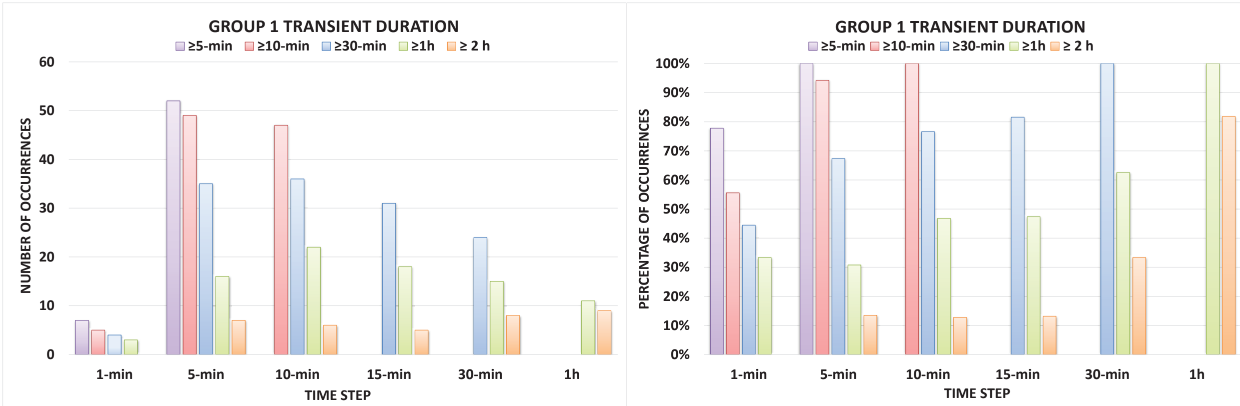
We can observe that there is a turning point in the number of occurrences of progressive transients (PTs) between one minute and five minutes. This same conclusion can be observed on table 9. Aiming to compute the entrance of the clouds, we count the number of occurrences that the sky condition changes from clear (($k_b > 0.8$ - G5) to any of the other defined states.

TABLE 9. Transition from G5 to the rest of the groups.

		Number of occurrences					Percentage of occurrences			
		Group				TOTAL	Group			
		G1	G2	G3	G4		G1	G2	G3	G4
Time Step	**5-seg**	246	696	1644	9167	11753	2%	6%	14%	78%
	1-min	9	10	98	1789	1906	0%	1%	5%	94%
	5-min	52	123	239	741	1155	5%	11%	21%	64%
	10-min	47	73	173	436	729	6%	10%	24%	60%
	15-min	38	56	123	306	523	7%	11%	24%	59%
	30-min	24	40	55	159	278	9%	14%	20%	57%
	1h	11	22	48	101	182	6%	12%	26%	55%

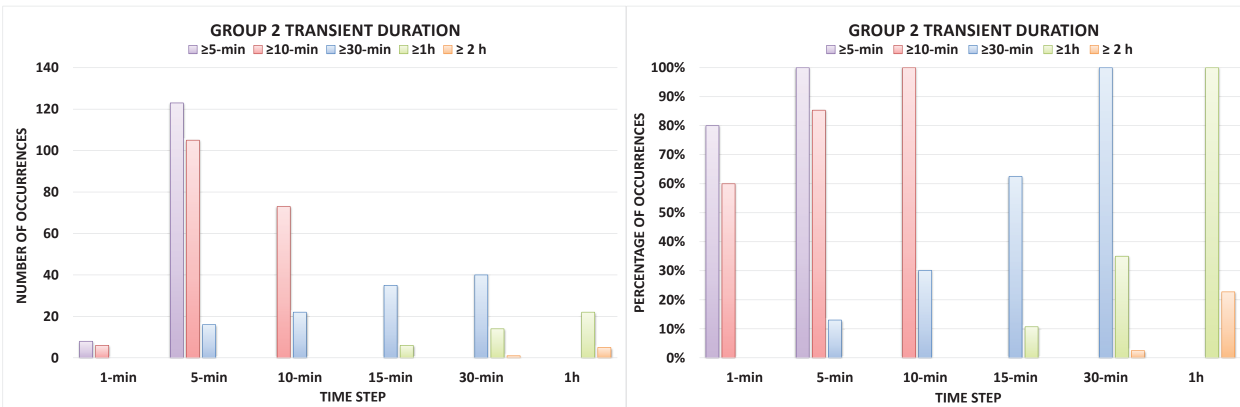
Table 9 shows that as we increase the time step there is a shift towards a reduction in the percentage of progressive transitions and an increase in the steeper transitions. This can be explained because in a larger time step, more situations are integrated into a single value, averaging the result of several phenomena.

We also quantify the duration of the transients. For that purpose, we count the time that the transient remains in each group. The starting point is once again the clear sky condition (($k_b > 0.8$ - G5). For this analysis we use the integrated data into the six selected resolutions. Figures 3-6 present the number and percentage of occurrences of the transient duration for each group.



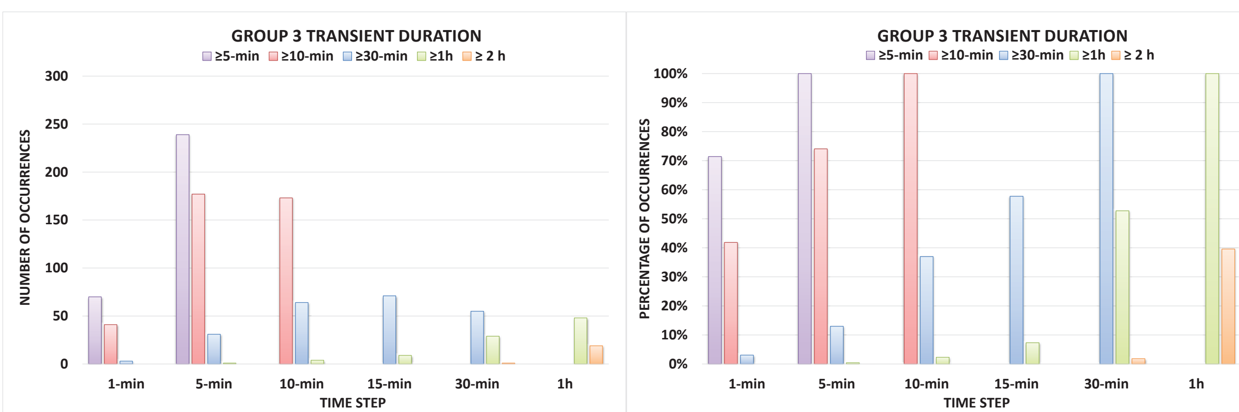
(a) (b)

FIGURE 3. Number of occurrences (a) and percentage of occurrences (b) of the transient duration from G5 to G1.



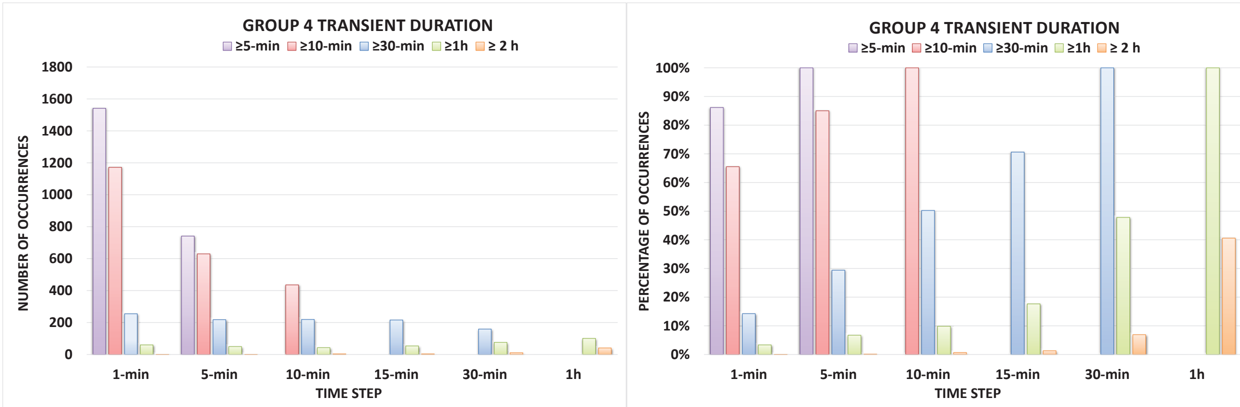
(a) (b)

FIGURE 4. Number of occurrences (a) and percentage of occurrences (b) of the transient duration from G5 to G2.



(a) (b)

FIGURE 5. Number of occurrences (a) and percentage of occurrences (b) of the transient duration from G5 to G3.



(a) (b)

FIGURE 6. Number of occurrences (a) and percentage of occurrences (b) of the transient duration from G5 to G4.

It is noted that the transients that last longer in all resolutions are the ones defined in group 1.

SUMMARY AND CONCLUSIONS

From the transient analysis in different time steps we have observed that the most common occurrence is a progressive transient. And that the use of large time steps entails a great loss of information. We define an average value of entrance and exit of clouds of 3 minutes by identifying a turning point in the overall number of occurrences of the progressive transients between the 1-min and 5-min resolutions and by observing that most of the cloud passages last for more than five minutes.

Future works will require a more complex definition of the cloud types with the help of sky-camera images that could lead to a better characterization of the transients.

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