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Assessing Changes in the Local Tropical Rainfall Seasons

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ABSTRACT:*A single procedure to assess possible changes in the tropical nominal rainfall seasons (rainless,transition and rainy) for almost any tropical location has beenwritten and applied. That procedure uses monthly rain gauge data series of a location embracing a reasonably large period of register. Three kindsof episodes(scarce, mild and copious) to characterizethe seasons of each year are defined. Two tropical thresholds of 25 mm and 50 mm define the seasons but four local thresholds define events. The period is divided into two segments (antique and modern) for frequency calculations.Occurrences of zero rainfall in the segments are carefully stated to verify results. Missing data items may be filled with adjusted satellite data obtained by Internet in a National Aeronautics Space Administration web portal. Annual enterprises plans could be enhanced with theannual perform of procedure application to their tropical operative locations. The procedure comes from simplified versions of two previous papers. Procedure application to the El Dorado tropical location data of 46 years divided into antique (31 years, 1968-1998) and modern (15 years, 1999-2013) segmentsgave as main preliminary result that frequency of copious(much rain) episodes of the rainless(no rainy) local season (January-March) have increased in +23% between segments; this fact is classified as a possible weak enhancement to wet in the rains indicated by an inner classification issued as part of the procedure. El Dorado frequency of the zero rainfalloccurrencesremained nearly constant from 2/31 (antique) to 1/15 (modern) requiring further verification. This kind of assessment must be constituted as a permanent activity inside tropical weather-sensitive enterprises.*

Keywords:*Change, frequency, procedure, rainfall, season, tropical.*

I. INTRODUCTION

Most locations in the inter-tropical latitudinal belt of the Earth (23.5°S to 23.5°N) undergo the annual sequence of the rainless (RL)and rainy (RN)seasons. In the rainy RN season the accumulated rain amounts received at the surface from atmospheric clouds and dew are greater than those received in the rainless (RL) season. It is possible to find more than one RL and more than one RN in a location in a year. Even more, intermediate or transitionalseason (RT) occurs between RL and RT.The most single case embraces one season either RL or RN only.Monthly rainfall data (*R*, mm) will be used here to assess rainfall variations.As in [1] monthly rainfall data appear in climatic research frequently. Of course, any analysis will evidence *R* is not constant but very variable from location to location and from year to year introducing uncertainties in weather sensitive enterprises. The minimum monthly rainfall is *R*=0 mm anywhere but the largest possible monthly rainfall in sometropical locations reaches gross order of *R*=1000 mm.Months of absolute drought with *R*=0 mm require accurate verification. To cope with this variability, enterprises managers have made yearly operational plans including nominalrainfall seasons but in last years in some locations the rains seems to be outside the expected, thus the possibility of loss of investments could be high. The word *nominal* indicates that the monthly time spans of seasons aretaken constant as defined by mean monthly rainfall values.For some locations the hydrological year beginning with the first rainy months and ending with the last rainless months is used toinclude a complete cycle. Thus, the hydrological year from April to March has been used in Venezuela. The words scarce(S), mild(M) and copious(C) were selected to characterize the seasons of each year as will be defined later.Most of the time, quantitative analysis of seasonalvariability is required but formally stated tropical procedures to do that are no easy to find. Here is outlineda simplified procedure that may be applied by non-meteorological personnel of tropical enterprise. This issue comes from a simplification of two previous papers on monthly tropical characterization where was assimilated satellite Outgoing Long-wave Radiation (*OLR*, W/m^2) as a second variable after *R* [2,3]. Those papers resulted complex to be replicated for non-meteorologist personal; thus a return was made to the single classical assessment based on *R*only. Due to the recently availability of interpolated *OLR* data, in next issues the inclusion of *OLR* will be made again. The procedure is outlined below and later a location is selected and its data gathered to finally undertake change assessment and drawn of conclusions.

II. THE PROCEDURE

Main steps of the above mentioned procedure are: (a) Select a location in the area of interest with a reasonable large period of register of N years. (b) Gather monthly values of *R* (mm) for each year of register and after filling missed data constructa matrix of monthly data with twelve columns one for each month of the year and N rows one for each year using the mm (millimeter) as rainfall unit. An inch equals2.54 cm or 25.4 mm. If necessary modify the original matrix using the concept of hydrological year. (3) Calculate twelve meansone mean for each month and N rows. (c) With those twelve mean values determine the months of the RL, RTand RN nominal seasons; use categories of Table 1. (d) Calculate accumulated rainfall values for each season and each year and prepare a column of data for each season. (e) Calculate means and deviations for RL, RT and RN using N years. (f) Definescarce (S), mild (M) and copious(C) classes of episodes using thresholds for each season as indicated in Table 2 for RL and RN but not for RT. Thresholds are computed with the format $\mu \pm 0.75\sigma$ where μ (mm) is a mean and σ (mm) is a standard deviation. The factor 0.75 can be modified for each location. (g) After the study of the weather history of the location divide the register into two segments of consecutive years named the antique with N_1years and the modern with N_2 years; of course $N=N_1+N_2$. (h) Count the frequency of episodes in each season for both antique and modern segments. (i) Calculate frequency changes and define categories using Table3. (i) Finally, verify results counting cases of *R*=0 in the segments. Small modifications mightbe necessary for each location.

Table 1. Definitions of categories for monthly rainfall means

Category	Range in mm
True Rainless (RL, ☐)	0 to 25
True Transition (RT, ▣)	26 to 49
True Rainy (RN, ■)	50 or greater

Table 2. Episodes definition based in threshold for both antique and modern times

Class of episode	Required parameter in mm	Range of episode in mm
Scarce (S, ☼) for RL	*A* the mean rainfall of a RL season *B* the standard deviation of RL season	0 to *A*- 0.75B
Mild (M, ○) for RL		A - 0.75*B* to *A* + 0.75*B*
Copious (C, **O**) for RL		greater than *A* + 0.75*B*
Scarce (S, ⊙) for RN	*C* the mean rainfall for a RN season *D*the standard deviation for a RN season	0 to*C* - 0.75*D*
Mild (M, ◘) for RN		*C* - 0.75*D* to *C* + 0.75*D*
Copious (C, ●) for RN		greater than *C* + 0.75*D*

Table 3. Categories for the changes of relative frequency in (%) from antique to modern

Category	Range of change
Inexistent	0% to +10%
Weak toward *wet*	+11% to 20%
Moderate toward *wet*	+21% to +30%
Strong toward wet	>= + 31%
Inexistent	-10% to 0%
Weak toward *dry*	-20% to -11%
Moderate toward *dry*	-30% to -21%
Strong toward *dry*	<= -31%

The most strict studies of the climates are based on periods of thirty years named *standards* (1901-1930, 1931-1960, 1961-1990, 1991-2020,...) established by the *World Meteorological Organization* (WMO)early. Most stations run outside those *standards* and the trouble caused in human affairs by rainfall changes represents a strong motive to avoid the strict study based in *standards*thereafter using the available register after a data enhancement process. As an empirical rule, minimum tropical registers must cover more than 15 years antique and more than 15 years modern, in total 30 years for preliminary studies. The outputs of this procedure must to include data and frequencies without the use of expressions as the *climatic change* that need of very large register and further analysis of variables as air temperature and water vapor pressure. Some missing data items can be filled with adjusted satellite data obtained by Internet in a NASA online web page named *Giovanni*.

III. PROCEDUREAPPLICATION

After the inspection of several old computer paper prints with *R* data of Venezuelan stations was selected *El Dorado*(6.75°N, -61.63°W, 120 m)by the minimum number of months with *R*=0 mm and large *R* values in much months catalogingthe station as *truly wet* with a unique RN station. The location of *El Dorado* is depicted in Fig. 1. The modern monthly data (*R*, mm) was recovered from some data banks and some missing values were filled using satellite data obtained from the above mentioned *Giovanni*web page of *NASA* (*GSFC*). The matrix of data of 12 monthly columns with*N*=46 rows one per year is shown in Appendix 1. From reviews of unusual rainy episodes in Venezuela after about 1998, we decide to define the two segments antique (31 years, 1968-1998) and modern (15 years, 1999-2013).

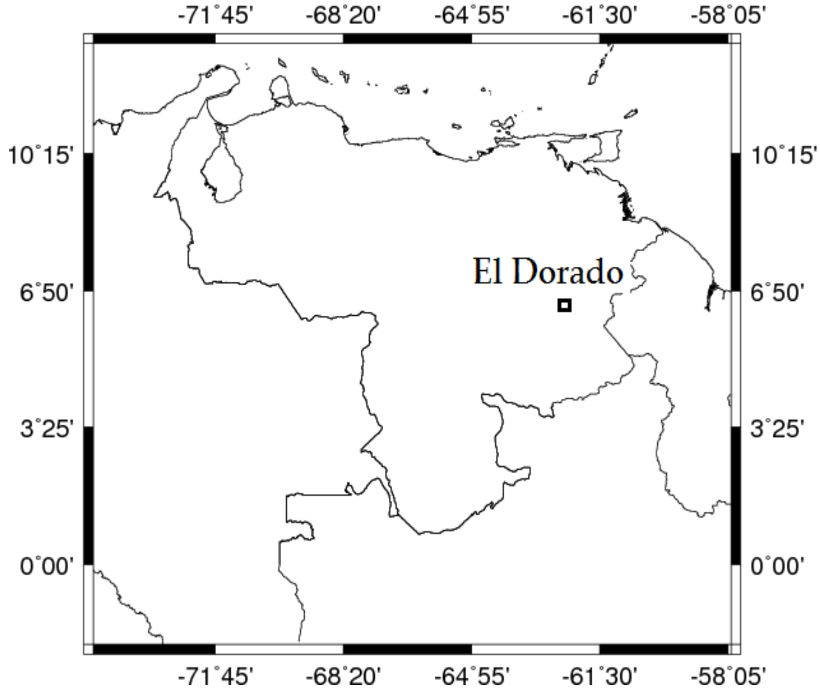

Figure I. *El Dorado*Location in the northern western hemisphere.

The Table 4 shows the 12 monthly means for the 46 years of whole register; all means are greater than 50 mm indicatingneither rainless RL nor transitionalRT seasons. The mean annual rainfall of *El Dorado*can be calculated in 1385.5 mm as the sum of the twelve items of Table 4. Even thou there are neither RL nor TR seasons we will use seasonsas indicated in Table 5. Thus, the Jan-Mar rainless season must be redefined as the season with minor rainfalls and the Apr-Decseason as the season with greater rainfalls as understood by the people in the area.

Table 4. Monthly mean rainfall values in mm for *El Dorado* (1969-2013)

Month	Value	True icon	Month	Value	True icon	Months	Value	True icon
Jan	83.5	■	May	121.9	■	Sep	119.8	■
Feb	53.6	■	Jun	203.5	■	Oct	116.7	■
Mar	52.7	■	Jul	200.0	■	Nov	100.5	■
Apr	73.4	■	Aug	150.6	■	Dec	102.5	■

Table 5. Nominal season's definition for *El Dorado* obtained from Tables 1 and 4

Season	Number of Months	Range of months
Rainless RL (☐) season*	3	January to March
Rainy RN (■) season	9	April to December
*This is not a true RL season but a low intensity RN small season		

Appendixes 2 and 3 were developed processing Appendix 1 to initiate the study of the seasons as a part of the procedure. Further processing of Appendixes 2 and 3 gives Table 6 which contains the *El Dorado*basic statistic. Of course, similar items for the rainless RL season are greater than those for the rainy RN season.Newly, even thou there is not a real rainlessdry season in *El Dorado*, four thresholds were defined to express RL and RN variability. Those thresholds are DTRL=112.0 mm, DTRN=989.2 mm, WTRL=269.4 mm and WTRN=1400.4 mm as seen in Table 6.

Table 6.Main *El Dorado*statistics for rainless (RL) and rainy (RN) seasons

Statistic for k=0.75	Rainless RL (☐)	Rainy RN (■)
Mean (mm)	*A*=190.7	*B*=1194.8
Standard deviation (mm)	*C*=104.9	*D*=274.1
Dry threshold (DT, mm)	112.0	989.2
Wet threshold (WT, mm)	269.4	1400.4

Tables 7-10 were made by counting occurrences in Appendixes 2 and 3 with the help of Tables 2 and 6. The changes of frequencies are low except +23% and +14% for copious RL and RN episodes. Those values represent more water for the hydrologic cycle and human consumptionin both seasons RL and RN. The kind of water use of each enterprise must be analyzed to insert variations in the yearly operational plans. To verify trends toward humid is necessary to count the frequency of *R*=0 in the segments finally. As unexpected, the Table 11 shows that this frequency has minimum decrement from *antique* to *modern* that can be forgotten by the time. As a main characterization of change for *El Dorado* is possible to say that there are possible changes to wet but new verifications in next years are necessary.

Table 7. Occurrences of rainless RL episodes for antique and modern years

Segment	Scarce (S, ☼)	Mild (M, ○)	Copious (C, **O**)	All
Antique	10	14	7	31
Modern	3	6	6	15

Table 8. Percentages (%) of rainless RL episodes for antique and modern years

Segment	Scarce (S, ☼)	Mild (M, ○)	Copious (C, **O**)	All
Antique	32	45	23	100
Modern	21	40	40	100
Δ	-9	-5	+23	

Table 9. Occurrences of rainy RN episodes for antique and modern years

Segment	Scarce (S, ⊙)	Mild (M, **O**)	Copious (C, ●)	All
Antique	8	17	6	31
Modern	3	7	5	15

Table 10. Percentages (%) of rainy RN episodes for antique and modern years

Segment	Scarce (S, ⊙)	Mild (M, **O**)	Copious (C, ●)	All
Antique	26	55	19	100
Modern	20	47	33	100
Δ	-6	-8	+14	

Table 11. Frequency of R=0 month for *El Dorado*

Segment	Years	Counts	Frequency
Antique	N_1=31	2	2/31

Modern	N_2=15	1	1/15

IV. CONCLUSION

After aresearchof nearly20 years, the development of a replicable procedure for assessment of changes in the rainfall of tropical rainless and rainy seasons has been possible. We could get for *El Dorado* location a single number of +23%quantifying an increment in the frequency number of copious episodes of the rainless season that surely will help to enhance yearly plans of tropical enterprises. A strong restriction for location selection represented by regional missing data items in the registers has been overcome by the use of interpolated satellite monthly data from the *Giovanni*Internet tool maintained operational by NASA. Thus, the availability of stations in mostarchivesturns higher than before and procedure applicability thereafter increased largely. This page will permit future recovering of several rain gauge data sets forgotten by register interruptions at regional level making the filling of gaps cumbersome. A limitation could be the possible inaccurate identification of the real R=0 condition in some data banks but this feature represents a minimum limitation at verification time that could be resolved by single field observations in future years. The very possible yearly procedure application will permit to weather sensitive enterprises cope with the variability of seasons characterized by variablefrequencies of scarce, mild and copiouscases discussed here.The procedure can be seen as diagnostic tool.Studies like this result in a never end affair.

V. ACKNOWLEDGEMENTS

The rainfall data sets used here were gathered mainly by open Internet access maintained by both the Venezuelan Institute of Meteorology and Hydrology (INAMEH) and the GES-DISC Interactive Online Visualization and Analysis Infrastructure (*Giovanni*) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC). The large effort of those organizations tokeep access on line made possible the realization of the present issue.

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Appendix 1

Monthly rainfalls (mm) for *El Dorado* (1968-2013)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
1968	86	64	57	222	137	228	73	69	68	34	126	77
1969	151	65	51	81	131	193	290	242	50	107	141	98
1970	147	55	113	90	185	181	272	231	65	40	167	96
1971	66	62	47	62	91	257	199	165	227	105	215	108
1972	177	56	127	244	229	194	118	129	76	99	92	54
1973	26	15	19	20	57	183	242	246	261	179	69	178
1974	160	76	93	63	68	104	195	86	107	91	106	63
1975	122	42	12	32	138	150	38	94	161	129	26	205
1976	154	137	149	202	116	226	202	18	33	211	14	136
1977	28	17	39	59	150	204	109	190	98	96	1	46
1978	58	17	4	44	164	367	143	273	156	125	30	104
1979	72	17	101	125	109	276	54	124	106	71	72	74
1980	38	12	11	108	223	220	202	103	50	115	110	31
1981	33	60	50	101	92	255	146	219	131	113	0	52
1982	57	155	90	135	115	211	250	81	21	67	31	43
1983	21	15	17	129	125	131	28	62	18	22	40	107
1984	99	37	18	1	185	141	146	154	133	109	164	124
1985	71	25	27	101	71	169	186	77	110	166	195	98
1986	47	44	11	30	131	263	296	47	63	107	153	119
1987	107	15	5	54	192	165	191	38	158	52	53	38
1988	26	68	18	0	90	228	235	506	265	222	136	142
1989	133	115	54	28	97	197	352	95	170	199	109	84
1990	147	87	74	124	144	253	227	216	81	98	65	166
1991	111	25	57	42	108	189	131	333	85	143	88	144
1992	21	23	30	48	74	78	139	194	150	14	19	46
1993	66	51	143	47	197	253	106	129	72	131	242	148
1994	74	44	87	28	132	254	185	405	198	273	40	27
1995	28	3	6	26	145	304	217	331	216	43	91	89
1996	70	94	59	19	27	311	377	117	185	29	25	40
1997	79	110	41	32	118	165	143	36	52	37	10	63
1998	10	5	0	50	81	308	110	94	177	105	71	150
1999	169	98	63	140	47	259	222	206	228	210	134	105
2000	91	107	113	196	104	358	231	92	192	19	274	102
2001	46	22	5	32	88	181	413	84	2	152	95	152
2002	93	31	63	124	147	127	130	124	112	20	87	71
2003	19	11	1	18	121	195	312	100	158	143	156	108
2004	91	32	45	83	192	145	232	93	245	92	63	80
2005	189	87	8	126	109	116	266	196	4	127	95	147
2006	165	45	69	2	192	146	324	91	61	197	40	119
2007	53	16	75	71	78	267	311	169	108	183	66	172
2008	93	103	51	82	83	239	301	125	147	264	142	164
2009	121	63	62	50	8	111	102	73	37	180	25	78
2010	30	0	3	134	138	207	467	156	263	77	216	100
2011	48	102	160	9	115	150	35	78	126	274	394	105
2012	105	78	91	92	148	28	111	114	45	68	13	131
2013	56	67	28	139	114	173	142	123	40	31	123	132

Appendix 2

Antique rainfalls (mm) calculated forseasons and years
Spans: RL (Jan-Mar), RN (Apr-Dec) and Year (Jan-Dec)

Year	m	RL (mm)	RL icons	RN (mm)	RN icons	Year (mm)
1968	1	207	○	1034	⭘	1241
1969	2	267	○	1333	⭘	1600
1970	3	315	⭘	1327	⭘	1642
1971	4	175	○	1429	●	1604
1972	5	360	⭘	1235	⭘	1595
1973	6	60	☼	1435	●	1495
1974	7	329	⭘	883	⊙	1212
1975	8	176	○	973	⊙	1149
1976	9	440	⭘	1158	⭘	1598
1977	10	84	☼	953	⊙	1037
1978	11	79	☼	1406	●	1485
1979	12	190	○	1011	⭘	1201
1980	13	61	☼	1162	⭘	1223
1981	14	143	○	1109	⭘	1252
1982	15	302	⭘	954	⊙	1256
1983	16	53	☼	662	⊙	715
1984	17	154	○	1157	⭘	1311
1985	18	123	○	1173	⭘	1296
1986	19	102	☼	1209	⭘	1311
1987	20	127	○	941	⊙	1068
1988	21	112	☼	1824	●	1936
1989	22	302	⭘	1331	⭘	1633
1990	23	308	⭘	1374	⭘	1682
1991	24	193	○	1263	⭘	1456
1992	25	74	☼	762	⊙	836
1993	26	260	○	1325	⭘	1585
1994	27	205	○	1542	●	1747
1995	28	37	☼	1462	●	1499
1996	29	223	○	1130	⭘	1353
1997	30	230	○	656	⊙	886
1998	31	15	☼	1146	⭘	1161

Appendix 3

Modern rainfalls (mm) calculated for seasons and years
Spans: RL (Jan-Mar), RN (Apr-Dec) and Year (Jan-Dec)

Year	m	RL (mm)	RL icons	RN (mm)	RN icons	Year (mm)
1999	32	330	⭘	1551	●	1881
2000	33	311	⭘	1568	●	1879
2001	34	73	☼	1199	⭘	1272
2002	35	187	○	942	⊙	1129
2003	36	31	☼	1311	⭘	1342
2004	37	168	○	1225	⭘	1393
2005	38	284	⭘	1186	⭘	1470
2006	39	279	⭘	1172	⭘	1451
2007	40	144	○	1425	●	1569
2008	41	247	○	1547	●	1794
2009	42	246	○	664	⊙	910
2010	43	33	☼	1758	●	1791
2011	44	310	⭘	1286	⭘	1596
2012	45	274	⭘	750	⊙	1024
2013	46	151	○	1017	⭘	1168