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INTRASEASONAL VARIABILITY OF RAINFALL OVER NORTHERN SOUTH AMERICA AND CARIBBEAN REGION

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ABSTRACT

Based on decadal (amounts for each ten days) precipitation data from meteorological stations situated in Northern South America and Caribbean region, a decadal precipitation index (DPI) was calculated in order to study the intraseasonal variability (ISV) of regional rainfall. The spectral analysis of DPI allows to identify signals with 20-25, 30, 40 and 50-60 days period. According to the analysis of their spatial distribution these signals are well defined over the Caribbean island and coastal sector such as in some sectors of the Andean region; the 60-days signal is presented only over Caribbean region and in some places in the Pacific sector; in the eastern lowlands of Orinoco and Amazon basin these signals are not clearly expressed.

Exploring the relationship between regional ISV and Madden-Julian Oscillation correlation analysis was made. Due to the presence of signals different of 30-60 days, the correlation coefficients were very low. Considering this situation, high frequency smoothing was applied to DPI time series; after that, a relative correlation was detected between smoothed DPI and Madden-Julian Index (MJI).

Keywords: Intraseasonal Variability, Madden-Julian Oscillation, Rainfall.

RESUMEN

Con base en datos de precipitación decadal (acumulados de diez días) provenientes de estaciones meteorológicas localizadas en el norte de Suramérica y en el Caribe, se calculó un Índice de Precipitación Decadal (IPD) para estudiar la variabilidad Intraestacional (VIS) de la precipitación de ésta región. El análisis espectral del IPD muestra señales con períodos de 20-25, 30, 40 y 50-60 días. De acuerdo con el análisis de la

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distribución espacial, estas señales están bien definidas sobre las islas del Caribe y la zona costera, así como en algunos sectores de la región andina; la señal de 60 días se presenta únicamente en el Caribe y sobre algunos lugares del Pacífico; en las tierras bajas de las cuencas del Orinoco y Amazonas las señales no se expresan claramente.

Se analiza también la relación entre la VIS regional de la precipitación y la Oscilación de Madden-Julian. Debido a la presencia de señales diferentes a las de 30-60 días en la precipitación, los coeficientes de correlación obtenidos son muy bajos. Por ésto, se realizó la suavización de las altas frecuencias en las series del IPD y se calcularon nuevamente los coeficientes de correlación del IPD con el Índice Madden-Julian, después de lo cual hubo un notorio aumento de los coeficientes de correlación.

Palabras clave: Variabilidad intrestacional, Oscilación Maden-Julian, Lluvia.

1. Introduction

Extreme phases of climate variability bring to different regions warm or cold periods, rainy (more precipitation than normal or more frequent heavy rainfall events) or dry conditions, and so. This variability impacts in several ways ecosystems and economic systems of the countries around the world, producing in some cases disasters. In the climate system many processes generate this variability. For example, the tropical Pacific phenomena El Niño (warm condition) and La Niña (cold conditions) are the cause of 2-7 years time scale oscillations of climatic variables known as ENSO cycle (Philander, 1990; Hastenrath, 1996; see also ENSO bibliography in COAPS, 2006). In addition to the ENSO cycle, signals such as quasi-biennial component (Ropelewski *et al*., 1992; Meehl, 1997; Baldwin *et al*., 2001), and fluctuations in the period interval of 20-90 days called intraseasonal oscillations (Knutson & Weickman, 1987; Bantzer & Wallace, 1996; Nogués-Paegle *et al*., 2000; Krishnamurti & Shukla, 2000; Goswami & Mohan, 2001; Bond & Vecchi, 2003; Krishnamurti & Shukla, 2007) have been identified.

Today the most studied signal of climate variability is that caused by ENSO. There are many works related to the effects of ENSO in monthly precipitation of different regions in the world (Ropelewski *et al.*, 1986; Ropelewski & Halpert, 1987; Pabón & Montealegre, 1992; Peel *et al.*, 2002; Poveda, 2004; and many others). Currently, seasonal climate prediction schemes are based on the knowledge about particularities of ENSO cycle in a given region, however, because they do not include other modes of climate variability, prediction fails frequently, especially in month-to-month range and less (see for example Hendon *et al.*, 2000; Jones & Schemm, 2000; Jones et al., 2004c). A source of fails in prediction in month-to-month range is associated to the no inclusion of intraseasonal variations in the schemes. In fact, the phases of intraseasonal fluctuations activate and deactivate rainfall for periods of a couple of weeks lasting or forwarding the beginning or end of rainy season, or breaking it. The rainy phase of intraseasonal variability also activates heavy precipitation events and related to them disasters (flashfloods, landslides, etc). Due to practical value to improve subseasonal predictability (Waliser et al. 2003; Webster & Hoyos, 2004), the interest on intraseasonal modes of climate variability has been increasing in last decade and many efforts have been doing to study this variability especially the associated to Madden-Julian Oscillation (Madden & Julian, 1994), the dominant mode in intraseasonal climate variability.

Several authors have been studied the intraseasonal variability (hereafter ISV) in precipitation for different geographical regions of the world. Krishnamurti & Shukla, (2000, 2007), for example, found modes with 45 and 20 days period in precipitation in India. Wang et al. (1996) explored ISV of precipitation in China finding 12, 21 and 43 days period. Analysis was made also for Africa (Janicot & Sultan, 2001; Mathews, 2004) and signals over 10-25 and 25-60 days period were found in convection and precipitation in the western region (Sultan *et al*., 2003; Mounier & Janicot, 2004); satatistically significant spectral peaks over 15 and 40 days period were found for Sahel precipitation (Janicot & Sultan 2001). Jones *et al.* (2004a) using outgoing long wave radiation data developed a climatology for tropical intraseasonal convective anomalies. Also, Ye & Cho (2001), analyzed precipitation data for United States, and found 24 and 37 days signals. ISV of convection and precipitation for different regions of South America has been studied by Garreaud (2000), Petersen *et al*. (2002), Misra (2005).

Exploring the causes of ISV of precipitation many researchers have been paying special attention to its relationship to Madden-Julian Oscillation (MJO), because the MJO is the dominant mode of tropical ISV. Thus, Bantzer & Wallace (1996) analyzed temperature and precipitation data using satellite data and found a 40-50 days component, close to MJO period. Liebman *et al*. (1994) investigated the relationship between tropical cyclones of the Indian and western Pacific oceans and the MJO and found that cyclones preferentially occur during the convective phase of the oscillation; but they noted, however, that the increase in cyclone activity during active periods of convection is not restricted to MJO activity and concluded that the last does not influence tropical cyclones in a unique fashion (this situation may be due to the existence of other modes of ISV). A similar analysis was done by Maloney & Hartman (2000a,b) for hurricanes of eastern north Pacific and Gulf of Mexico (information on Caribbean is also included). Kayano & Kousky (1999) studied the MJO in the global tropics using pentad-means for the 1979-1995 period computed for 200- and 850-hPa zonal winds, 200-hPa velocity potential, 500-hPa geopotential height and pressure vertical velocity, 925-hPa temperature and specific humidity, SLP and total precipitable water (PW); they found in all variables an eastward traveling large-scale oscillatory regime with a period of approximately 45 days. In the other hand, Jones et al. (2004b) using pentadal precipitation data based on Global Precipitation Climatology Project (GPCP) confirmed that over Indian Ocean, Indonesia, Western Pacific, Eastern South America, Western North America, northeast Africa, the Middle East, and Eastern China, extremes precipitation events increases with the presence of active (convective) phase of MJO. Barlow *et al.* (2005) analyzing daily precipitation for Southwest Asia found that this variable is modulated by MJO activity in the eastern Indian Ocean, with strength comparable to the interannual variability. Bond & Vechi (2003) found a relationship between MJO and precipitation of Oregon and Washington states. ISV was detected in convective processes over Amazon region by Petersen *et al*. (2002).

The climate variability for northern South America and Caribbean region has been studied mainly in interannual scale (Hastenrath, 1976; Pabón & Montealegre, 1992; Enfield, 1996; Alfaro *et al.*, 1998; Enfield & Alfaro, 1999; Montealegre &

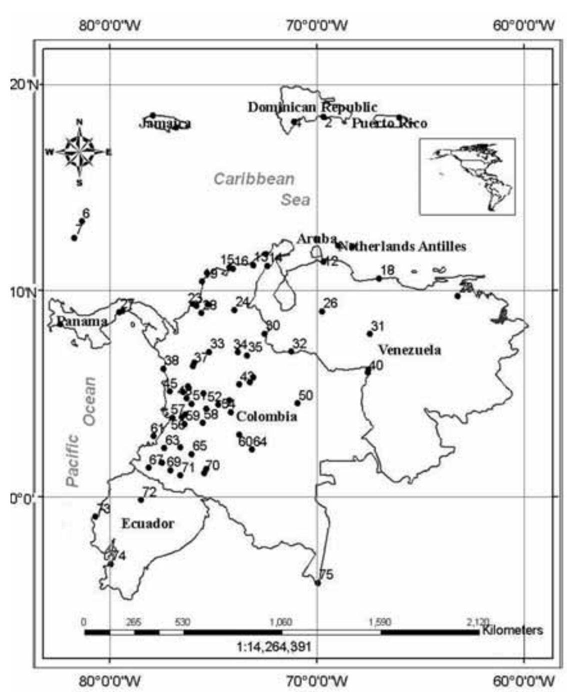


Figure 1. Northern South America and Caribbean region and distribution of meteorological stations used for analysis (The number corresponds to station listed in Table 1).

Table 1. List of meteorological stations used in the study.

ID	Station name	Latitud	Longitude	Altitude (m.s.n.m.)	Country
1	Montego Bay	18,50	–77,91	1	Jamaica
2	Las Américas	18,43	–69,66	18	Dominican Rep.
3	Aeropuerto San Juan Intl	18,41	–66,00	19	Puerto Rico
4	Barahona	18,20	–71,10	3	Dominican Rep.
5	Kingston	17,93	–76,78	3	Jamaica
6	Aeropuerto El Embrujo	13,37	–81,35	1	Colombia
7	Aeropuerto Sesquicentenario	12,58	–81,72	1	Colombia
8	Aeropuerto Queen Beatrix	12,50	–70,01	18	Aruba
9	Aeropuerto Hato	12,20	–68,96	9	Netherl Antills
10	Aeropuerto Flamingo	12,15	–68,28	6	Netherl Antills
11	Manaure	11,77	–72,45	1	Colombia
12	Coro	11,41	–69,66	16	Venezuela
13	Matitas	11,25	–73,05	20	Colombia
14	Esc Agr Carraipia	11,22	–72,37	118	Colombia
15	Apto. Simón Bolívar	11,13	–74,23	4	Colombia
16	San Lorenzo	11,07	–74,03	4	Colombia
17	Aeropuerto Ernesto Cortissoz	10,88	–75,30	14	Colombia
18	Maiquetía Apto. S. Bolívar	10,60	–66,98	43	Venezuela
19	Aeropuerto Rafael Núñez	10,45	–75,52	2	Colombia
20	Maturín	9,75	–63,18	65	Venezuela
21	San Bernardo D.	9,37	–75,97	22	Colombia
22	Aeropuerto Rafael Barvo	9,33	–75,26	166	Colombia
23	Lorica	9,27	–75,82	30	Colombia
24	Aeropuerto Las Flores	9,07	–73,98	34	Colombia
25	Tocumen	9,05	–79,36	45	Panamá
26	Guanare	9,01	–69,73	163	Venezuela
27	Marcos A. Gelabert	8,98	–79,55	13	Panamá
28	El Salado	8,92	–75,58	40	Colombia
29	David	8,40	–82,41	29	Panamá
30	Aeropuerto Camilo Daza	7,93	–72,52	250	Colombia
31	San Fernando de Apore	7,90	–67,41	47	Venezuela
32	Aeropuerto Arauca	7,06	–71,22	128	Colombia
33	Aeropuerto Otu	7,03	–75,20	630	Colombia
34	Aeropuerto Yariguíes	7,02	–73,80	126	Colombia

ID	Station name	Latitud	Longitude	Altitude (m.s.n.m.)	Country
35	El Cucharo	6,87	–73,37	975	Colombia
36	Tulio Ospina	6,53	–75,92	1438	Colombia
37	Aeropuerto Olaya Herrera	6,37	–75,97	1490	Colombia
38	Panamericana	6,22	–77,40	4	Colombia
39	Aeropuerto Puerto Carreño	6,18	–67,48	50	Colombia
40	Tuparros Boca Torno	6,05	–67,52	250	Colombia
41	Surbata Bonza	5,82	–73,07	2485	Colombia
42	U.P.T.C.	5,57	–73,22	2690	Colombia
43	Isla del Santuario	5,47	–73,73	2580	Colombia
44	Aeropuerto Matecaña	5,37	–77,08	53	Colombia
45	Aeropuerto El Carano	5,12	–77,08	53	Colombia
46	La Camelia	5,08	–76,45	1670	Colombia
47	Aeropuerto La Nubia	5,03	–75,47	20,80	Colombia
48	Aeropuerto El Edén	4,78	–76,28	1204	Colombia
49	Tibaitatá	4,70	–74,22	2543	Colombia
50	Las Gaviotas	4,55	–70,93	171	Colombia
51	Centro Ad. La Unión	4,53	–76,05	920	Colombia
52	El Salto	4,47	–74,77	450	Colombia
53	Aeropuerto Santiago Villa	4,28	–75,33	266	Colombia
54	Aeropuerto El Dorado	4,12	–74,15	2547	Colombia
55	Aeropuerto Farfán	4,02	–76,37	955	Colombia
56	Palmira ICA	3,87	–76,53	975	Colombia
57	Aeropuerto Buenaventura	3,85	–76,97	14	Colombia
58	Aeropuerto Benito Salas	3,62	–75,50	439	Colombia
59	Aeropuerto Alfonso Bonilla	3,55	–76,38	961	Colombia
60	Vista Hermosa	3,03	–73,73	325	Colombia
61	Bonanza	2,95	–77,88	10	Colombia
62	Aeropuerto G. L. Valencia	2,43	–76,58	1730	Colombia
63	La Sierra	2,37	–77,37	1870	Colombia
64	La Macarena	2,30	–73,13	350	Colombia
65	Paleterá	2,08	–76,05	2900	Colombia
66	Aeropuerto Antonio Nariño	1,67	–77,47	1796	Colombia
67	Aeropuerto San Luis	1,42	–78,13	2961	Colombia
68	Aeropuerto Artunduaga	1,36	–75,32	244	Colombia
69	Obonuco	1,30	–77,05	2710	Colombia
70	Valparaiso	1,15	–75,42	270	Colombia

ID	Station name	Latitud	Longitude	Altitude (m.s.n.m.)	Country
71	Villagarzón	1,05	–76,60	440	Colombia
72	Aeropuerto Mariscal Sucre	–0,13	–78,48	28,11	Ecuador
73	Manta	–0,95	–80,68	13	Ecuador
74	Aeropuerto Gral. M. Serrano	–3,25	–69,93	84	Colombia
75	Aeropuerto Vásquez Cobo	–4,16	–69,93	84	Colombia

Pabon, 2000; Giannini *et al.,* 2000; Chang & Stephenson, 2000; Chang & Taylor, 2002; Taylor *et al.*, 2002; Poveda, 2004, Nobre *et al.,* 2006), especially the associated to ENSO, with purpose to improve seasonal-interannual climate prediction. The ISV of precipitation have been less studied, however some attempts have been carried out by Poveda et al. (2002), who analyzed the daily cycle of precipitation of Colombian Andes and found a significant relationship between MJO and daily precipitation, such as between MJO and amplitude of daily cycle. Pabón (2007), explored ISV using decadal (ten days amounts) precipitation data for different regions of Colombia and found 20-25 and 50-70 days periodical components; searching the relationship of the analyzed times series with MJO it was found a low correspondence because the presence of other mode of ISV different to MJO mode. These works show the evidences of ISV modes in climate of the region.

Taking in account the state of knowledge about the ISV and the regional importance for improving climate prediction and to strength the disaster prevention systems, especially in the component related to heavy rainfall, this paper try to analyze in more detail the characteristics of ISV of precipitation in northern South America and Caribbean region.

2. Data and methodology

For the analysis in the current study as basic data was used daily precipitation for the 1978-2004 period from meteorological stations distributed over northern South America and Caribbean region as showed in Figure 1 (the 75 are listed in Table 1). Selection of the meteorological stations was done considering criteria as representativeness of a given region, length of record period at least 20 years and minimal gaps in data series. Considering the complex topography over Colombian territory that generates a rich climate diversity, it was necessary to include a relatively high density of the network for this region.

An initial check was carried out in order to test the quality of data. After this quality control a decadal (amounts for each ten days period) precipitation series were organized and an index (DPI) was calculated using the equation:

$$DPI = \frac{P - \overline{P}}{\sigma_P} \qquad (1)$$

(or simply, the z-score of decadal precipitation) where: P – decadal precipitation; multianual precipitation average for respective decade; standard deviation for the series of a given decade (time sequences of first decades, or second decades of the year and so on).

To facilitate the presentation of analysis and results the report was organized for five sectors of the region: islands in Caribbean Sea region, continental plain lowland of the Caribbean coastal zone, mountainous (Andean) region, eastern lowlands of Orinoco-Amazon basin, and Pacific sector.

To identify signals of ISV of precipitation spectral analysis (Wilks, 1995) was applied to time series

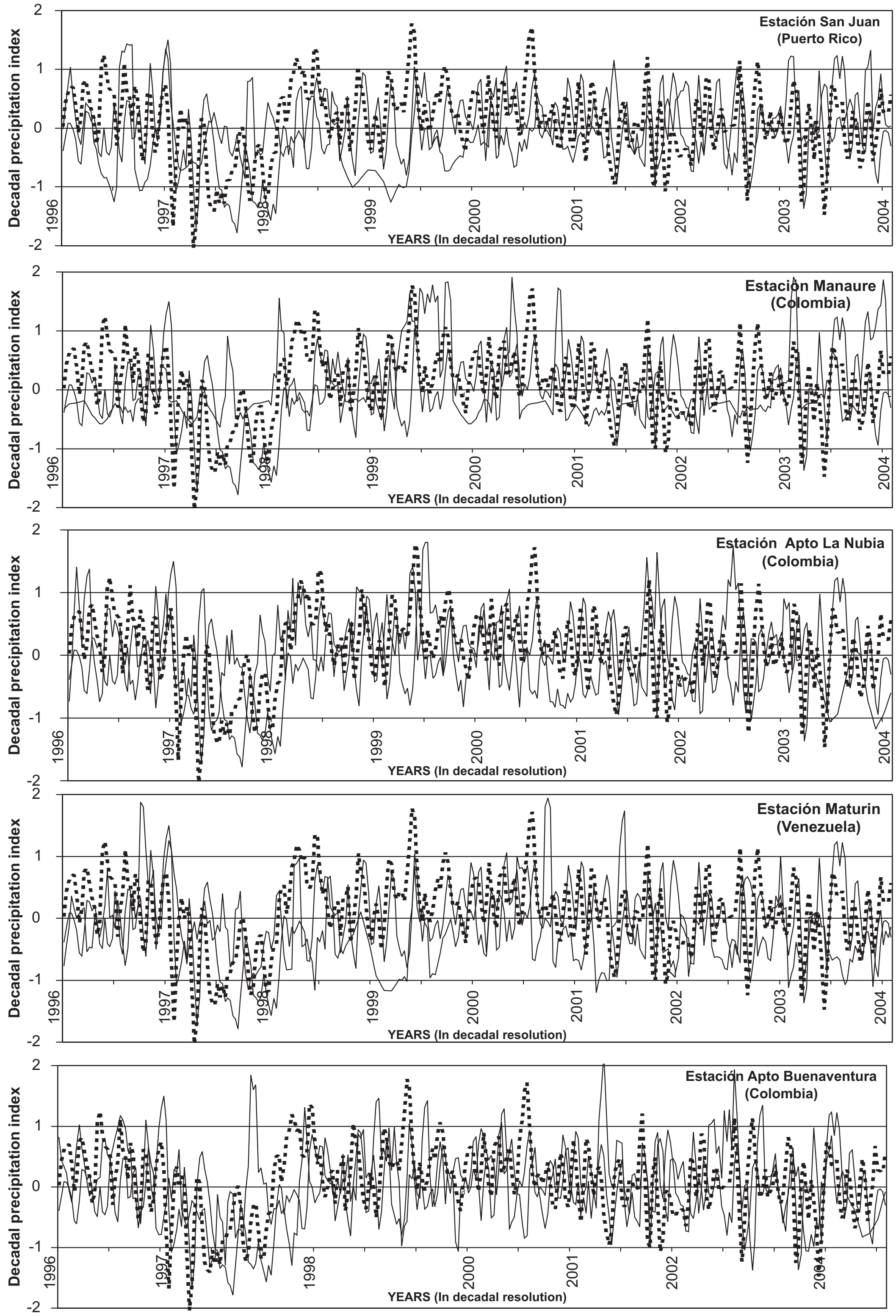


Figure 2: Intraseasonal fluctuations of DPI.

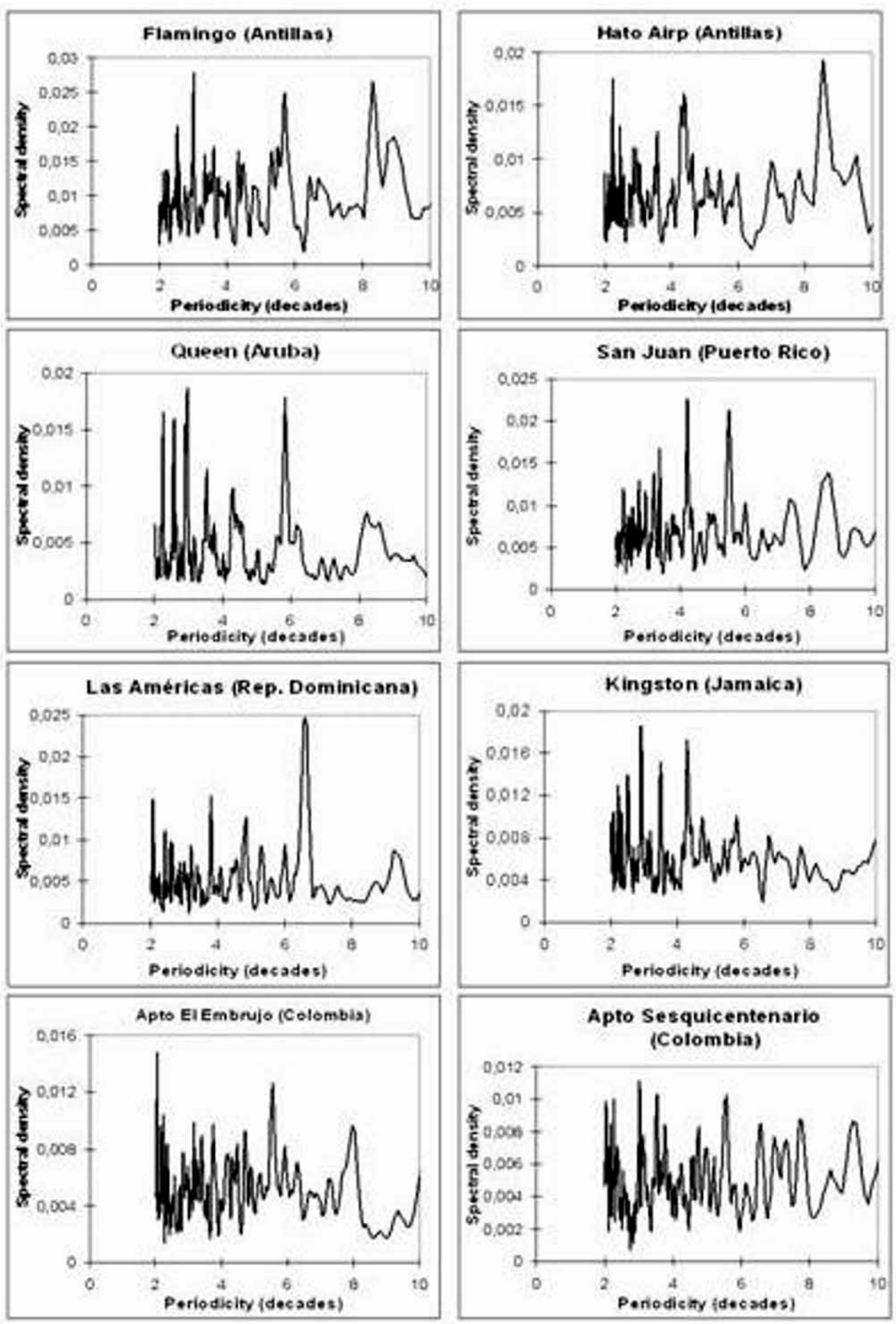
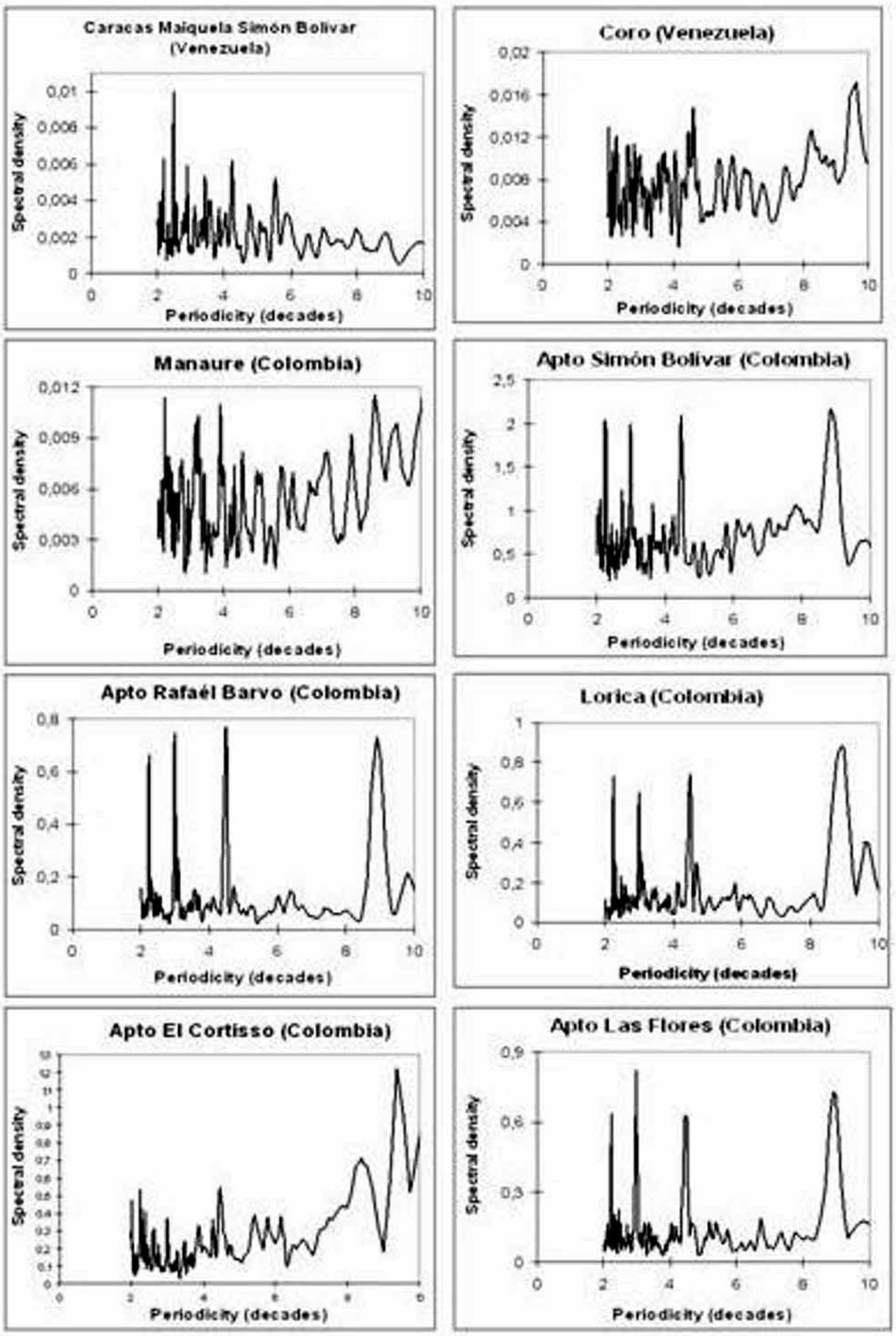


Figure 3. Spectral density for DPI of stations located on the islands (left) and coastal sector (right) of Caribbean region.



Cont. Figure 3.

of DPI using commercial software that calculates the spectral density.

Considering that Madden-Julian Oscillation induces the most outstanding signal of ISV in the tropics, an attempt to associate the regional ISV of precipitation with MJO was done; therefore the Madden-Julian Index (MJI) for 120 and 40°W was compared with DPI series. For that, DPI was smoothed using moving averages to filtrate high frequency modes. MJI data was taken from NOAA/NCEP/CPC Web page (see http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_mjo_index/details.shtml)

Finally, correlation coefficients for MJI and original and smoothed DPI were calculated.

3. Analysis and discussion

Figure 2 shows the 3-points (30 days) moving averages of DPI for five stations (one for each delimited sector) in the region; this presentation visualizes the intraseasonal fluctuations of DPI. The MJI for 120 and 40°W is also presented to compare with DPI series.

The lines that correspond to MJI over both 120 and 40°W has similar fluctuations with a noticeable delay caused by the eastward propagation of MJO, however in 1997-1998 (during strong El Niño event) this concordance was disrupted. It is possible to observe also that during El Niño events (1997-1998 and 2002-2003 in the analyzed period) the MJI tends to have the lowest values, while during cold events La Niña (1996, 1999-2000, and 2003-2004) the highest values are presented.

At first glance, in the Figure 2 it is possible to observe too, that some extreme events of DPI are synchronic in different regions in spite they differ by their magnitude. Comparing DPI and MJI evolution is not possible to identify any pattern of correlation because in some periods they are in the same phase, and in times are in counter phase. However, a correspondence may be detected for extreme rainfall events: maximums values of DPI are associated with minimum of MJI; at least the most outstanding rainfall (heavy rainfall) events are associated to low values of MJI.

The figures 3-5 present spectra of several stations of the regions analyzed in this paper (due to limitation of space, is not possible to present the spectra for all 78 stations). Also, it is necessary to consider that in these graphics the periods less than 2 decades (20 days) are not observed, because 2 decades coincide with 0.5 frequency (Niquist frequency), under which is not possible to represent the spectrum.

The analysis of Figure 3 (left side) shows that for East and Central Caribbean region the graphics are similar: all spectra have peaks at 20, 30, 45 and 60 days period. In the Western sector (Aeropuerto El Embrujo–Providence Island, and Aeropuerto Sesquicentenario – San Andres Island) these peaks are not marked and just the 20, 30 and 60 days period are slightly noticeable. In several spectra peaks are presented even over 80-90-days period, however this interval approaches to seasonal scale. The spectra over Caribbean coastal sector (Figure 3, right) show also peaks at 20, 30, and 45-days period, but the signal over 60-days period is very weak or is missing.

In the mountainous sector of the region (Figure 4) there are some places were spectra did not presented an outstanding signal or the signals are weak (Airport La Nubia, Airport A Nariño and Obonuco in Pasto, Colombia), however many of them (Airport Camilo Daza – Cúcuta, UPTC and Eldorado, also in Colombia) have the 20, 30, and 45-days periods are well defined

The Figure 4 (right side) shows spectra for meteorological stations of the eastern lowlands of Orinoco and Amazon basin. These spectra in the sector of intraseasonal frequencies are very noisy and it is difficult to identify clearly defined peaks at a given period.

The same situation occurs in several places in the Pacific sector (Figure 5), however there are points like Tocumen (Panama), Panamericana and Bonanza (Colombia) and Manta (Ecuador) where peaks outstand over 20-25, 30 and 45-days period. Also, a

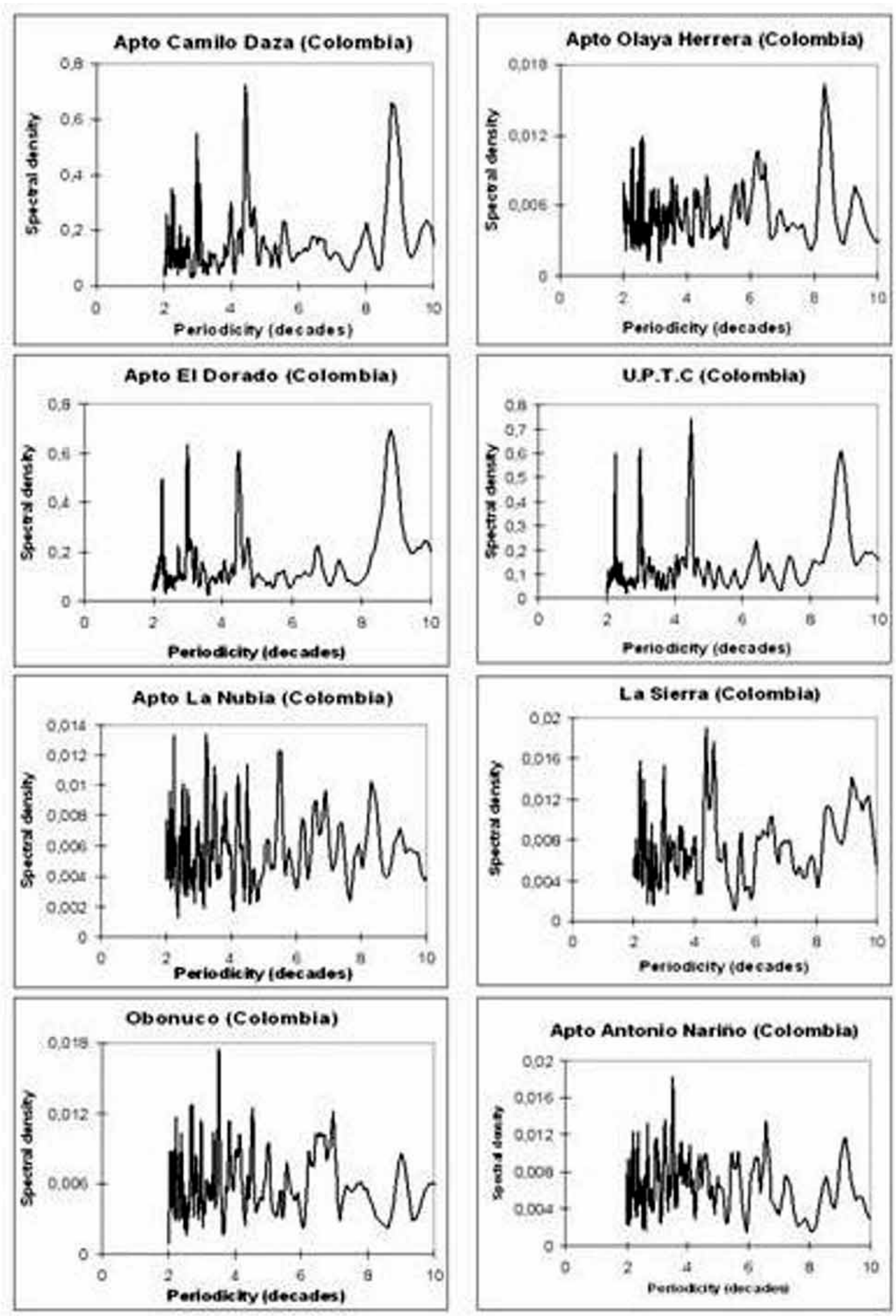
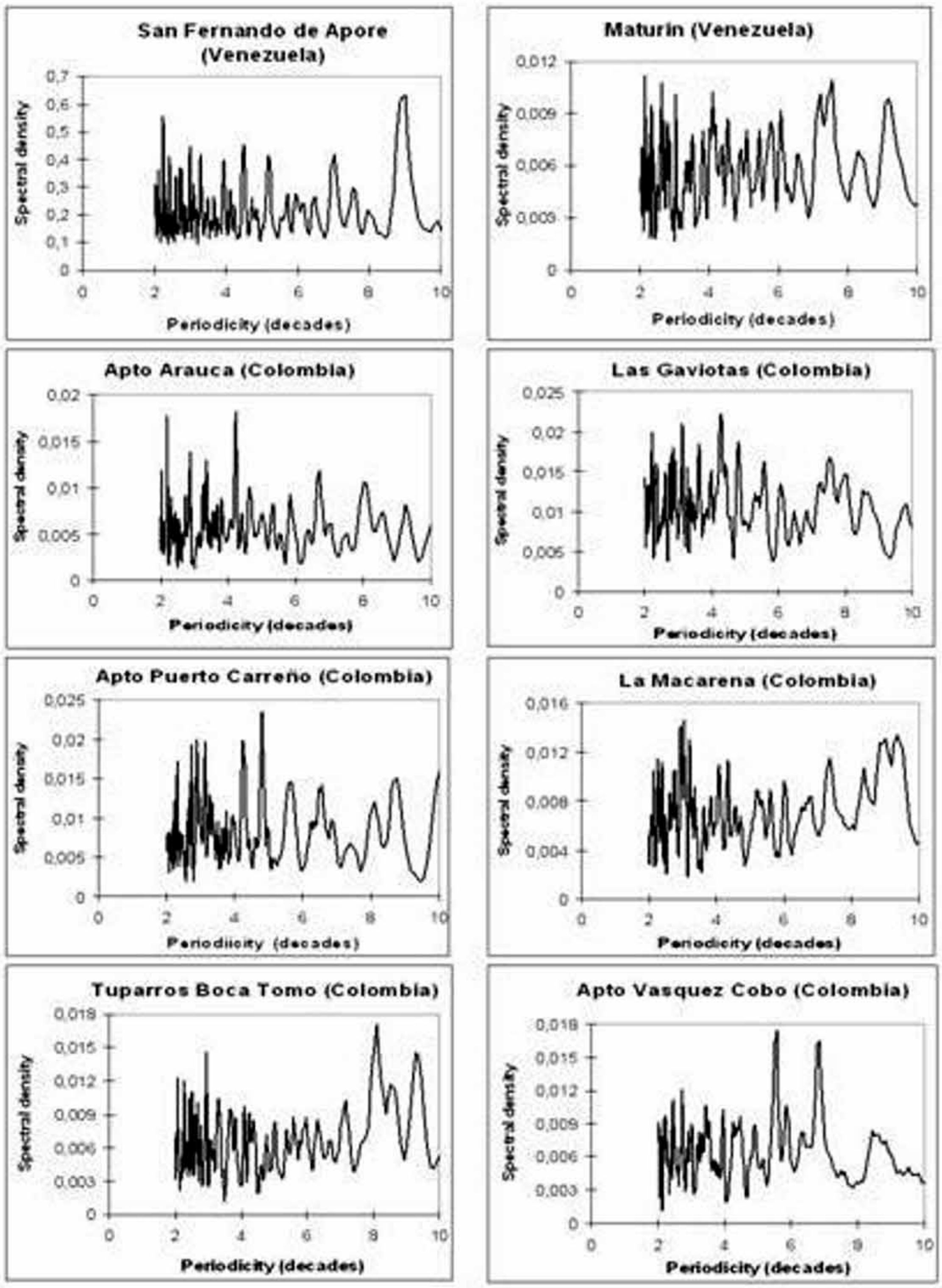


Figure 4. Same as Figure 3, but for the stations located on Andean (left) and eastern plain (right) zone region.



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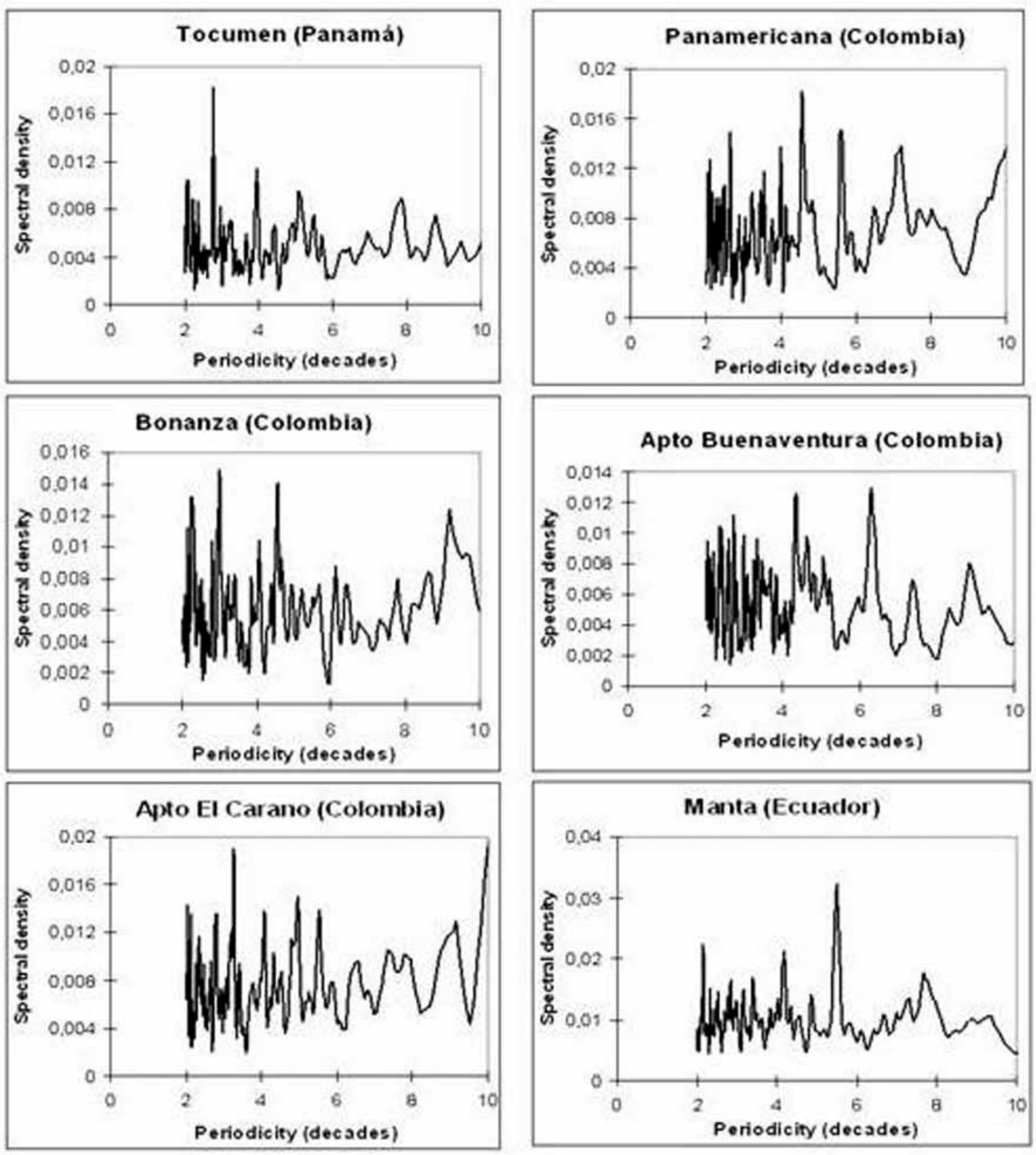

Figure 5. Same as in Figure 3, but for the stations of Pacific zone.

marked peak appears over the interval of 50-60-days period in Panamericana and Buenaventura (Colombia) such as in Manta (Ecuador).

Summarizing in a whole the region, the signals 20-25, 30- and 45-days period are the most noticeable of the ISV of precipitation. A 50-60-days sig-

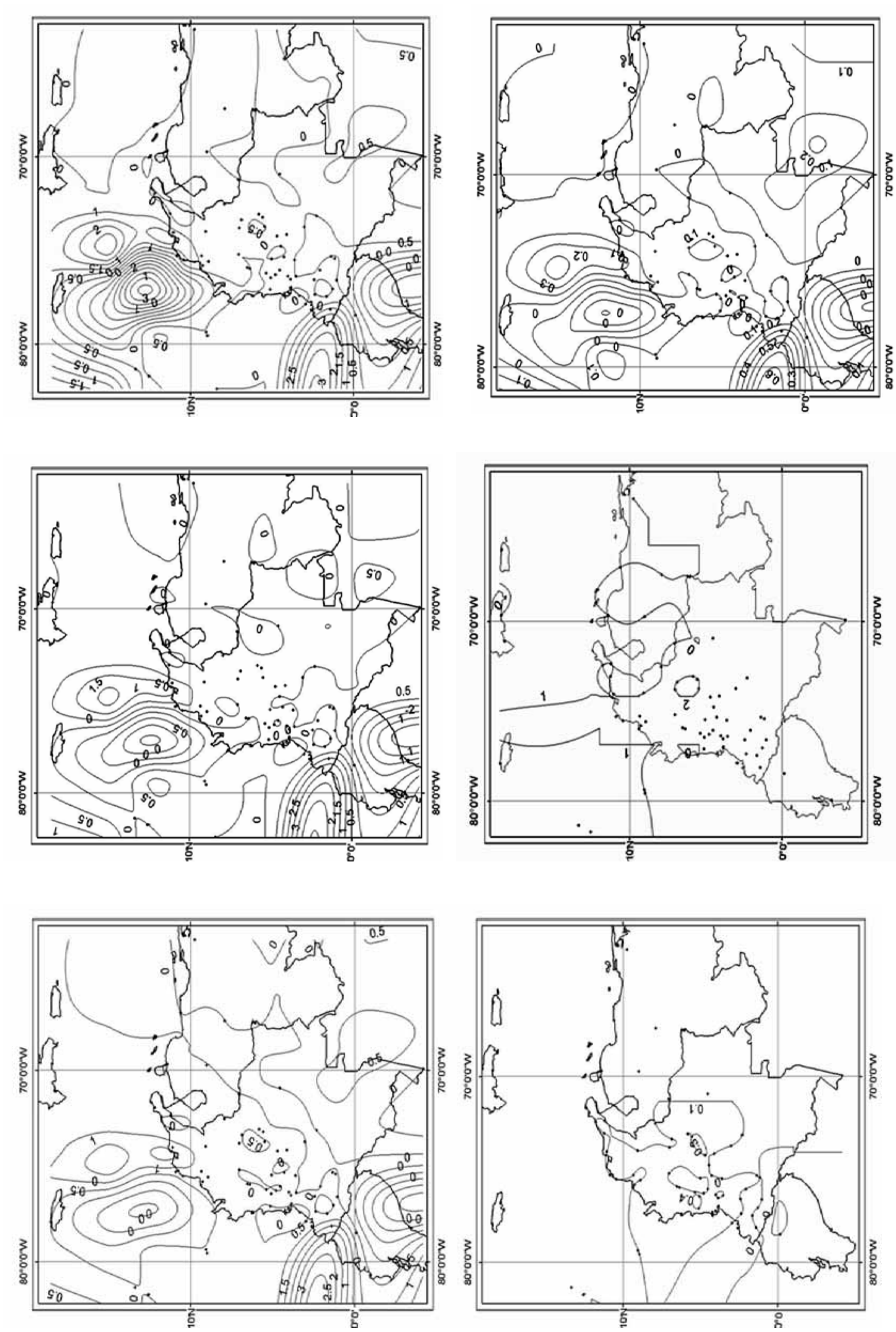

Figura 6. Spatial distribution of spectral density for 20-, 30-, 45- (top, form left to right), 55-, 60- and 90-days (bottom).

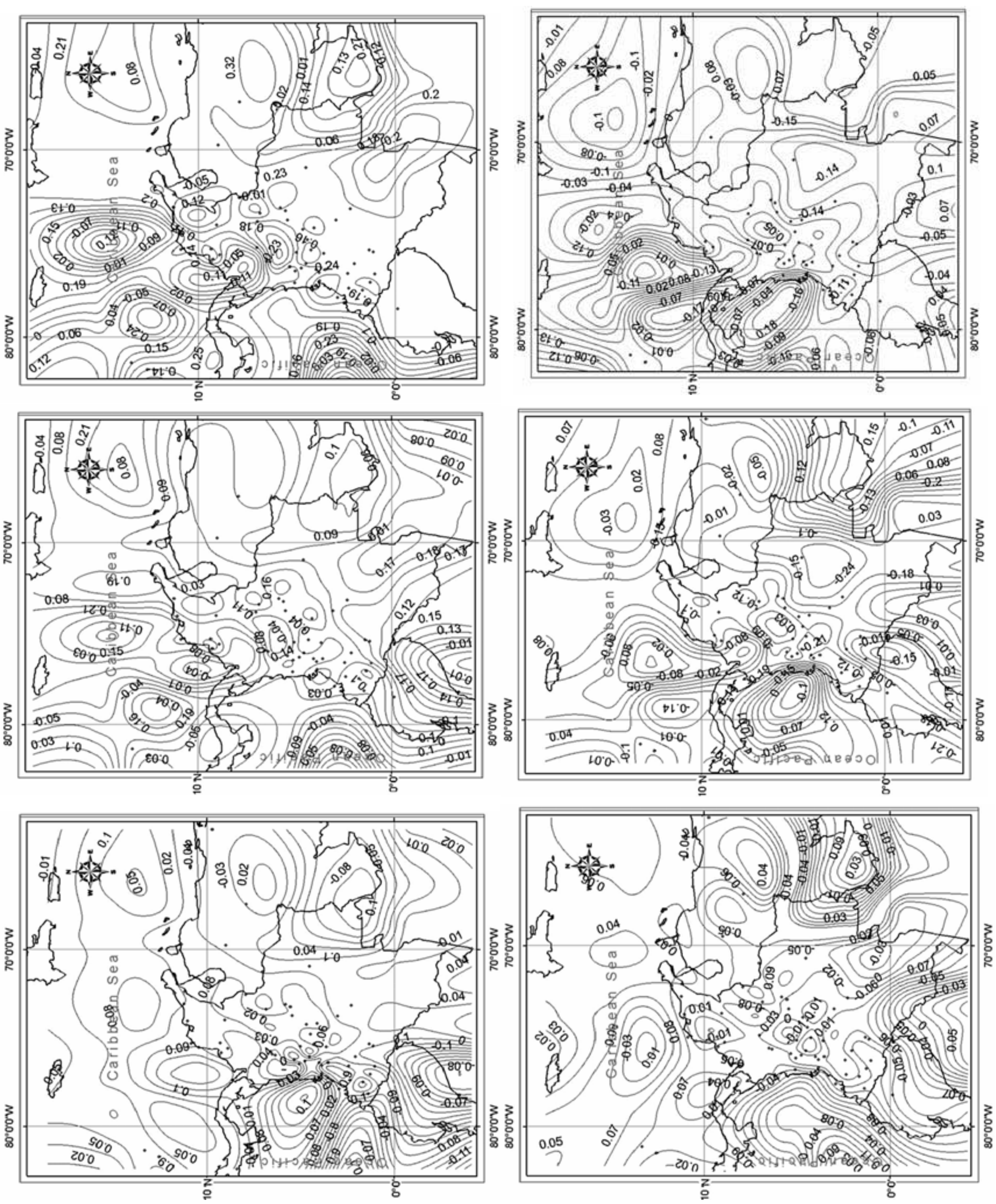

Figure 7. Spatial distribution of correlation coefficients between MJI over 120°W (top) and 40°W (bottom) and the DPI original series (left), its 3-points smoothed DPI (center), and 5-points smoothed DPI (right).

nal appears clearly in the Caribbean region, but is not important in others regions.

The maps presented in Figure 6 show the spatial distribution of spectral density of 20-, 30-, and 45-days signals. It is possible to conclude that in spite the 20-days signal is observed in all region, the major spectral density is observed over Western Caribbean and southwestern sector (Ecuador and Pacific ocean). For 30- and 45-days signals there is a similar distribution.

The relationship between DPI and MJI was explored calculating the correlation coefficients. These coefficients are very low when the correlation is calculated for original (not smoothed) DPI time series, and increase as the high frequency modes are smoothing by moving averages. This fact suggests that the high frequency of ISV of regional precipitation is controlled by processes different from MJO. The spatial distribution of correlation coefficients are presented in Figure 7.

4. Conclusions

The analysis made above shows that in the ISV of precipitation over Northern South America and Caribbean region there are signals with 20, 30, 45 and 60-days period. The three first are persistently observed in all the zones of the analyzed region, while the last is observed only in both the Caribbean islands and some places of Pacific sector.

Searching the relationship between intraseasonal variability of regional precipitation and Madden-Julian Oscillation it did not find a defined association pattern and even the correlation coefficients between MJI and DPI were very low; however, was established that the heavy rainfall events are associated with low values of MJI.

The low values of correlation coefficients and their increasing with smoothing of DPI suggest that the regional ISV is controlled not only by MJO. It is necessary to explore the nature of high frequency (20-days, for example) modes.

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