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Analysis of long runoff series of selected rivers of the Asia-Pacific region in relation with climate change and El Niño effects

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been proposed by the Climate Prediction Center of NOAA-NCEP, Washington DC, USA (Ropelewski and Jones, 1987), by the Climate Diagnostics Center of NOAA-CIRES, Boulder CO, USA (Wolter and Timlin, 1998) and others. Their differences is quite limited to the number of variables taken into account, by the period of reference and by an eventual normalization.

With this representation, negative values of the index (<-5) correspond to the **"warm"** phase (low SOI) of the ENSO index, referred often as an **El Niño event**; positive values (>+5) correspond to the **"cold"** phase (high SOI) of the ENSO index, also called **La Nina event** (Philander, 1990). **El Niño** and **La Nina years** are identified by smoothing the monthly SOI values by an 11-point moving average and selecting **years** with 5 consecutive months or more with smoothed SOI values lower than -5 or higher than +5 respectively, and lasting at least 3 seasons. **El Niño** and **La Nina months** are identified by smoothing the monthly SOI values by an 5-point moving average and selecting **strings of 5 consecutive months or more**, with smoothed SOI values lower than -5 or higher than +5 respectively, and lasting at least 3 seasons. In the literature, no precision is given about the definitions of either the year or the seasons, both characteristics being related to the particular climate and regime of the region under study. Under these circumstances, Table 36 presents the labeling of years and months used for this study according to the previously defined criteria, with the restriction that it uses calendar years and disregards the number of seasons that should be present to constitute an event. Periods that were **not labelled** as belonging to either El Niño or La Nina events were considered as **normal or neutral** conditions and used as reference.
One can also note that some researchers, recognizing the fact that some El Niño events were lasting more than one year, have tried to differentiate the months of the first year or rising limb by a subscript 0, from the months of the second year or sinking limb subscripted +1; in this study, no such differentiation was attempted.

3.4 Preliminary analysis: a yearly appraisal

Using the previously defined labeling of the years, a preliminary analysis was conducted in order to try to discriminate which areas and which river stations responded significantly to the El Niño/La Nina signals. Three populations of years were created (El Niño, La Nina and Neutral years) and **percentiles** (10%, 30%, 50%, 70% and 90%) of the runoff **distributions**, belonging to these populations were computed.
The results are presented on Tables 43 to 47; on the Table 43, as an example, one can see that, for the Murrumbidge River in Australia, the distribution of the yearly discharges varies from 74 to 2818 m^3/s for the 10% and 90% percentiles respectively, with a median value of 589 m^3/s for the years belonging to the La Nina phase. During the El Niño phases, the yearly discharges are distributed from 43 to 1656 m^3/s for the 10% and 90% percentiles, with a median value of 245 m^3/s. These values are fairly different: For a same recurrence period the values occurring during the El Niño phases are lower than the corresponding values during the La Nina phases; but a same yearly discharge can occur during either of the phases, but with different frequencies of exceedance. The same kind of behaviour occurs is other areas, but with less contrast than in the Oceania-Pacific area.
In the following part, some statistical techniques will be used in order to pinpoint which stations present statistically different discharges during the three phases of the ENSO; these techniques are applied to the 3 yearly series (mean yearly, monthly maximum and minimum).

Table 15 **Segmentations of the mean yearly discharges (Indian Subcontinent area).**

GRDC number	River	Begin year	End year	1st Segment mean	s.d.	Begin year	End year	2nd Segment mean	s.d.	Begin year	End year	3rd Segment mean	s.d.
2357500	Mahaweli Ganga	1950	1984	66	15								
2357750	Gin Ganga	1928	1989	62	11								
2548400	Karnali River	1962	1993	1380	225								
2549300	Kali Gandaki (1)	1964	1969	253	25	1970	1976	311	34	1977	1993	245	31
2549350	Kali Gandaki (2)	1964	1968	546	57	1969	1985	448	68				
2550500	Tamur River	1965	1986	334	44								
2646200	Ganges R. (1)	1934	1989	11400	2130								
2846800	Ganges R.(2)	1949	1985	12500	2400								
	Sapt Kosi	1947	1967	1540	206	1968	1978	1800	204				
2856900	Godavari	1902	1979	3050	985								
2854300	Krishna	1901	1964	1780	445	1965	1979	1070	488				
2853500	Narmada	1949	1974	304	153								

Table 16 **Segmentations of the maximum monthly discharges (Indian Subcontinent area).**

GRDC number	River	Begin year	End year	1st Segment mean	s.d.	Begin year	End year	2nd Segment mean	s.d.	Begin year	End year	3rd Segment mean	s.d.
2357500	Mahaweli Ganga	1950	1984	160	50								
2357750	Gin Ganga	1928	1989	135	37								
2548400	Karnali River	1962	1993	4390	815								
2549300	Kali Gandaki (1)	1964	1993	873	132								
2549350	Kali Gandaki (2)	1964	1985	1530	254								
2550500	Tamur River	1965	1986	998	138								
2646200	Ganges R. (1)	1934	1945	35300	5230	1946	1989	42600	767				
2846800	Ganges R.(2)	1949	1985	45900	9120								
	Sapt Kosi	1947	1969	4500	851	1970	1978	5580	783				
2856900	Godavari	1902	1979	13500	5100								
2854300	Krishna	1901	1970	7300	2280	1971	1979	4470	2320				
2853500	Narmada	1949	1971	1490	560	1972	1974	3580	3570				

Table 17 **Segmentations of the minimum monthly discharges (Indian Subcontinent area).**

GRDC number	River	Begin year	End year	1st Segment mean	s.d.	Begin year	End year	2nd Segment mean	s.d.	Begin year	End year	3rd Segment mean	s.d.
2357500	Mahaweli Ganga	1950	1983	13	7.2								
2357750	Gin Ganga	1928	1971	21	6	1972	1989	14	7				
2548400	Karnali River	1962	1993	317	61								
2549300	Kali Gandaki (1)	1964	1975	34	7	1976	1985	45	2	1986	1993	55	5
2549350	Kali Gandaki (2)	1964	1985	75	20								
2550500	Tamur River	1965	1986	50	14								
2646200	Ganges R. (1)	1934	1975	1960	357	1976	1989	1000	270				
2846800	Ganges R.(2)	1949	1985	1730	317								
	Sapt Kosi	1947	1978	342	35								
2856900	Godavari	1902	1924	40	40	1925	1969	72	36	1970	1979	146	59
2854300	Krishna	1901	1953	11	12	1954	1979	43	48				
2853500	Narmada	1949	1974	1.9	1.2								

Table 33 : Trends in mean yearly discharges (Indian Subcontinent area).

River and GRDC #		Start Year	End Year	type of trend	level	sd	sd (mean)	RMSE
Kali Gandaki (1)	period 1	1964	1976		284	42	12	..
2549300	period 2	1977	1993	Step trend	247	30	7	35
Kali Gandaki (2)	period 1	1964	1968		530	45	22	..
2549350	period 2	1969	1985	Step trend	457	74	17	70
	period 1-2	1964	1985	Monotonic trend	525-415(-5/yr)	2/yr	..	67
Sapt Kosi	period 1	1947	1967		1540	206	46	..
	period 2	1968	1978	Step trend	1770	202	58	204
	period 1-2	1947	1978	Monotonic trend	1480-1780(10/yr)	4/yr	..	216
Krishna	period 1	1901	1960		1780	454	37	..
2854300	period 2	1961	1979	Step trend	1250	522	74	472

Table 34 : Trends in maximum monthly discharges (Indian Subcontinent area).

River and GRDC #		Start Year	End Year	type of trend	level	sd	sd (mean)	RMSE
Ganges R. (1)	period 1	1934	1945		35200	5220	1580	..
2646200	period 2	1946	1989	Step trend	42500	7560	1130	7160
Sapt Kosi	period 1	1947	1969		4510	848	181	..
	period 2	1970	1978	Step trend	5440	814	257	837
	period 1-2	1947	1978	Monotonic trend	4180-5420(40/yr)	17/yr	..	866
Krishna	period 1	1901	1960	Monotonic trend	9590-3960(-245/yr)	100/yr	..	311
2854300								
Narmada	period 1	1949	1974	No trend	1730	1300	255	1300
2853500								

Table 35 : Trends in minimum monthly discharges (Indian Subcontinent area).

River and GRDC #		Start Year	End Year	type of trend	level	sd	sd (mean)	RMSE
Gin Ganga	period 1	1928	1957	No trend	19.5	5.7	1	5.7
2357750	period 2	1958	1989	Monotonic trend	26.3-11.3(- 0.5/yr)	0.2	..	7
Kali Gandaki (1)	period 1	1964	1993	Monotonic trend	31.2-55.7(0.9/yr)	0.13	..	7.4
2549350								
Ganges R. (1)	period 1	1934	1974		1950	353	25	..
2646200	period 2	1975	1989	Step trend	1130	442	50	380
Godavari	period 1	1902	1979	Monotonic trend	23.7-120(1.3/yr)	0.2/yr	..	42
2856900								
Krishna	period 1	1901	1979	No trend	21.7	32.1	1.4	32
2854300								

Table 45: Distribution, by type of years, of runoffs of rivers in the South East Asia area.

River name	Year type	Percentiles 10%	30%	50%	70%	90%
Pampanga 5654500	La Nina	23,0	47,0	103,0	264,0	590,0
	Neutral	23,0	44,0	105,5	266,0	631,0
	El Nino	25,0	68,0	132,0	294,0	559,0
Bonga 5654100	La Nina	1,0	2,0	5,5	23,0	53,5
	Neutral	2,0	3,0	9,0	27,0	93,0
	El Nino	1,0	3,0	6,5	31,0	76,0
Kelanatan 5223100	La Nina	324,0	387,5	459,0	624,0	1102,0
	Neutral	199,0	300,0	405,5	585,0	966,0
	El Nino	206,0	341,0	447,0	618,0	908,0
Mekong(3) 2969100	La Nina	1620,0	2320,0	4447,0	9850,0	20630,0
	Neutral	1450,0	2130,0	4311,5	10890	20781
	El Nino	1580,0	2000,0	4340,5	9760,0	18970,0
Nam Chi 2969150	La Nina	13,0	54,0	114,0	298,0	656,0
	Neutral	16,0	58,0	112,5	334,0	715,0
	El Nino	11,0	56,5	94,5	224,0	667,0
Nam Mun 2969200	La Nina	47,5	87,0	238,0	619,5	1621,0
	Neutral	48,0	94,0	206,0	846,0	1910,0
	El Nino	26,5	85,0	154,0	543,0	2178,0
Nan 2964080	La Nina	24,0	39,0	75,0	230,0	546,0
	Neutral	19,0	43,0	81,5	182,0	567,0
	El Nino	20,0	34,0	60,0	140,0	368,0
Mekong(1) 2969010	La Nina	839,0	1150,0	1966,0	3370,0	6540,0
	Neutral	845,0	1120,0	1830,0	3731,0	5750,0
	El Nino	861,0	1100,0	1905,0	3480,0	5601,0
Mekong(2) 2969095	La Nina	1460,0	2160,0	4450,0	9650,0	19290,0
	Neutral	1450,0	2210,0	4030,0	9673,0	16690,0
	El Nino	1550,0	2140,0	3850,0	8840,0	15750,0

Table 50: Duncan test, Parametric and Non-Parametric ANOVA results for the discrimination of El Nino, La Nina and Neutral years (South East Asia area).

River	Mean Yearly flows			p-value	p-value	Monthly Maximum			p-value	p-value	Monthly Minimum			p-value	p-value
	La Nina	Neutral	El Nino	ANOVA	Kruskall-Wallis	La Nina	Neutral	El Nino	ANOVA	Kruskall-Wallis	La Nina	Neutral	El El Nino	ANOVA	Kruskall-Wallis
Pampanga	215.6(A)	224.7(A)	251 5(A)	0.56	0.75	707.6(A)	730.2(A)	854.6(A)	0.52	0 92	25.2(A)	22.6(A)	24.9(A)	0.85	0.98
Bonga	21.4(A)	28.5(A)	25.6(A)	0.38	0.27	83.6(A)	109 6(A)	110.2(A)	0.38	0 35	1.30(A)	1.85(A)	1.50(A)	0.52	0.66
Kelantan	639.7(A)	1	506.1(A)	0.0447	0.0384	1669.3(A)	1230.6(A)	1584.7(A)	0.21	0 42	304.4(A)	228.0(A)	225.2(A)	0.11	0.0510
Mekong (1)	8065.1(A)	8043.0(A)	7557.5(A)	0.32	0.37	23383(A)	23778(A)	22099(A)	0.38	0.33	1549.8(A)	1410.7(A)	1491.8(A)	0 0916	0.18
Nam Chi	239 2(A)	256.5(A)	228.9(A)	0.66	0.89	796.8(A)	826.2(A)	860.1(A)	0.88	0.77	23.0(A)	30.8(A)	27.6(A)	0.66	0.66
Nam Mun	556.9(A)	666.2(A)	620.0(A)	0 40	0.57	2018.5(A)	2543.1(A)	2514.9(A)	0.32	0.21	44.3(A)	55 4(A)	51.3(A)	0.69	0 66
Nan	192.0(A)	186.8(A)	138.5(B)	0.0395	0.0375	728.6(A)	752.9(A)	545.3(A)	0.20	0.14	20.9(A)	23.7(A)	20.1(A)	0.61	0.92
Mekong (2)	2761.4(A)	2681.0(A)	2722 5(A)	0.90	0.85	7350.1(A)	6801.2(A)	6723.4(A)	0.69	0 54	807.9(A)	809.7(A)	839 1(A)	0.65	0.74
Mekong (3)	7413.6(A)	7096.7(A)	6671 8(A)	0.40	0.35	21311(A)	20254(A)	18988(A)	0.54	0.62	1381.8(A)	1391.5(A)	1562.9(A)	0.18	0 38

Numbers associated with the same letters are not discriminated by the Duncan test on the equality of several mean values.

very significant

significant

differences in the mean values as demonstrated by the ANOVA tests.

Table 54c: Monthly runoff distributions according to SOI classification (Far East Asia area).

River	SOI	Month	J	F	M	A	MA	JN	JL	AU	S	O	N	D	Total
Huanghe		N obs	8	9	8	8	7	9	9	10	10	11	10	11	110
	La Nina	**Mean**	**581**	**605**	**1089**	**1178**	**1151**	**1100**	**2084**	**2710**	**2597**	**2615**	**1751**	**809**	**1574**
		sd	154.6	237.7	431 3	302.2	650.5	652.9	920.8	1379.5	1387.9	1395.9	843.1	398.7	1150.8
		N obs	26	24	25	25	24	24	23	22	22	20	23	22	280
	Neutral	**Mean**	**574**	**537**	**973**	**995**	**976**	**863**	**2130**	**3121**	**3332**	**2762**	**1359**	**773**	**1484**
		sd	183.2	198.1	314.8	285.8	416.9	489.8	963.7	1255.8	1357 4	1109.6	610 0	293.4	1197.5
		N obs	6	7	7	7	9	7	8	8	8	9	7	7	90
	El Nino	**Mean**	**458**	**414**	**901**	**946**	**931**	**754**	**1791**	**2161**	**1459**	**1207**	**831**	**560**	**1068**
		sd	81.2	135.2	292.4	345.7	311 4	246.1	850.7	1139.2	475.4	686.2	262.2	93.3	720.5
Mean Huanghe (n=40)			**558**	**531**	**984**	**1023**	**996**	**897**	**2052**	**2826**	**2774**	**2372**	**1364**	**746**	**1427**
P-Value Huanghe			0.29	0.17	0.54	0.26	0.58	0 35	0.67	0.19	0.00	0.00	0.0210	0.21	0.00
Beijiang		N obs	6	7	7	7	6	7	7	8	8	9	8	8	88
	La Nina	**Mean**	**344**	**544**	**694**	**1333**	**2462**	**3143**	**1672**	**1265**	**897**	**679**	**500**	**419**	**1128**
		sd	101.9	381.8	590.8	796.0	1336 5	912.2	803.5	504 5	492.9	385.8	195.2	189.7	1007.1
		N obs	22	20	21	21	20	21	20	19	19	17	19	19	238
	Neutral	**Mean**	**290**	**415**	**776**	**1842**	**2368**	**2674**	**1287**	**1018**	**904**	**500**	**387**	**271**	**1077**
		sd	151.4	197.5	395 9	666.0	1077.6	1382.1	629.0	403.6	729.6	234.1	145 7	57 7	1020.7
		N obs	6	7	6	6	8	6	7	7	7	8	7	7	82
	El Nino	**Mean**	**652**	**684**	**1285**	**1430**	**2439**	**1797**	**968**	**1100**	**605**	**549**	**538**	**426**	**1038**
		sd	527.4	600.5	1611.6	457.9	918.0	525.2	333.6	257.0	304.2	236.4	249.0	266.1	842 9
Mean Beijiang (n=34)			**363**	**497**	**849**	**1664**	**2401**	**2616**	**1300**	**1093**	**841**	**559**	**445**	**338**	**1080**
P-Value Beijiang			0.01	0 22	0.31	0.15	0.98	0.14	0.12	0.36	0.53	0.32	0.1200	0.03	0.83
Dongjiang		N obs	5	6	6	5	4	5	5	6	6	7	6	6	67
	La Nina	**Mean**	**325**	**379**	**343**	**533**	**1154**	**1794**	**1120**	**1021**	**1081**	**825**	**449**	**395**	**765**
		sd	122.7	139.5	152.6	179 4	919.3	435.3	410.1	302.9	552.5	400.8	129.3	108.6	545.3
		N obs	18	16	17	17	16	17	17	16	16	14	16	16	196
	Neutral	**Mean**	**361**	**321**	**356**	**686**	**999**	**1616**	**1102**	**1081**	**1022**	**555**	**475**	**414**	**751**
		sd	141.4	137 4	135 4	342.6	372.0	904.5	378.6	350.5	617.7	235.9	152.1	143.2	554.2
		N obs	5	6	5	6	8	6	6	6	6	7	6	6	73
	El Nino	**Mean**	**360**	**472**	**920**	**867**	**1183**	**1241**	**903**	**1123**	**657**	**481**	**395**	**329**	**755**
		sd	145.0	399.5	984.2	597.6	386 7	323.0	232.4	245.6	150.6	101.4	104.1	77.8	481.4
Mean Dongjiang (n=28)			**354**	**366**	**454**	**697**	**1074**	**1567**	**1062**	**1077**	**956**	**604**	**452**	**392**	**755**
P-Value Dongjiang			0.87	0.36	0.03	0.38	0.63	0 45	0.48	0.86	0.32	0.05	0.4900	0.38	0.98
Yana		N obs	10	11	10	10	9	9	9	10	10	11	11	12	122
	La Nina	**Mean**	**1**	**1**	**0**	**1**	**468**	**3471**	**2344**	**1953**	**959**	**151**	**38**	**10**	**721**
		sd	1 8	0.5	0.5	0.7	454.8	928.3	1018.2	478 7	465.0	68.8	24 9	11.8	1167.9
		N obs	29	27	29	29	28	30	29	28	28	26	27	26	336
	Neutral	**Mean**	**1**	**1**	**0**	**0**	**644**	**3831**	**3212**	**2492**	**1265**	**190**	**38**	**8**	**1005**
		sd	1.3	0.9	0.9	0.8	643.7	1272.2	914.7	1172.6	549.2	118.2	17.5	5.5	1505.0
		N obs	8	9	8	8	10	8	9	9	9	10	9	9	106
	El Nino	**Mean**	**4**	**3**	**2**	**3**	**768**	**3091**	**2832**	**2116**	**1447**	**170**	**35**	**8**	**869**
		sd	3.3	3.7	4.5	4.4	444.7	677.4	1089.5	580.5	625 4	46.1	9.0	1.8	1211.8
Mean Yana (n=47)			**2**	**1**	**1**	**1**	**637**	**3636**	**2973**	**2305**	**1235**	**177**	**37**	**9**	**918**
P-Value Yana			0.01	0.00	0.05	0.03	0.53	0.25	0.07	0.27	0.15	0.53	0.9300	0.66	0.14
Penzhina		N obs	5	6	6	5	4	5	5	6	6	7	6	6	67
	La Nina	**Mean**	**42**	**31**	**25**	**23**	**478**	**4232**	**904**	**626**	**916**	**443**	**113**	**62**	**622**
		sd	13.9	9 2	5.1	7.5	185.3	684.6	309.5	181.9	712 6	274.7	27.6	19.2	1121.7
		N obs	18	16	17	18	17	18	17	16	16	15	16	16	200
	Neutral	**Mean**	**30**	**23**	**21**	**24**	**655**	**4104**	**1229**	**1066**	**798**	**362**	**95**	**50**	**726**
		sd	10.0	8.1	5 5	8 6	461 8	1574.2	698.1	372 7	435 7	211.4	34 8	19.5	1268 7
		N obs	5	6	5	5	7	5	6	6	6	6	6	6	69
	El Nino	**Mean**	**36**	**26**	**20**	**25**	**403**	**3864**	**1377**	**810**	**1297**	**369**	**112**	**60**	**679**
		sd	10.8	6 1	7 0	8.8	289.2	1182.9	343.7	292.8	818.1	213.3	34.9	11.9	1091 5
Mean Penzhina (n=28)			**33**	**25**	**22**	**24**	**567**	**4084**	**1203**	**917**	**930**	**384**	**102**	**55**	**695**
P-Value Penzhina			0.08	0.11	0.21	0 91	0 35	0.91	0 42	0.02	0.23	0.73	0 4000	0.28	0.82

= Monthly event runoff significantly different from the global monthly average