

Calendar of Oceanic Physical Phenomena in Puerto Rico

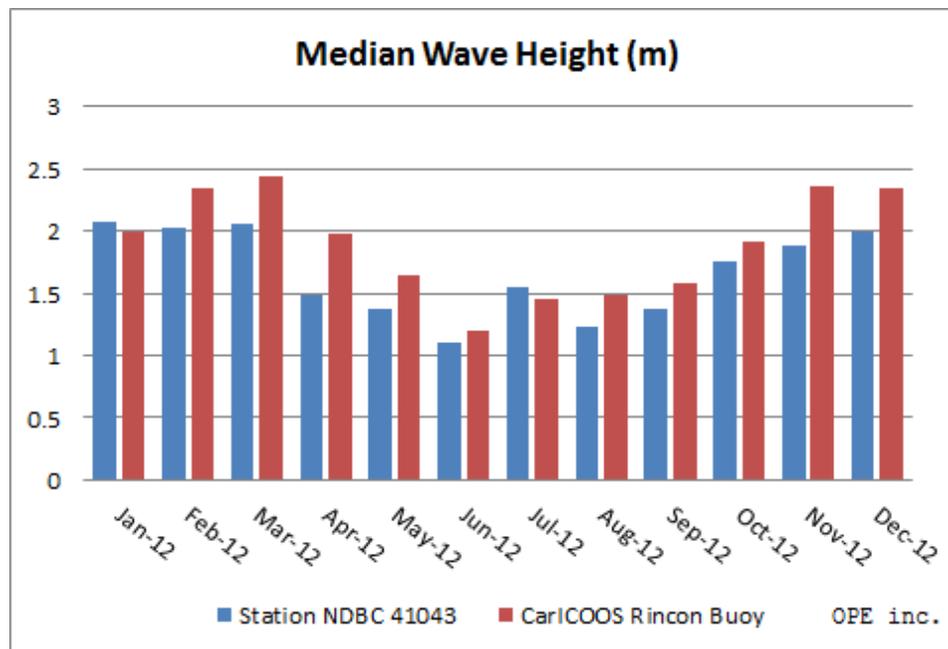
By

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Calendar of Oceanic Physical Phenomena

Energy moving across the deep oceanic waters surrounding Puerto Rico continuously arrives to our shores. Here on the island, surfers regularly enjoy the swells from the Northwest that are generated in the North Atlantic, by distant storms during autumn and winter. Puerto Ricans are familiar with the season of strong waves, waves of a long period ($T \geq 10$ s), extending from late October until mid-April. On the contrary, from May to September, wave activity is lower, but a close pass by a strong storm or hurricane may alter this period of relative calm for several days. The annual cycle of the wave regime is well known by the inhabitants of the northwest coast of PR. Below we show a graph that fully outlines the annual cycle of wave heights in Rincon, PR.



Annual cycle of the average height of the waves in Puerto Rico. The blue bars correspond to the data registered in the NDBC 41043 station, about 170 nautical miles NNE of San Juan, and the Red bars to data recorded by the buoy of CarICOOS in corner (located 1 mile from the Rincon lighthouse).

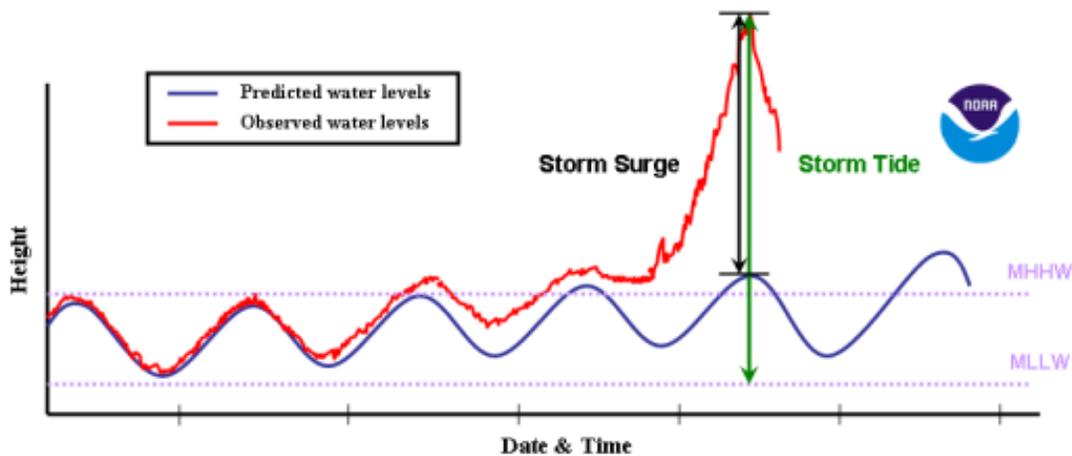
There are other ocean physical phenomena that also have an annual cycle, but these are unknown to the majority of Puerto Ricans. We then present a calendar that summarizes some of these ocean-coastal phenomena that affects Puerto Rico.

Calendario de Fenómenos Físicos Oceánicos en Puerto Rico													
Fenómeno Físico Oceánico	MES	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC
Marejadas otoñales e invernales ($T \geq 10$ s)		█										█	
Mareas ciclónicas por sistemas tropicales								█					
Oleaje de periodo corto por S. tropicales ($T < 10$ s)							█						
Pleamar más alta (mareas)										█			
Bajamar más baja (mareas)		█			█		█						█
Corrientes más fuertes (aguas del Sur y del Oeste)						█			█				
Seiches costeros extremos (Costa Sur)					█					█		█	
Meteotsunamis locales									█				
Meteotsunamis transatlánticos				█									

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The above calendar indicates with a color bar the season of each oceanic physical phenomenon. This calendar was constructed using data from many years of observation by CarICOOS, CO-OPS program from the US NOAA, the DART program and data collected and provided by the author of this document.

Another phenomenon of interest that appears in the second position in the calendar, are storm tides generated by the passage of storms and hurricanes through our region. It usually occurs between the months of August and October. I want to clarify, that we can experience storm tides even as the path of the hurricane not crosses over Puerto Rico. Systems with extreme low barometric pressures, such as was the case of Hurricane Gilbert (1988), can increase the height of the water by the effect of the inverted barometer effect, despite going rather far away from the South Coast of PR.



The observed storm tide height includes the effect of the astronomical tide. Figure is a courtesy of NOAA.

Nivel del Agua Máximo registrado en Isla Magueyes, La Parguera, Puerto Rico			
Nombre	Clase	Fecha (LST)	Nivel del Agua Max. (ft) Relativo a MLLW
Isaac	Tormenta	8/23/2012 20:00	1.8
Dean	Huracán	8/18/2007 16:00	1.4
Alpha_2005	Tormenta	10/22/2005 16:00	1.2
Ernesto	Tormenta	8/3/2003 22:00	1.2
Debby	Huracán	8/22/2000 19:00	1.2
Georges	Huracán	9/22/1998 5:00	2.5
Hortense	Huracán	9/10/1996 9:30	1.7
Hugo	Huracán	9/19/1989 2:00	1.1
Gilbert	Huracán	9/11/1988 8:30	1.6

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Maximum height of the storm tides registered at the station 9759110 of NOAA/NOS/CO-OPS, Isla Magueyes (1988-2013)

The highest storm tide (2.5 feet) took place on 22 September 1998, during the scourge of H. Georges on the SW of Puerto Rico.

In the third position of the calendar stand the short period waves ($T < 10$ s), occupying the months from June to October. The hurricane season extends from June 1 to November 31. During those months the tropical waves approaching from the East are accompanied by a strong breeze (25-30 knots), which is capable of generating short period waves locally.

In the fourth position in the calendar we locate the highest tides of the year. These generally occur in the months of October and November. The highest astronomical tide between the years 1995 to 2012, took place on 6 November 2006.

Marea Astronómica Más Alta en Puerto Rico (1995-2012)			
Localización	Estación NOS/NOAA	Fecha (LST)	Nivel del Agua Max. (ft) Relativo a MLLW
Isla Magueyes	9759110	11/6/2006 11:36	1.61
USCG Compound, San Juan	9755371	11/6/2006 9:54	2.68

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Details are from the station 9759110 from NOAA/NOS/CO-OPS, Isla Magueyes (1995-2012) and the station 975371 in la Puntilla, San Juan.

The lowest low tides have been reported between December and January, when we are close to the perihelion. They have also reported during April and June-July. The lowest low tide record occurred on June 11, 1968 (- 0.878 ft).

Based on the last 4 years of current measurements from the ADCP installed in the PR-1 buoy of CariCOOS, located south of Caja de Muertos, we identify 10 events where the currents have a magnitude greater than 2 knots (103.2 cm s^{-1}), these events take place in the period from late August to late October. In the calendar, this period is identified with a purple band. Below, the table details such events. Strong currents respond to the perigee, the equatorial tide, the tropical tide and the spring tides. Some events are combined with the passage of a tropical cyclone, but its track pass at a safe distance from the buoy.

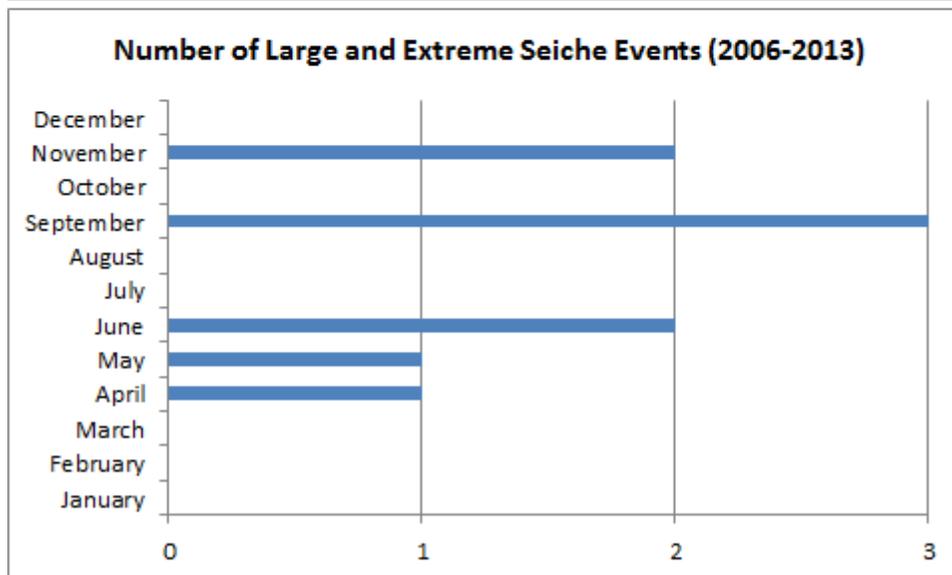
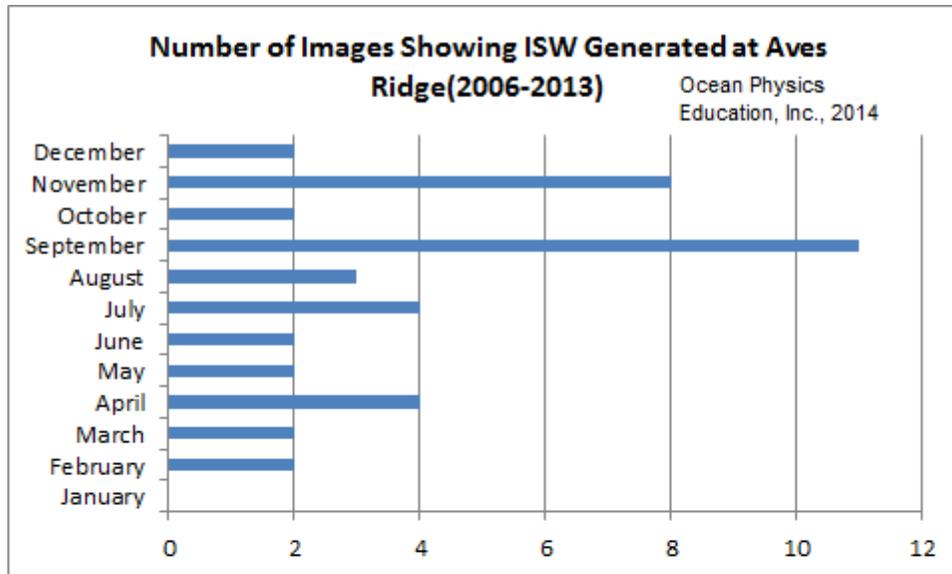
Strong Current Events at PR1 CariCOOS Buoy, 3 km South of Caja de Muertos, Speeds ≥ 2.0 knots.											
Event Number	Date	Lunar Phase	Lunation (days)	Tide	Declination (Deg)	Distance From Earth (km)	Date	Depth (m)	Max. Speed (cm/s)	Max. Speed (knots)	DIR (DEG)
1	8/22/2010 4:00		12		-18.8	404964	8/22/2010 4:00	7	111.3	2.2	132
2	8/31/2010 12:00	Last Quarter	20	Neap, Tropic, Hurricane Earl	21.5	391548	8/31/2010 12:00	8	143.5	2.8	116
3	9/2/2010 6:31	Last Quarter	22	Neap, Tropic	24.4	375737	9/3/2010 1:00	7	142.4	2.8	293
4	9/8/2010 13:10	New Moon	0	Spring, Equatorial, Perigean	0	353153	9/8/2010 20:00	7	103.2	2.0	307
5	10/6/2010 10:10		27	Perigean	-2.8	355107	10/6/2010 18:00	8	111.1	2.2	95
6	9/12/2011 11:00	Full Moon	14	Spring, Equatorial, T. Storm Maria	0	407677	9/13/2011 10:00	9	138.0	2.7	119
7	9/27/2011 11:31	New Moon	29	Spring, Perigean	-6.8	353852	9/27/2011 8:00	8	144.4	2.8	118
8	9/1/2012 13:10	Full Moon	15	Spring, Equatorial	0	393495	9/2/2012 21:00	7	155.2	3.0	145
9	10/18/2012 14:00		3	Tropic, Perigean	-21.5	359935	10/18/2012 23:00	7	113.2	2.2	316
10	10/25/2014 10:00	New Moon	1	Spring	-15.8	384064	10/25/2014 10:00	8	131.3	2.6	107

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Strong currents events with magnitude equal to or greater than 2.0 knots. Based from records of the ADCP in the PR-1 CariCOOS buoy located south of Caja de Muertos.

So far the fastest current at PR-1 - with a magnitude of 3 knots - took place on 2 September 2012 at 2100 GMT, with a value of 155.2 cm s^{-1} (3 knots). Another strong current, 113 cm s^{-1} , was detected on June, by Dr. Jorge Capella in the *Tourmaline*, at the northwestern end of the Cabo Rojo-Mayaguez insular platform.

In the seventh position of the calendar we have the extreme coastal seiches, who are excited by the arrival of packages of internal solitary waves (ISW), which, in turn, are generated at the Aves Ridge and make a journey of 450 km - in 4-5 days - so they hit the submarine slopes of the southwest of Puerto Rico. Therefore, the occurrence of coastal extreme seiches will depend on the frequency with which these ISW's are generated and reach Puerto Rico, with enough energy to excite them. Below we show a graph that shows the frequency of both phenomena. The extreme coastal seiches occur in the period from April to May, and later on September and November, while increasing the frequency of them. Also on September and November the sensor *MODIS/Terra/Aqua* satellite detected most frequently ISW's generated at Aves Ridge. The extreme coastal seiche (67.4 cm), called the Super Seiche, took place on 9 November 2006 in Magueyes Island, three days after the highest astronomical tide, which we already mentioned above.



Frequency of occurrence of internal solitary waves and coastal seiches.

In the eighth position indicate that the meteotsunamis are locally generated in August and September. During this period, jumps in atmospheric pressure are accompanying the arrival of strong tropical wave from the East. The jump generates a surface wave, travelling in the shelf waters with the same speed that the atmospheric pressure jump and acquiring more power and increasing its breadth; to then reach the port where occurs a second amplification of the wave. In Puerto de Fajardo the meteotsunamis are a common occurrence on August (see table below).

Meteotsunami Events at Fajardo Harbor, Puerto Rico (Years 2011-2014) compiled by Edwin Alfonso-Sosa (2014).													
Location	Date (GMT)	Atm. pressure Jump at the sea surface Δp (mb, hPa)*	Static Inverted Barometer Response, $\Delta \eta^*$ (m)	Arrival Time of Pressure Jump	Speed of Atmospheric Disturbance U (MPH)	Distance from the pressure maximum to the front L1 (m)	Distance travelled by the front xf (m)	Maximum elevation of the water level $\Delta \eta$ (m)	Amplification factor $ \Delta \eta / \Delta \eta^* $	Long Wave Celerity C (MPH)	Amplitude in the harbor (m)	Harbor Amplification Factor (m)	
Fajardo, PR	8/16/11 18:30	1.3	-0.013	8/16/11 18:30	38.64	1.88E+04	5.08E+04	1.75E-02	1.4	35.0	0.0934	5.3	
Fajardo, PR	8/17/11 2:42	0.6	-0.006	8/17/11 2:42	32.20	1.04E+04	5.08E+04	1.46E-02	2.4	35.0	0.1261	8.7	
Fajardo, PR	8/4/12 0:18	0.9	-0.009	8/4/12 0:12	38.64	1.25E+04	5.08E+04	1.82E-02	2.0	35.0	0.1753	9.6	
Fajardo, PR	8/4/12 4:24	0.6	-0.006	8/4/12 4:18	38.64	6.26E+03	5.08E+04	2.43E-02	4.1	35.0	0.1204	5.0	
Fajardo, PR	8/13/12 3:18	1.6	-0.016	8/13/12 3:06	21.47	1.04E+04	5.08E+04	3.88E-02	2.4	35.0	0.1943	5.0	
Fajardo, PR	8/8/14 16:53	0.4	-0.004	8/8/14 16:48	34.86	5.65E+03	5.08E+04	1.79E-02	4.5	35.0	0.1495	8.3	
*Esperanza, Vieques				Length of Platform along 115°T									

List of Meteotsunamis occurred in the port of Fajardo during the years 2011-2014.

Finally, the calendar shows that the transatlantic meteotsunamis occur during the month of April, May and the first half of June. The meteotsunamis are generated in the continental shelf break outside New Jersey, during the exit into the ocean of **Derechos**. These windstorms occur during the spring and generated an extensive band of winds that exceed the 58 MPH and gusts of up to 75 MPH. The Derecho moves at 47 MPH from East to West. When the Derecho exits to the sea, it begins to impart energy to the wave, and a few minutes after the wave emerges from the shelf break, it can cross 1478 miles of the Atlantic Ocean in 3.25 hours, to reach the coasts of Puerto Rico. The speed of the meteotsunami can reach 455 MPH, but on average is 427 ± 24 MPH. Below we show a table with the transatlantic meteotsunamis reported by the station of 9759938/CO-OPS located west of Mona.

Meteotsunami arrival times, heights and speeds. (Ocean Physics Education, Inc., 2014)			
Gauge	Start Meteotsunami	$\Delta x / \Delta t$ (MPH)	Height (cm)
Mona Island	5/14/2010 12:24	397.80	6.0
Mona Island	4/10/2013 13:06	422.43	12.0
Mona Island	4/11/2013 8:11	432.73	15.2
Mona Island	6/13/2013 20:19	455.31	12.0
Average		427.07	
Standard Deviation		23.86	

Speed and height of the transatlantic meteotsunamis detected in Mona Island.

The **Calendar of ocean physical phenomena** tries to capture the annual cycle of various phenomena that are unknown to the majority of the inhabitants of Puerto Rico. Given that we live on an island, it is important to know the oceanic phenomena that affect us and when they occur.

References

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[Current Applications for an Array of Water Level Gauge Stations: New Discoveries in the Seiche Band and the Meteorological-Oceanic Band](#). PDF

[Current Applications for an Array of Water Level Gauge Stations: New Discoveries in the Seiche Band and Meteorological-Oceanic Band](#) (pptx file)

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