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CO_2 flux behavior in the *maritorium* of San Andres Islands on 2019

Comportamiento del flux de CO2 en el maritorio de san Andrés Islas en 2019

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ABSTRACT

This document estimated the behavior of the CO2 flux in the San Andrés Islas maritime for the first half of 2019. This behavior was established based on the thermodynamic relationship between the sea surface temperature, the partial pressures of CO2 in the atmosphere, and the water column, this from data derived from remote sensors. The satellite data were derived from the MODIS aqua sensors and the MERRA model for sea surface temperature and wind speed respectively. Satellite images were obtained from NASA databases, subsequently processed and specialized in ArcGis 10.1. Finally, the behavior of the CO2 flux is shown for the San Andrés Islas maritime, finding that it does not tend to capture CO2, so acidification processes are discarded for the selected study period.

Keywords: CO2 flux, sea surface temperature, acidification, maritime.

RESUMEN

En el presente documento se estimó el comportamiento del flux de CO2 en el maritorio de San Andrés Islas para el primer semestre de 2019. Dicho comportamiento se estableció a partir de la relación termodinámica entre la temperatura superficial del mar, las presiones parciales del CO2 en la atmosfera y la columna de agua, esto a a partir de datos derivados de sensores remotos. Los datos satelitales fueron derivados de los sensores MODIS aqua y el modelo MERRA para la temperatura superficial del mar y la velocidad del viento respectivamente. Las imágenes satelitales se obtuvieron a partir de las bases de datos de la NASA, posteriormente procesadas y especializadas en ArcGis 10.1. Finalmente, se muestra el comportamiento del flux de CO2 para el maritorio de San Andrés Islas, encontrando que este no tiene una tendencia a la captura de CO2, por lo cual se descartan procesos de acidificación para el periodo de estudio seleccionado.

Palabras clave: Flux de CO2, temperatura superficial del mar, acidificación, maritorio.

Introduction

The anthropogenic CO2 is emitted in an approximate amount of 35,000 million [1] tons each year, mainly due to the combustion of fossil fuels such as coal, oil and gas. This chemical species has attracted the attention of scientists around the world in recent years because a correlation has been observed between the proportional increase in global temperature [2] and, the concentration of CO2 in the atmosphere [3], [4], which is why it has been attributed as the main precursor to the phenomenon of climate change [5].

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In this sense, several investigations show the effects of CO2 on the atmosphere, climate and its consequent effects on some strategic ecosystems [6], [7], since around 46% of CO2 emitted (approximately 16,000 tons/year) [8] remain in the atmosphere for several centuries, there being no consensus around their residence time; What is well known is the proportion of the remaining CO2: 54% [9] is absorbed in the continental and marine ecosystems [8] - [10], the highest proportion being that ending in the oceans, which is estimated between 30 and 40% of the total of the emitted CO2 [11], [12].

Therefore, understanding the behavior of CO2 in the Colombian maritime is essential for the conception of conservation strategies and public policies [13], [14] that allow the safeguarding of marine ecosystems, especially coral reefs [15]. This need is evident when reviewing environmental regulations in Colombia, where there is a gap around the mechanisms for monitoring and mitigating acidification by CO2 in the national maritime.

That is why this article aims to show the behavior of CO2 in one of the main areas of coral reef coverage, San Andres Islands, which is located in the Seaflower Biosphere Reserve, and which houses 3% of the biodiversity of coral species and 33% of fish species, being one of the most diverse ecosystems in Colombia**.**

Materials and methods

Study area

The San Andres Islands Archipelago is located in the transition zone between the humid and dry tropics (12-16 degrees' latitude N. and 78-82 degrees' latitude O.). Specifically, the island of San Andrés is 12.8 km long and 3 to 5 km wide, housing a diversity of marine ecosystems, the most relevant being coral reefs, prairie beds, sandy shorelines and, mangroves (16). The study area is shown in Figure I.

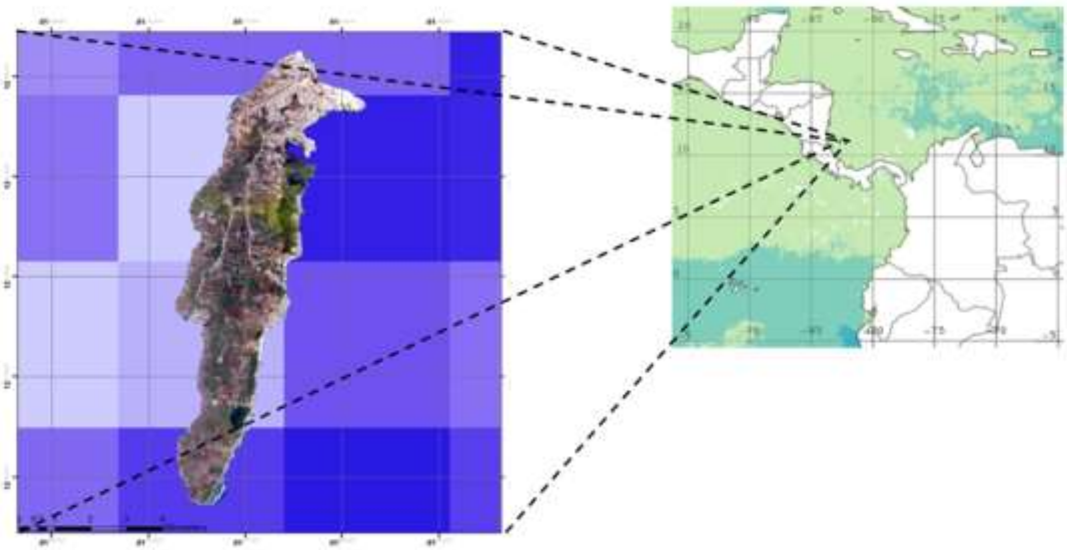

Figure I. Study area. San Andrés Islas.
Source: Authors, 2019.

The CO_2 flux is conditioned by the thermodynamic relationships between the solubility of CO_2 in seawater, the salinity of the environment, the differential of partial pressures of CO_2 in the atmosphere and in the marine environment, and wind speed [17]. Among this group of variables, the action of the wind allows the interaction between the CO_2 present in the atmosphere and the surface of some water, due to the action of the waves [18]. In this sense, the behavior of the CO_2 flux [19] for the study area is defined from the expression (Equation 1).

$$FCO_2 = kS(pCO_{2a} - pCO_{2A}) \quad (1)$$

Where the CO_2 flux (FCO_2) is expressed in *m*mol /m^2/day. Where pCO_{2a} is the partial pressure of CO_2 in the sea, pCO_{2A} the partial pressure of CO_2 in the atmosphere, S is the solubility of the gas and k is the rate of gas transfer [20].

It is necessary to indicate that the CO_2 flux values obtained through the previous one are negative when the ocean captures CO_2 and therefore is a sink of this, and they become positive when the study area emits CO_2 product of ocean dynamics [21].

Due to the logistical difficulty related to taking the in situ data of the oceanographic variables described in equation 1, each variable was decomposed into a set of physicochemical factors that can be determined from measurements made with remote perception [22].

In this way it has to be that k is a function of the sea surface temperature [23] according to the following expression (Equation 2):

$$k = cU_{10m}^{b}\left(\frac{Sc}{660}\right)^{-1/2} \qquad (2)$$

Where U_{10} is the wind speed at 10 m/s, Sc is the Schmidt number, which is a function of the SST, and the coefficient c and b, which are empirically obtained values.

The transfer speed of a gas, in this case CO_2, can be estimated by the relationship between the wind speed and its influence on the transfer constant (k). In this way, it is possible to assume that k is proportional to Sc, which can be obtained from equation 3.

$$Sc = A - B * SST + C * SST^2 D * SST^2 \qquad (3)$$

Thus, a third-order polynomial equation is established [24], which is based on the close dependence of Schmidt's number on sea surface temperature (SST) [25] for various gases present in the environment, and their behavior in fresh and marine water [26]. whose empirical coefficients are shown in table I.

Table I. Empirical coefficients for the Smidt equation

Gas	***A***	***B***	***C***	***D***
O_2	1953,4	128	3,9918	0,050091
CH_4	2039,2	120,31	3,4209	0,040437
CO_2	2073,1	125,62	3,6276	0,043219

Source: adapted from: [26]

On the other hand, the second variable to consider is S, which depends mainly on temperature, pressure and salinity. According to the above, the variation in the solubility of CO_2 is relatively low in relation to salinity, since this tends to be constant, while the variation in solubility is more influenced by the sea surface temperature [27], Therefore, the solubility of studies based on an adaptation of Henry's law and the Bunsen solubility coefficients [26], [28] were used, whose values can be seen in Table II:

Finally, the differential between the partial pressures of CO_2 on the sea surface and the atmosphere should be established, for which it is first proposed to calculate pCO_2 (expressed in µatm) in the water from the SST [29] (Equation 4).

$$ln[pCO_{2\,a}(10°C)] = A + B(SST) + C(SST)^2 + D \qquad (4)$$

Where: A = 6.030; B = -0.06076; C = 0.0007021; D = 0.001655

Table II. Relationship between CO_2 solubility in the marine environment and depth

Depth (m)	Temperature (°C)	Concentration (*K*mol/m^3)	Status CO_2
0	20	0,033	Gas bubbles
100	20	0,349	Gas bubbles
200	19,5	0,663	Gas bubbles
300	18,5	0,965	Gas bubbles
400	13,5	1,412	Gas bubbles

Source of consultation: Adapted from: [29]

In this sense, pCO_2 (expressed in µatm) will be assumed as constant (350.0 µatm) due to the low variability of the partial pressure of CO_2 [30].

Sea surface temperature (SST) data was downloaded from the Moderate-resolution Imaging Spectroradiometer (MODIS-AQUA) sensor [31] available at http://oceancolor.gsfc.nasa.gov/, with a spatial resolution of 4 km and a daily temporary resolution.

On the other hand, wind speed data were obtained from The Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2), a re-analysis of atmospheric data estimated by NASA with the Goddard Earth model Observing System Model, Version 5 (GEOS-5), where georeferenced wind speed information is obtained with a monthly temporal resolution and 1/8 degrees of spatial resolution, available from January 1980 to the present, available at The GES- DISC Interactive Online Visualization and Analysis Infrastructure (Giovanni) (https://giovanni.gsfc.nasa.gov/giovanni/), which processes climatological and oceanographic data [32] obtained from remote sensors administered by NASA.

Finally, with the purpose of calculating CO_2 for the San Andrés Islas maritime, 11 points of strategic importance were taken for tourism and fishing activities, and three control points (C), distributed in the coral reef of the Island of San Andres The geographical location of these points is shown in table III.

Table III. Geographical points of CO_2 interpolation

Stations	Latitude Y	Longitude X
German Point	12.600.177	-81.703.175
Pleasant Point	12.582.123	-81.682.857
San Andres Bay	12.569.665	-81.691.715
Old Point	12.554.411	-81.696.666
Genie Bay	12.535.598	-81.694.840
Sound Bay	12.513.976	-81.703.172
South End	12.473.041	-81.730.520
Cove Seaside	12.521.360	-81.738.980
Sukey Bay	12.537.376	-81.742.630
Evans Point	12.557.715	-81.741.329
Low Bight	12.576.530	-81.728.567
C1	12.599.414	-81.681.677
C2	12.570.436	-81.672.815
C3	12.549.326	-81.676.473

Source: Authors, 2019.

Results and Discussion

The behavior of the SST obtained from the MODIS sensor data is shown in Figure II.

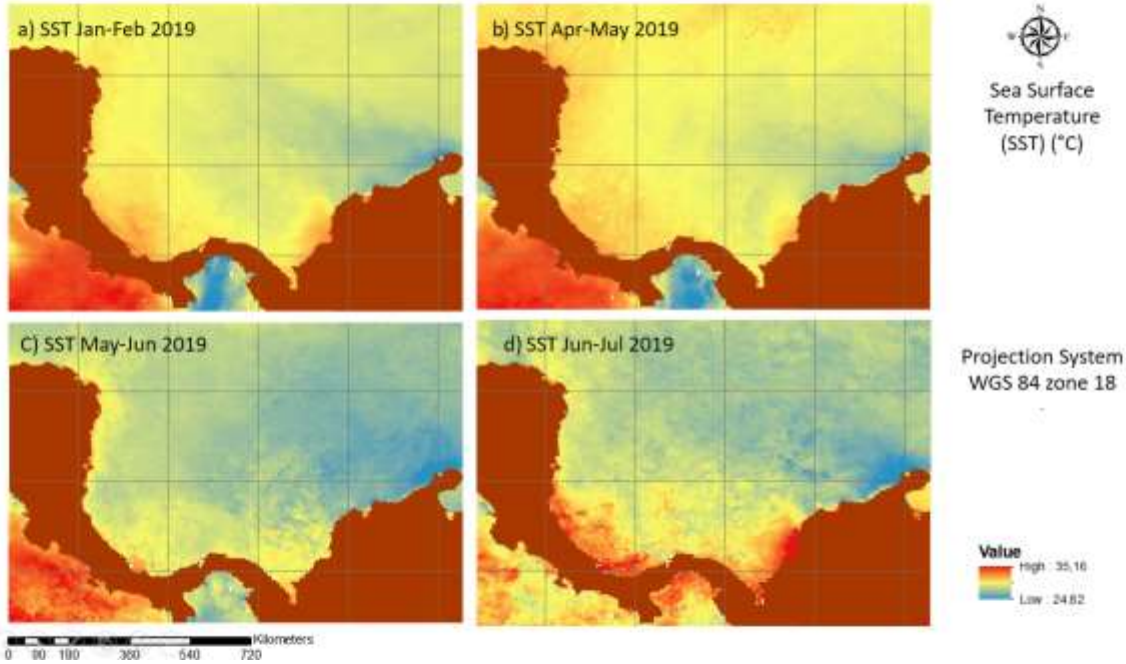

Figure II. Sea surface temperature (° C) for the Colombian Caribbean between January and June 2019.
Source: Authors, 2019.

Figure II shows the dynamics of SST between January and June 2019, showing oscillations between 24 and 31 ° C for this time of year. It can be seen on the maps that the area where San Andrés Islas is located presented an SST of ± 24.5 ° C, with March to April showing average values of 32 and 33 ° C, which is shown in figure III.

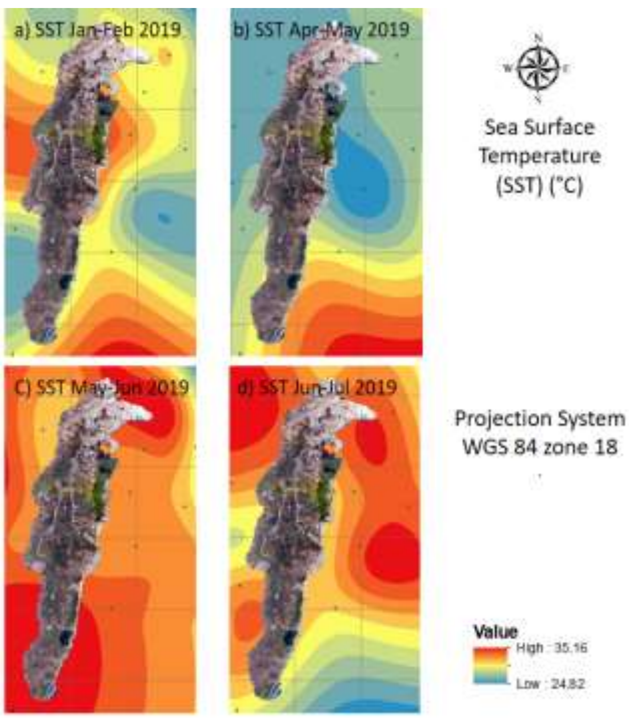

Figure III. Sea surface temperature (° C) for the San Andrés Islas maritime between January and June 2019.
Source: Authors, 2019.

In the case of the study area, that is, the San Andrés Islas maritime, it was observed that the surface temperature ranges of the sea did not showconsiderable variation. The oscillation of the surface temperature of the sea oscillated between 24 and 35 ° C, being the months of April and May the ones that showed higher temperatures, which conditions the CO_2 flux to the marine environment.

On the other hand, Figure IV shows the wind speed map (U_{10}) obtained from the re-analysis with the MERRA model for the Colombian Caribbean.

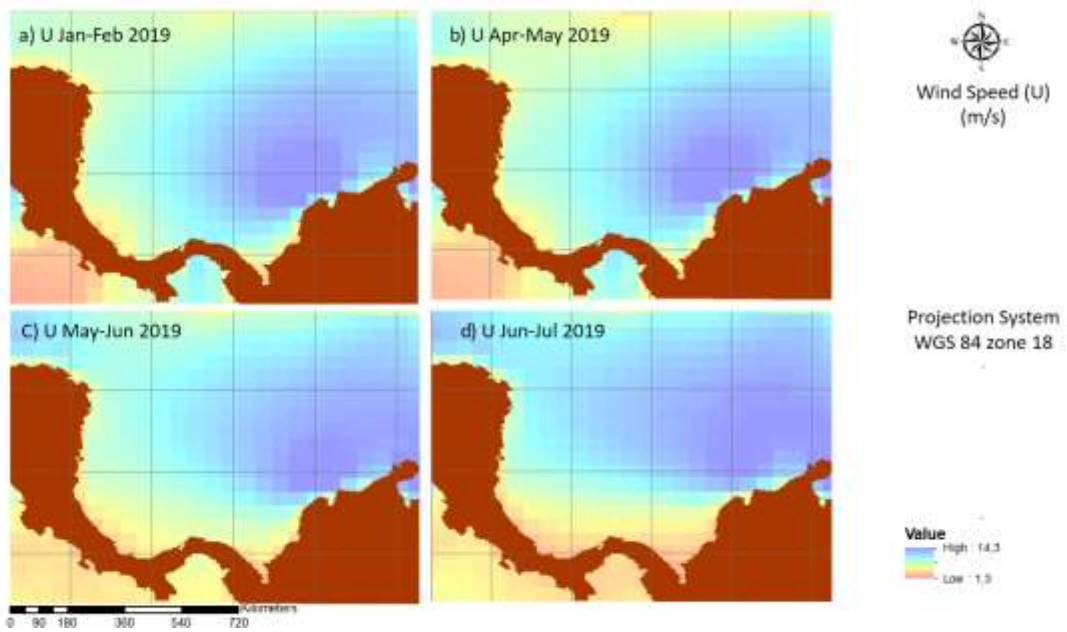

Figure IV. Wind speed (U) over the sea surface for the Colombian Caribbean between January and June 2019.
Source: Authors, 2019.

In the same way, in figure V, the wind speed map (U_{10}) obtained from the re-analysis with the MERRA model for the sanctuary of San Andres Islands between January and June 2019 is shown.

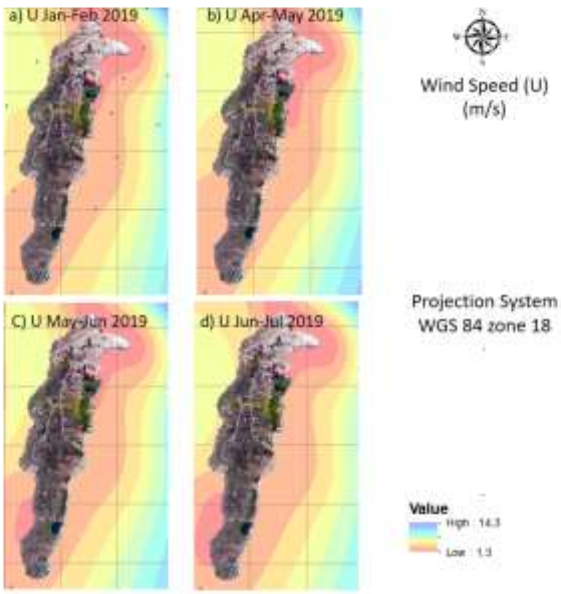

Figure V. Wind speed (U) over the surface of the San Andrés Islas maritime between January and June 2019.
Source: Authors, 2019.

From ArcGis 10.3, the satellite image information for the SST and *U* variables was extracted, and with the georeferenced values for the months between January and June 2019, CO_2 flux calculations were made using equation 1 The georeferenced data of the CO_2 flux is shown in Figure VI..

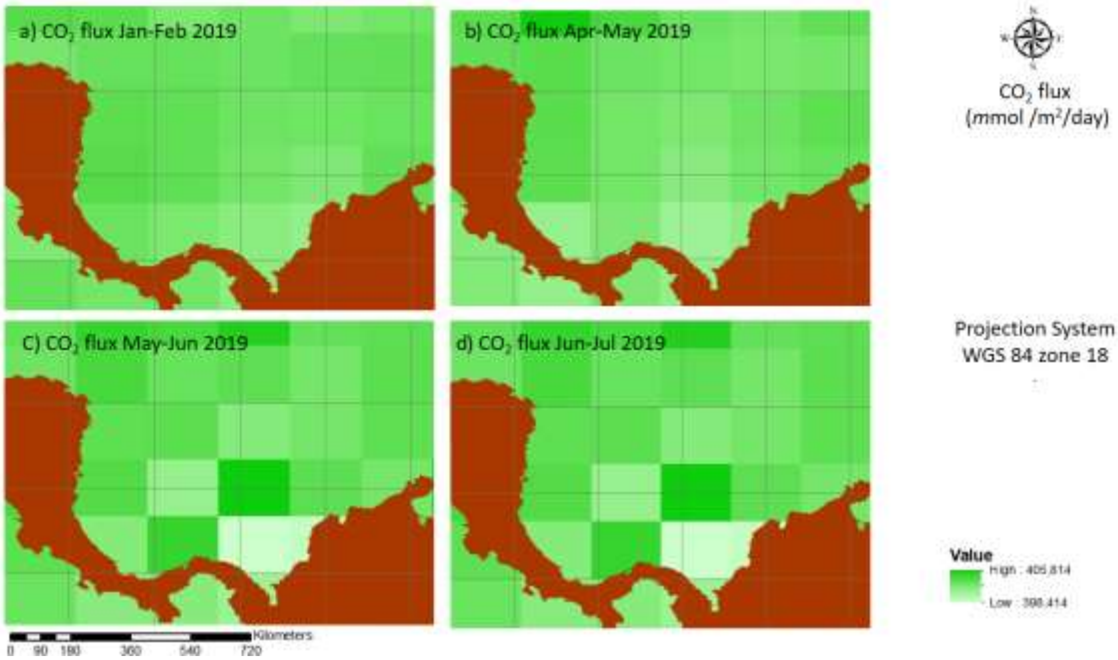

Figure VI. CO_2 flux (*m*mol / m^2 / day) over the sea surface for the Colombian Caribbean between January and June 2019.
Source: Authors, 2019.

Figure VI shows that the Colombian Caribbean is not a considerable CO_2 sink, at least for the selected period of time. In this sense, the average values of CO_2 flux were in the range between 398 and 495ppm in the ocean-atmosphere direction, which would be showing that the occurrence of severe acidification phenomena for the Colombian Caribbean seafaring is despised. Despite this, it is necessary to carry out validations of the satellite data, as this would provide greater reliability to CO_2 determinations through remote sensing techniques.

For the specific case of the San Andrés Islas maritime, little variability of the CO_2 flux was observed, based on the average estimate derived from equation 1, is shown in table IV.

Table IV. Estimates of CO_2 flux from wind and sea surface temperature data

Estaciones	SST Ene_Feb	SST Mar_Abr	SST Abr_May	SST_May-Jun
German Point	26,5	25,7	27,8	28,5
Pleasant Point	27,7	27	28,3	29
San Andres Bay	28,4	26,4	28,4	27,5
Old Point	27,3	28,5	26,7	26,8
Genie Bay	28	24,4	24,4	27
Sound Bay	26,3	26,3	32,3	28
South End	25	27,8	34,1	29
Cove Seaside	27	24,3	28,9	28,5
Sukey Bay	25,4	28,4	27,9	27,5
Evans Point	27,3	29,3	28	28,5
Low Bight	28,3	26,3	27,4	26
C1	26,7	24	30,1	24,7
C2	27	24,7	28,8	25

C3	27,9	25,5	29,5	26
Estaciones	***Wind* Ene_Feb**	***WindMar*_Abr**	***WindAbr*_May**	***Wind*_May-Jun**
German Point	2,5	3	3,5	4
Pleasant Point	3	3,5	4	4,5
San Andres Bay	3,5	4	4,5	5
Old Point	4	4,5	5	5,5
Genie Bay	4,5	5	5,5	6
Sound Bay	5	5,5	6	6,5
South End	5	5,5	6	6,5
Cove Seaside	5,5	5	5,5	6
Sukey Bay	8	8,5	9	9,5
Evans Point	8,5	9	9,5	10
Low Bight	9	9,5	10	10,5
C1	14	14,5	15	15,5
C2	13,5	13	12	12,5
C3	13	12	12,5	13
Estaciones	***CO2* Ene_Feb**	***CO2* Mar_Abr**	***CO2* Abr_May**	***CO2* _May-Jun**
German Point	390	385	380	400
Pleasant Point	350	345	340	360
San Andres Bay	365	360	355	375
Old Point	370	365	360	380
Genie Bay	380	375	370	390
Sound Bay	387	382	377	397
South End	390	385	380	400
Cove Seaside	405	400	395	415
Sukey Bay	400	395	390	410
Evans Point	395	390	385	405
Low Bight	380	375	370	390
C1	390	385	380	400
C2	385	380	375	395
C3	380	375	370	390

Source: Authors, 2019.

From the values of sea surface temperature and wind speed for the sampling points, the interpolation of the CO_2 flux was obtained, whose ranges are shown in Figure VII.

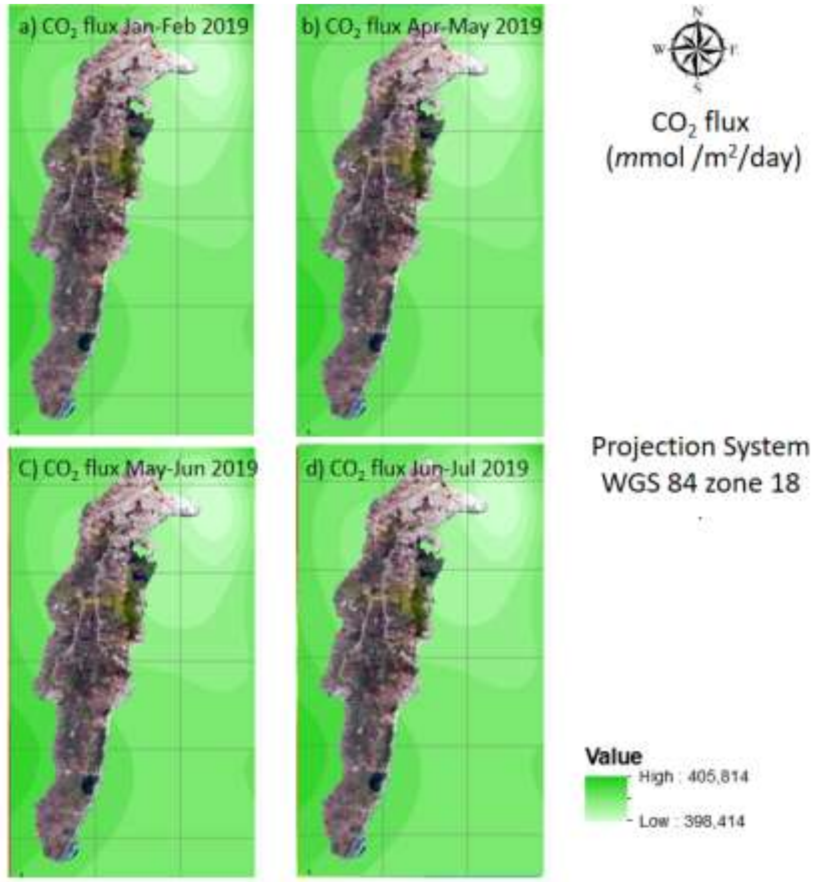

Figure VII. CO_2 flux (*m*mol / m^2 / day) over the sea surface for the San Andres Islands maritime between January and June 2019

Source: Authors, 2019.

Conclusions

From the estimation of the CO_2 flux for the San Andrés Islas maritime, it can be said that it does not assume a significant sink trend, since the values for the selected study period were always negative, whose oscillation was between 390 and 405 *m*mol / m^2 / day approximately, discarding considerable acidification processes per CO_2 account.

This tendency in the behavior of the CO_2 flow positively favors the survival of the coral structures present in the Seaflower reserve, since there is no considerable threat due to the alteration in the process of bioaccumulation of calcium carbonate, the main precursor to coral reefs.

On the other hand, the impact of the CO_2 flux on the abundance and distribution of ichthyo fauna is uncertain, mainly of those species of commercial interest for the San Andres Islands root communities.
Finally, it is necessary to strengthen the research processes around the behavior of CO_2 and its impact on the marine and coastal ecosystems of the Colombian Caribbean maritime.

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