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Air Pollution in the Gulf of Mexico

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Abstract

An integral analysis of Air Pollution in the Gulf of Mexico was made considering pollutants emissions assessment and diagnosis; air pollution monitoring; and modeling of air pollution dispersion. Combustion sources considered in this work were: thermoelectric power plants and open flares; and pollutants considered were sulfur dioxide, nitrogen dioxides, particulate matter (PM_{10} and $PM_{2.5}$), Total suspended particles (TSP) and carbon monoxide (CO). This study made evident a lack of more recent information and a homogenization in emissions factors in order to know the conditions of air pollution in the Gulf of Mexico in a more reliable way.

Keywords

Air Pollution, Dispersion Models, Air Pollution Monitoring, Gulf of Mexico

1. Introduction

In past years, a few efforts were made to diagnosis/assess air pollution from main sources in the Gulf of Mexico. Recently, some researchers have provided more information to help to understand an old pollution problem [1]-[11]. Nevertheless, there is not a systematic set of information that can allow an integral analysis of Air Pollution in the Gulf of Mexico.

In this paper, we present the results of our review and attempt to make an integral analysis covering three main topics:

- Pollutants Emissions Assessment and Diagnosis.
- Air Pollution Monitoring.
- Modeling of Air Pollution Dispersion.

It is important to mention that pollution information is scarce and that some of it is not public. Pollutants referred in this work are those mainly emitted by combustion sources such as thermoelectric power plants and open flares: sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter fraction 10 µm (PM_{10}), particulate

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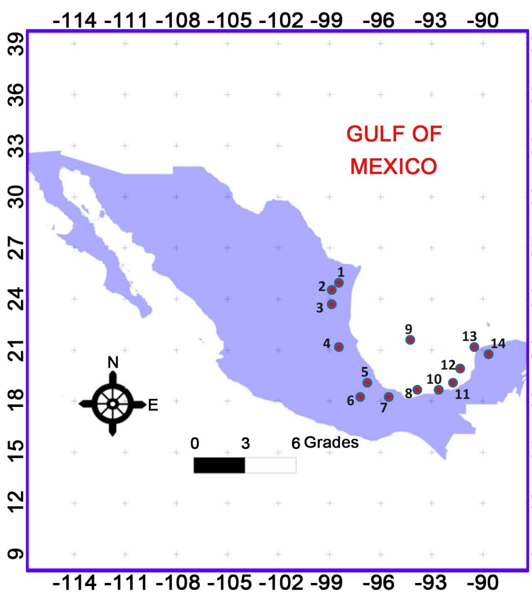
matter fraction 2.5 µm ($PM_{2.5}$), Total Suspended particles (TSP) and carbon monoxide (CO). There is also some information about Non-Methane Hydrocarbons (NMHC), Volatile Organic Compounds (VOC) and Total Organic Compounds (TOC) that might be emitted in some petroleum storage and transport processes and in some extent in combustion process.

2. Study Area

Currently, the states bordering the Gulf of Mexico have more than 17×10^6 inhabitants, contributing with almost 15% of the total population in Mexico. More than 30% of this population is concentrated within 9 major cities with more than 220,000 inhabitants, these urban centers are Mérida, Yucatán; Cancun, Quintana Roo; Reynosa, Tamaulipas; Matamoros, Tamaulipas; Veracruz, Veracruz; Villahermosa, Tabasco; Tampico, Tamaulipas; Coatzacoalcos, Veracruz; and Campeche, Campeche. Oil industry, tourism, maritime transport, livestock farming, and agriculture are the main economical activities in the coastal zone of the Gulf of Mexico, contributing with approximately 16% of the gross domestic product (GDP). The region of the Gulf of Mexico produces daily 2.5×10^6 petroleum barrels (98% of the total production in the country) and it has 75% of the total installed capacity to obtain and process this mineral resource. The main activities in Tamaulipas State are port activities (importation and exportation) and fish production. In the case of Veracruz, this state ranks first in petrochemical production, electricity production and livestock farming, other important activities in Veracruz are sugar cane production and maritime transport. On the other hand, Tabasco and Campeche States have increased their contribution to GDP due to oil and gas industry, other activities in this region are fishery and cattle raising. Finally, in the case of Quintana Roo, its economy is mainly based on tourism industry.

Information found for this work covers these major cities which are located along the coast of Gulf of Mexico, this region is displayed in **Figure 1**.

During the period 1995-2000, the National Institute of Ecology (INE) with the technical and economical support from the Environment Protection Agency of the United States (US EPA) developed and applied for first time in Mexico an appropriate methodology for the particular conditions of Mexico to estimate emissions inventory at a national scale. In addition, the main metropolitan zones in the country (Valley of Mexico, Guadalajara, Monterrey and Toluca), the main border towns (Mexicali, Tijuana and Ciudad Juarez), and some cities such as Salamanca, Guanajuato and Puebla, have developed disaggregated inventories as part of the programs to improve the air quality in these regions, unfortunately, these emissions inventories have differences in the inventories characteristics, activity data and estimation methods with respect to those used in the National Emissions



Sites Location		
1	Altamira	Tamaulipas
2	Ciudad Madero	Tamaulipas
3	Tampico	Tamaulipas
4	Tuxpan	Veracruz
5	Veracruz	Veracruz
6	Boca del Río	Veracruz
7	Coatzacoalcos	Veracruz
8	Paraíso	Tabasco
9	Sound of Campeche	Gulf of Mexico
10	Carmen	Campeche
11	Champotón	Campeche
12	Campeche	Campeche
13	Progreso	Yucatán
14	Dzilam González	Yucatán

Figure 1. Main cities of Mexico which are located in the Gulf of Mexico.

Inventory of Mexico (INEM) [1]. Therefore, it has not been possible to integrate these results to the National Inventory, making impossible any comparison between them.

The results of the National Emissions Inventory of Mexico for the states located along the coast of the Gulf of Mexico are presented in **Table 1** [2]. From this, it can be observed that activities linked to the petroleum industry, the coastal zone of Tabasco, and the south region of Campeche and Veracruz states, show the highest concentration of air pollution sources, contributing with 227, 197 and 32 $Gg \cdot yr^{-1}$, respectively [3]. The main pollutants emitted from these sources are sulfur oxides (SO_x), nitrogen oxides (NO_x) and volatile organic compounds (VOC's), which constitute approximately 60%, 12% and 8% of the total emissions, respectively. The main fixed sources of these pollutants are: the industrial sector in the border of Tamaulipas with Texas [4]; port and industrial zone in Altamira [5]; oil fired power plants in Tuxpan [6] [7]; chemical and petrochemical industry in Coatzacoalcos [5]; Dos Bocas Maritime Terminal (DBMT) in Paraíso, Tabasco [8]; offshore oil and gas production area in the Sound of Campeche [9] [10], and gas recompression station in Atasta, Campeche [8] [11].

3. Pollutants Emissions Assessment and Diagnosis

In 1999, Muriel [12] [13] carried out the first air pollution emission inventory (EI) in the Sound of Campeche [12] [13]. This endeavor covered only some offshore platforms: Abkatun-A, Abkatun-D, Abkatun-N, Pool-A and Dos Bocas Maritime Terminal (DBMT), located in the southwest operations of oil industry in the Sound of Campeche. From the main results it can be concluded that none of the emitted pollutants was above maximum allowed level in the Mexican Regulatory. In the EI for this work were reported 1.29 $KTon \cdot yr^{-1}$ of NO_x and 18.96 $KTon \cdot yr^{-1}$ of SO_2. These estimations only considered southwest operations of oil industry, which was less than half of total production in 1999 in the Sound of Campeche, they are more in agreement with 16.01 $KTon \cdot yr^{-1}$ and 51.83 $KTon \cdot yr^{-1}$, which are for all the region [14] [15].

An EIof all offshore operations for the exploration and production of petroleum by the Mexican Oil Industry, in the Sound of Campeche, was performed by Villaseñorr *et al.* [8], where primary pollutants emissions were obtained by means of emission factors reported in the literature. They described results for the 1999 period, including NO_x, SO_2, H_2S, CO, NMHC and PM_{10}. They claim to be the first emission inventory for the Sound of Campeche region, but it showed some differences with other EI for the same region [9] [14]-[16], SO_2 is in good agreement, but NO_x seems to be overestimatedand H_2S, 1.1 $KTon \cdot yr^{-1}$, is much lower than 9.10 $KTon \cdot yr^{-1}$ value reported a few years later [8], even though this reported value is an average for part of 2001 year.They argue that previous work did not consider combustion efficiency due to local meteorological conditions [8], although they also employed literature emission factors as well. Gas consumption for November 2000 to November 2001 period was used for this study as well as meteorological information from the same area (see **Table 2**).

The most recent information available was published by SEMARNAT [17]. This report covers all Mexican Republic, but it has not sufficient detail to make a straight comparison with some other EI [8]-[18]. Still some important information can be retrieved. For instance, total pollutants emissions in Gulf of Mexico produced by Mexico's coastal places amounts 1,973,096.32 $KTon \cdot yr^{-1}$. Total major contributions are for SO_2 (725,616.8 KTon yr^{-1}) followed by VOC and CO (518,492.05 and 497,914.88 $KTon \cdot yr^{-1}$, respectively) (see **Figure 2**).

Table 1. Emissions inventory of atmospheric pollutants in the states located along the coast of the Gulf of Mexico [1].

State	Emissions ($Gg \cdot yr^{-1}$)					
	CO	NO_x	SO_2	$PM_{2.5}$	PM_{10}	VOC's
Tamaulipas	11.74	15.22	151.9	4.26	6.29	26.8
Veracruz	20.1	46.8	336.71	49.93	78.15	40.59
Tabasco	22.98	8.99	145.45	10.06	18.21	21.88
Campeche	13.86	23.04	150.89	2.54	3.76	3.1
Yucatán	0.32	3.32	27.94	1.51	1.87	1.7
Quintana Roo	0.72	1.66	1.02	0.47	0.94	0.63

Table 2. Air pollutants emissions in the Gulf of Mexico (kton·yr^{-1}).

Place	CO	CO_2	H_2S	NH_3	NMHC	NO_x	$PM_{2.5}$	PM_{10}	SO_2	Soot	TOC	TSP	VOC	Reference
Altamira Tamaulipas	-	6367.9	-	-	-	11.85	-	-	116.12	-	-	-	-	[18]
Altamira Tamaulipas	-	6201.2	-	-	-	12.03	-	-	110.89	-	-	-	-	[18]
Altamira Tamaulipas	16,276.37	-	-	1413.8	-	13,280.5	3756.0	4646.4	18,933.3	336.8	-	-	28,831.7	[17]
Boca del Río Veracruz	45,039.55	-	-	344.99	-	7062.93	85.46	98.61	59.11	14.39	-	-	6286.25	[17]
Campeche Campeche	-	938.23	-	-	-	1.18	-	-	20.91	-	-	-	-	[18]
Campeche Campeche	-	796.03	-	-	-	1.01	-	-	17.74	-	-	-	-	[18]
Campeche Campeche	28,291.0	-	-	1330.3	-	15,983.3	1655.1	2079.1	19,266.7	171.7	-	-	53,090.9	[17]
Campeche Campeche	31,354.8	-	-	1303.2	-	50,024.3	3502.8	3764.1	556.129	280.2	-	-	133,602.2	[17]
Champotón Campeche	14,370.34	-	-	1191.9	-	13,022.3	2083.9	2743.5	611.01	331.5	-	-	201,971.1	[17]
Cd Madero Tamaulipas	67,535.96	-	-	1695.8	-	5856.60	1637.4	2676.0	28,420.7	39.09	-	-	15,401.4	[17]
Coatzacoalcos Veracruz	70,481.07	-	-	743.35	-	13,002.44	559.51	603.31	1293.91	70.84	-	-	15,888.91	[17]
Dzilam Gonzalez Yucatán	588.61	-	-	112.07	-	1768.38	69.34	77.85	1.29	9.48	-	-	5624.57	[17]
Paraíso Tabasco	6608.49	-	-	206.50	-	6834.97	566.33	607.68	362.74	104.2	-	-	6328.62	[17]
Progreso Yucatán	3211.07	-	-	190.31	-	760.19	233.85	258.19	797.89	45.55	-	-	5494.15	[17]
Sound of Campeche	145.51	-	1.10	-	276.84	41.16	-	14.43	181.00	-	-	-	-	[8]
Sound of Campeche	146.42	-	14.3	-	277.59	182.69	-	-	185.91	-	-	14.7	-	[9]
Sound of Campeche	5.09	340.61	9.10	-	-	0.94	-	-	4.07	-	447.6	0.06	-	[10]
Sound of Campeche	-	6200.00	-	-	-	15.53	-	-	83.28	-	3.78	0.65	0.24	[15]
Sound of Campeche	-	9050.00	-	-	-	9.56	-	-	199.23	-	0.00	0.44	5.54	[16]
Sound of Campeche	-	6100.00	-	-	-	16.01	-	-	51.83	-	2.38	0.40	1.31	[14]
Tampico Tamaulipas	18,473.82	-	-	354.15	-	3617.60	246.86	266.02	970.57	59.21	-	-	6058.26	[17]
Tuxpan Veracruz	-	-	-	-	-	22.00	-	17.00	257.00	-	-	-	-	[26]
Tuxpan Veracruz	-	12,391.31	-	-	-	20.67	-	-	261.04	-	-	-	-	[18]
Tuxpan Veracruz	-	12,524.98	-	-	-	20.73	-	-	266.20	-	-	-	-	[18]
Tuxpan Veracruz	40,173.42	-	-	1235.7	-	21,955.5	6,013.2	7979.4	97,075.4	476.7	-	-	15,398.5	[17]
Veracruz Veracruz	155,510.2	-	-	1223.7	-	17,038.1	582.59	657.60	1694.19	128.5	-	-	24,515.2	[17]

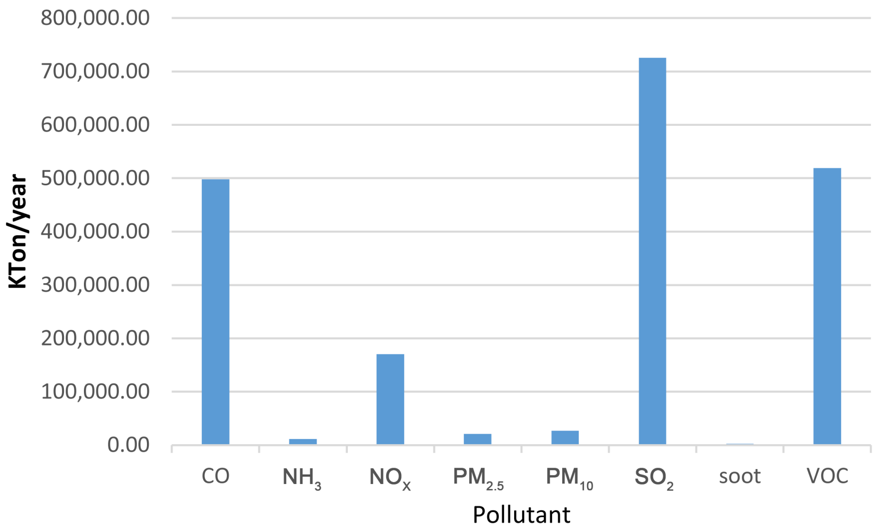


Figure 2. Total pollutants emission (Kton·yr^{-1}) in the Gulf of Mexico [17].

Distribution of contributions of different cities to main pollutants, considered in **Table 2** and **Figure 2** are illustrated in **Figure 3**. Cities of Coatzacoalcos, Ciudad Madero and Veracruz are the bigger contributors to CO (>67,535 KTon·yr^{-1}). NO_x emissions are leaded by Ciudad del Carmen (>37,501 KTon·yr^{-1}), this is probably because of oil production presence in this area. Regarding SO_2 emissions, Ciudad del Carmen is the greatest producer compared to the rest (>450,000 KTon·yr^{-1}), again oil industry emission are included in this value. This fact is supported by the results reported by Cerón *et al.* [11] in a study about spatial and temporal distribution of N and S deposition fluxes in Ciudad del Carmen, where S and N deposition fluxes were high in comparison with critical load values reported for sensitive ecosystems in United States and European countries. In the other hand, $PM_{2.5}$ and PM_{10} are mostly produced by industrial facilities in Tuxpan, where a big thermoelectric power plant is operating. VOC's show a strange behavior, while Ciudad del Carmen has the first place (>18,000 KTon·yr^{-1}), Champoton has the second place which is odd, because there is any industry. Regarding this, Cerón *et al.* [19] reported formaldehyde and acetaldehyde concentrations in air ambient higher than those reported for other authors in Mexico and other sites around the world. In addition, the results obtained during this study indicate that BTEX levels in Carmen City are comparable with those found in big polluted cities. However, it is necessary to assess the source-receptor relation by using models to estimate the contribution of regional and local emissions to the total levels of VOC's in this site.

In counterpart, to the previous EI works, there has been individual assessment works that have been accomplished in some places of oil industry in the Sound of Campeche. These works involved proper source measurements following standard procedures [20]-[25], including sources in some offshore complex and terrestrial petroleum facilities (Pol-A, "Inyección de Agua (Water Injection platform)", Abkatun-A, Abkatun-D, Akal-GC, Pol-Chucand DBMT), where measurements indicated that emission levels were under the maximum allowed by the environmental regulations.

Vijay *et al.* [18] estimated air pollution emissions from fossil fuel used in the electricity sector in Mexico. This work constitutes one of the few works regarding Thermoelectric Power Plants. Their results include Installed Fossil-fuel-based Generation Capacity and Estimated Emissions for CO_2, Hg, NOx, and SO_2 for Campeche, Tamaulipas, Veracruz and Yucatan (2001-2002). They point out that the use of emission factors is not necessarily the best way to estimate emissions; however, given the lack of any continuous emissions measurements or frequent stack measurements, it is the only feasible option. Even if we assume emission factors to result in good quality estimations, there are several other simplifications and assumptions made that further affect the precision of the estimations, like exact percentage fuel carbon and sulfur content, tangentially fired or normal fired or wall-fired boilers (see **Table 2**).

Mendoza *et al.* [9] give a partial EI with different values for different months of the year, which is not consistent with some other EI that are expressed on a year basis [8] [18]. They argue that variations are due to gas/oil relation changes together with oil production and meteorological conditions that affects combustion effi-

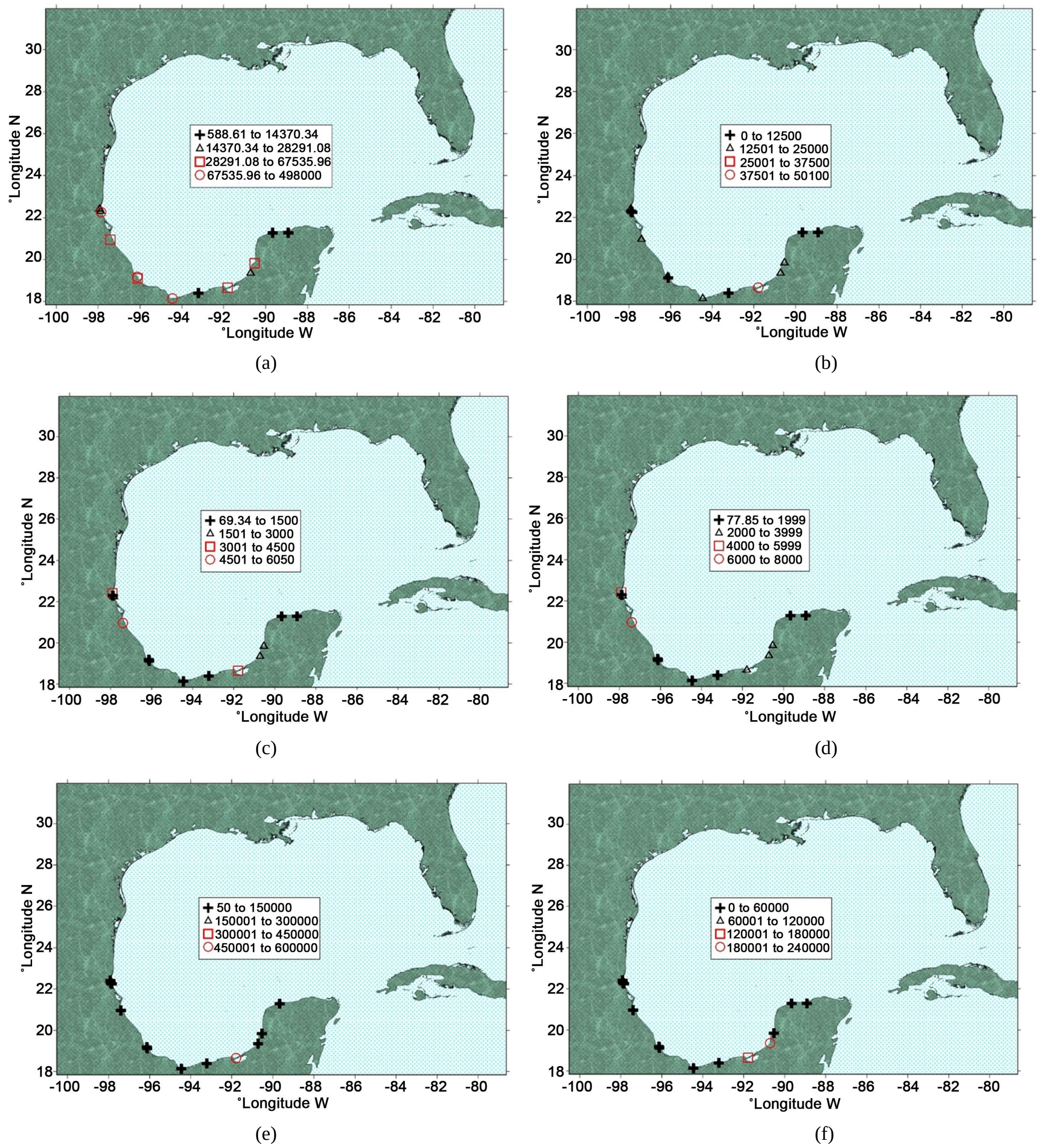


Figure 3. Pollutants emissions (KTon·yr^{-1}) in 2008. (a) CO; (b) NO_x; (c) $PM_{2.5}$; (d) PM_{10}; (e) PM_{10}; (f) VOC.

ciency, but they do not give a conclusive weight to each factor. Although their results are consistently lower than Villaseñor's, H_2S shows an unexpected higher value (see **Table 2**).

4. Air Pollution Monitoring

If pollutants emissions assessment and diagnosis in the Gulf of Mexico is an activity where there is not enough compromise from Mexican environmental authorities, there is still less involvement in Air Pollution Monitoring (APM). Existing studies are very few and APM information of oil production regions is not public.

A first APM study was registered in April 1990 and took place in the surroundings of Campeche's Thermal Power Plant (site number 12, see **Figure 1**) [27]. Three points were included and only SO_2 and PST were monitored by a short period of time. Obtained results are very preliminary and they have only an historical meaning (see **Tables 3-5**).

Table 3. SO_2 monitoring results in Lerma, Campeche [20].

Monitoring point	1	2	3
Q std ($l \cdot min^{-1}$)	0.395/0.397	0.580/0.572	0.598/0.592
V std (l)	511.6	777.65	982.90
C ($\mu g \cdot m^{-3}$)	N.D.	2.613	21.526
C (ppm)	N.D.	0.001	0.0082

Table 4. PST monitoring results in Lerma, Campeche [20].

Monitoring point	1	2	3
V (m^3)	928.19	914.18	1096.96
C ($\mu g \cdot m^{-3}$)	59.5	68.69	223.89

Table 5. Average PST concentration in the Gulf of Mexico [21].

Date	PST concentration ($\mu g \cdot m^{-3}$)	
	Day	Night
1986	18.4 ± 4.6	32.1 ± 9.0
September-October, 2002	15.6 ± 4.5	13.6 ± 4.8
November-December, 2002	16.4 ± 4.4	19.9 ± 5.0
September-October, 2003	23.6 ± 4.6	25.7 ± 5.5
May-Jun, 2004	34.6 ± 7.0	38.9 ± 8.1

Later on Sosa and colleagues [28], in the period 2002-2004, made PST measurements in the Gulf of Mexico]. Basically they measured for a two months period in each reported year, except in 2002 when they made it twice. In this work they also include values obtained previously [29] [30]. They show some statistics for their results, but it can be observed that PST concentrations are very low, as it should be expected for that region. Additionally monitoring periods are short and monitoring points are no source orientated.

During November 2007, the air quality was studied for a short period in three places around DBMT. The limited amount of time for these measurements does not allow doing any valid conclusion, even though standard methods were employed [30].

It is acknowledged that two Monitoring Network were installed in 1997, one in Atasta (a few kilometers from Ciudad del Carmen, Campeche) and other around DBMT (within the Paraíso, Tabasco municipality) [31]. Unfortunately DBMT's network does not exist anymore and Atasta's station has been working very intermittently. Further, information about air quality is not public and monitoring sites are not well positioned, therefore produced information is not quite about pollution produced by main sources in Atasta's region. This might be confirmed by a few of the available public information where it is confirmed that SO_2 in the 2003 period had a maximum % value in DBMT and Atasta of 8.5 and 14, respectively, with regard to maximum allowed level [31]. NO_2 showed a similar behavior. Atasta's information can be confirmed through an analysis of 1999-2005 monitoring information made on 2010 [30]. This analysis also concludes that all pollutants ambient concentrations are low.

According to National System of Air Quality Information (SINAICA), Tabasco is the only one state along the coast of the Gulf of Mexico which is registered in this system [32]. The rest of the states located along the coast of the Gulf of Mexico do not have automatic monitoring stations operating regularly. In the case of Veracruz, just this year, one mobile station began to operate in the city of Xalapa; whereas in Campeche State, one fixed station is operating since November 2014. Air quality monitoring in the state of Tabasco began in 1999, this network has also 4 manual stations collecting data of PM_{10} for 4 main cities in the state: Comalcalco, Cárdenas, Villahermosa and Tenosique. However, excepting PM_{10}, collected information from this network does not meet the established criteria for its inclusion in the SINAICA'S reports, therefore, this information is not available. In fact, the performance evaluation report [33] showed that the overall performance of this network is the minimum acceptable and requires a lot of attention. These equipments have never been subjected to audits, negatively impacting on their performance. Regarding to PM_{10} levels, in Cardenas, Villahermosa and Comalcalco cities during 2003 and 2004, PM_{10} concentrations exceeded 120 $\mu g \cdot m^{-3}$, whereas between 2005 and 2007, the maximum values of PM_{10} for these cities reached levels ranged between 60 to 120 $\mu g \cdot m^{-3}$. It could indicate that air quality in this region has been progressively improving over time; however, the available information is scarce and does not allow assessing the air quality in a reliable way. Therefore, it can be concluded that there is a general lack of information about air quality in the states of the Gulf of Mexico.

5. Modeling of Air Pollution Dispersion

Modeling of air pollution dispersion is an activity that has been done a few times form this region. One of this studies was done in Tuxpan Power Plant [26] [34], three others were done in the Sound of Campeche [8] [9] [12], one in DBMT [20] and one in Atasta Processing Center [35].

Making use of EI produced in 1997, for the oil industry operations in the Sound of Campeche [20], together with 1995 meteorological information of the same region [12] to feed Ocean and Coastal Dispersion Model (OCD) [36], the first air pollution dispersion exercise was accomplished in order to envisage if air pollution emissions from oil industry in the Sound of Campeche were impacting the environment, according to environmental regulations [12]. It might be discussed if the use of OCD is a good option, while there is some more powerful dispersion models e.g. AERMOD [37] [38], there are a few reasons to be considered. First, most of oil industry operations in the Sound of Campeche are offshore, so there are two scenarios at least: off shore and in shore operations. Second, off shore operations are far from main land, so pollutants will be under a big dilution process and free from obstacles, before reaching land. Third, advanced models need more meteorological information which is not available even at the present time. Fourth, in order to use advanced models, some meteorological information can be retrieved from available data bases and make some interpolation to get local met data. Nevertheless, this will be as imprecise or even more than employing a Gaussian model. Fifth, OCD is a straight line Gaussian model developed to determine the impact of offshore emissions from point, area or line sources on the air quality of coastal regions and incorporates overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline. Results for 1997 dispersion modeling are shown in **Figure 4** and **Figure 5**.

It is interesting to observe that this first approach reveals the no impact, on average, of southwest oil industry operations in the Sound of Campeche. This result make considered arguments, in previous paragraph to be stronger.

Lopez and collaborators studied health impacts from power plant emissions in Mexico [35]. They obtained ambient annual average concentrations for Tuxpan Power Plant during 2001 [31]. Main results for $PM_{2.5}$ and SO_2 are 0.12 and 3.09 $\mu g \cdot m^{-3}$, respectively. Air Quality Standards for $PM_{2.5}$ and SO_2 annual average are 15 and 79 $\mu g \cdot m^{-3}$. It is stated that Tuxpan is the largest power plant emitter of SO_2 in North America with emissions intensities approximately 50% greater than the Mexican average (4.5 times the US average) and $PM_{2.5}$ emissions are 10 times higher than the US average (38% times greater than Mexican average) due to lack of emissions controls and to the high-sulfur content of the "combustóleo". Even tough is obvious, that calculated ambient concentrations are much lower than Mexican quality standards.

Later on another pollution dispersion exercise at the Sound of Campeche was done by Villaseñor *et al.* in 1999 [8]. For this study they used CALMET [39] and CALPUFF [38] and included all sources from oil industry in the region. They results confirm the no impact or air pollution emission, consequently confirms previous result using OCD.

Another work using HYPACT [40] and RAMS [41] was done in the locality of Paraiso in Tabasco State [12]. For this effort surface meteorological information of 2005 was available. Upper meteorology was obtained from Veracruz, Mérida and Acapulco [42] and global meteorological data were obtained from the National Center for Environmental Prediction [37]. In order to do a more comprehensive modeling study, five meteorological scenarios were chosen:

1) February, 14-16,
2) April, 21-23,
3) June, 09-11,

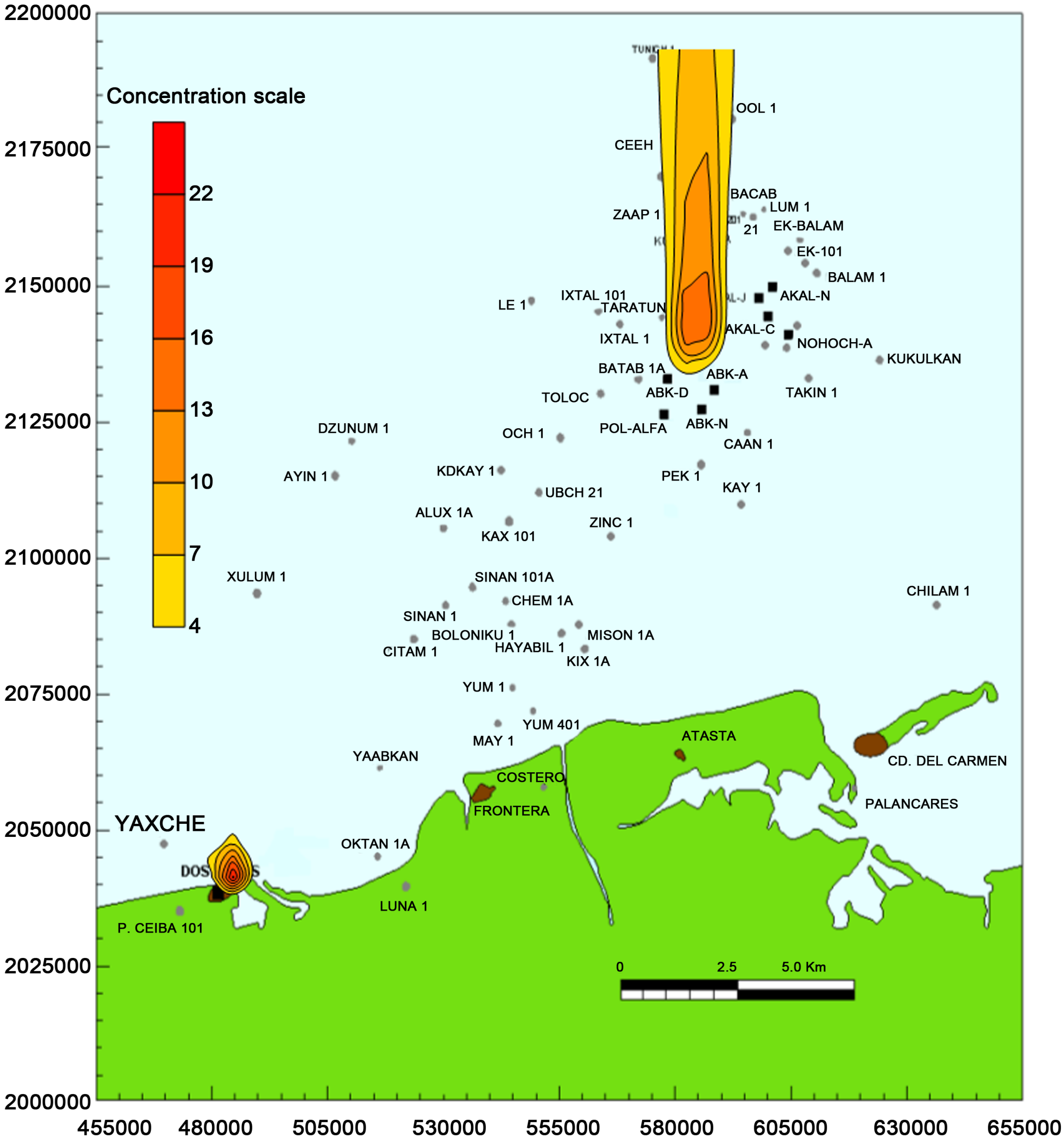


Figure 4. Average 24 hr. SO_2 concentration ($\mu g \cdot m^{-3}$) produced by maximum emissions of the south west oil industry process.

4) October, 17-19,

5) December, 18-20.

Sometimes, it was observed a presence of a maritime air in the north or northeast direction. Land air is less frequent, showing a southeast or south-southwest direction. Additionally analysis of dispersion results reveals that air quality standards are not exceeded in all 2005 year. Most significant scenarios are depicted in **Figure 6** and **Figure 7** [20].

Mendoza and Graniel [43] made another study in the Sound of Campeche, using a previous EI [9] which has been discussed before. This work employed California/Carnegie Institute of Technology (CIT) version 3.0 model, which is a tri-dimensional model that describes pollutants dynamics through atmosphere [44]. They also included a modified version of SPARC90 photochemical mechanism [45].

Modeled scenarios were the same for EI periods reported previously [10]. They found maximum concentration values for low wind speed values (1 to 2 $m \cdot s^{-1}$) in the December 2000-January 2001 period, which is different to Villaseñors' result [8], but they also conclude that maximum ambient concentrations did not exceeded maximum allowed levels. This result is similar to those found by Muriel [12] and Villaseñor [8].

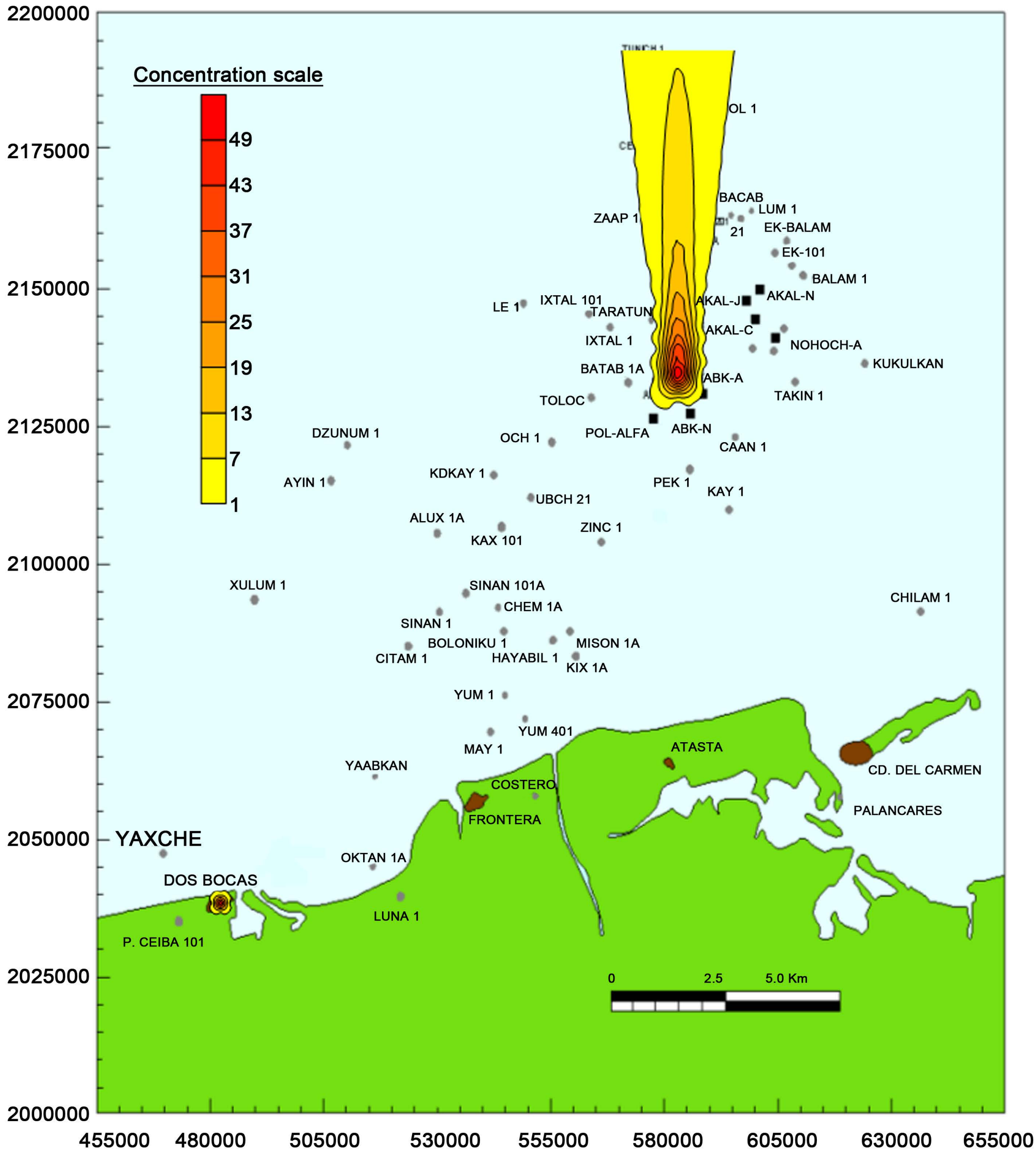
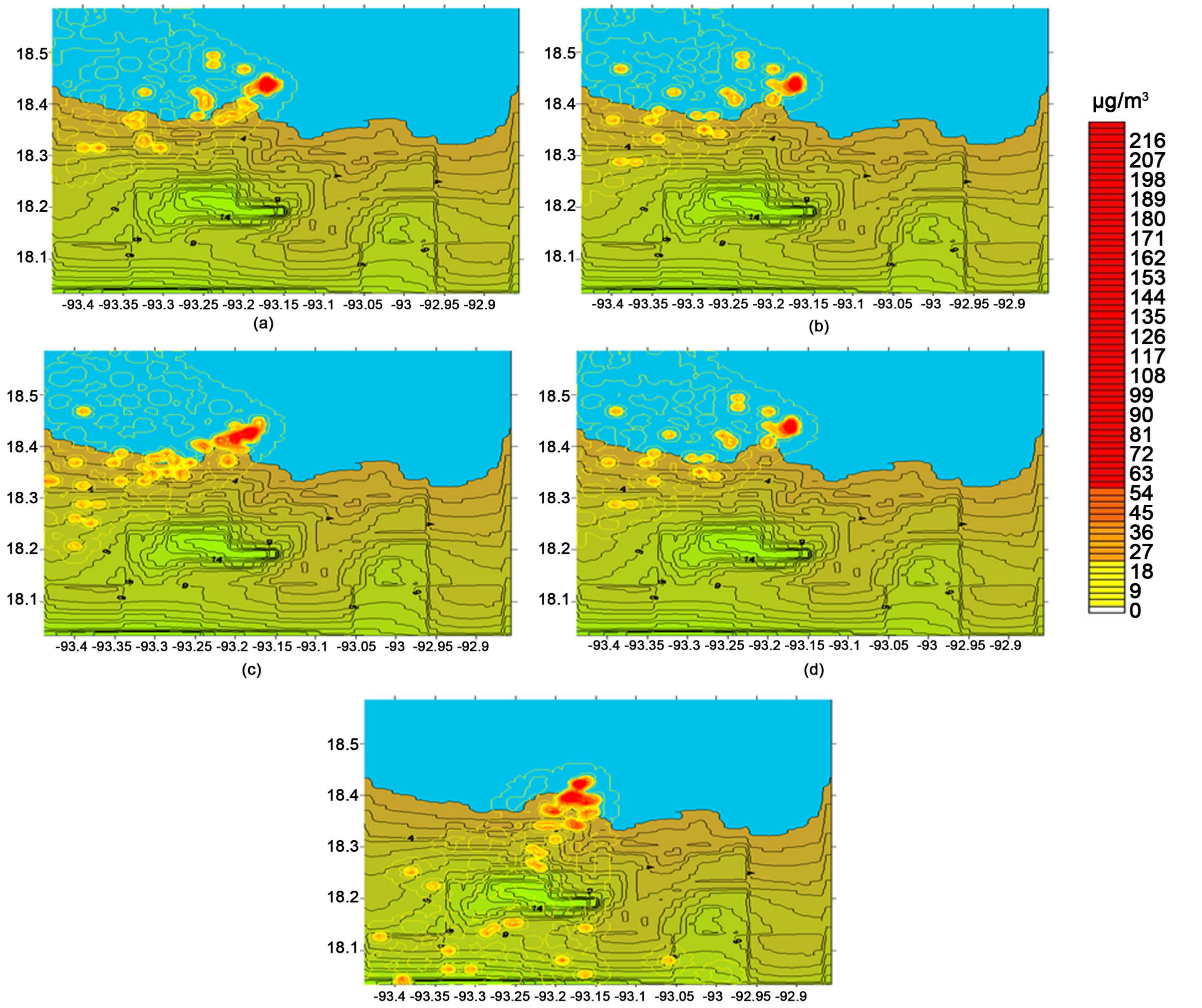


Figure 5. Average 1 hr. NOx concentration ($\mu g \cdot m^{-3}$) produced by maximum emissions of the south west oil industry process.

More recently, in 2010 another dispersion modeling study for the Atasta Region was made, which is 36 km to west from Ciudad del Carmen [34]. An atmospheric vertical profile was included and covered from august 31 to September 4, 2010. Results indicated a stable meteorological condition at synoptic level, with the presence of an anticyclone system in the Gulf of Mexico. Ciudad del Carmen surface meteorology was analyzed for 2007 to 2010 period, showing a most frequent wind component form east-southeast. In order to establish the circumstances where dispersion is less favored and the highest ambient concentrations are expected, the most critical scenario for modeling pollution dispersion was selected. This section was made having in mind four conditions: the most frequent wind direction must be considered; average wind intensity must be near to 2.5 m/s; average temperature must be around 29˚C; and relative humidity should be between 77% and 88%. Therefore the selected critical period was from September 17 to September 20, 2010. Under this scenario, the Regional Atmospheric Meteorological Model [41] was applied using reanalysis information [42], three nested grids with horizontal spacing of 40, 10 and 1 km, surface data from Carmen, CayoArcas, Eco, Rebombeo, Kuh and Dos Bocas



(e)

Figure 6. Air pollution dispersion for scenario No 1 in year 2005. (a) April 22, 00 h; (b) April 22, 12 h; (c) April 23, 00 h; (d) April 23, 12 h; (e) April 24, 00 h.

Maritime Terminal (DBMT) and upper meteorology from Veracruz, Mérida and Acapulco [42]. Having done meteorological modeling, dispersion calculation was completed by means of CALPUFF [37] [38]. Main results illustrate that most of pollution plumes follow a southeast and east-southeast direction and maximum concentrations at floor level do not exceed SO_2 regulations (**Figure 8**). The rest of pollutants showed the same behavior [34].

Cerón *et al.* [46] [47] studied N and S atmospheric deposition fluxes as nitrate and sulfate, respectively during one year, demonstrating that during Norths season, both, Ciudad Del Carmen and Atasta, are subjected to the influence of long-range transport, so that sulfate levels are increased as a result of regional transport. From analysis of air masses trajectories, Cerón *et al.* [46] [47] conclude that prevailing winds come from NE during cold fronts or Norths season, and it has been reported that main sources improving sulfate background levels in this region are offshore platforms in the Sound of Campeche. Therefore, air pollution dispersion modeling in the Sound of Campeche considering longer periods of time is required. Also, it is necessary to obtain complete data at least in an annual basis, allowing to consider different meteorological scenarios, and to assess the contribution of regional sources during Norths season. Regarding to air dispersion models, the main limitation in most of studies reported here is that modeling studies have not only been made during short periods of time but also much of the information used is obtained from reanalysis data, resulting in a general lack of meteorological information in this region.

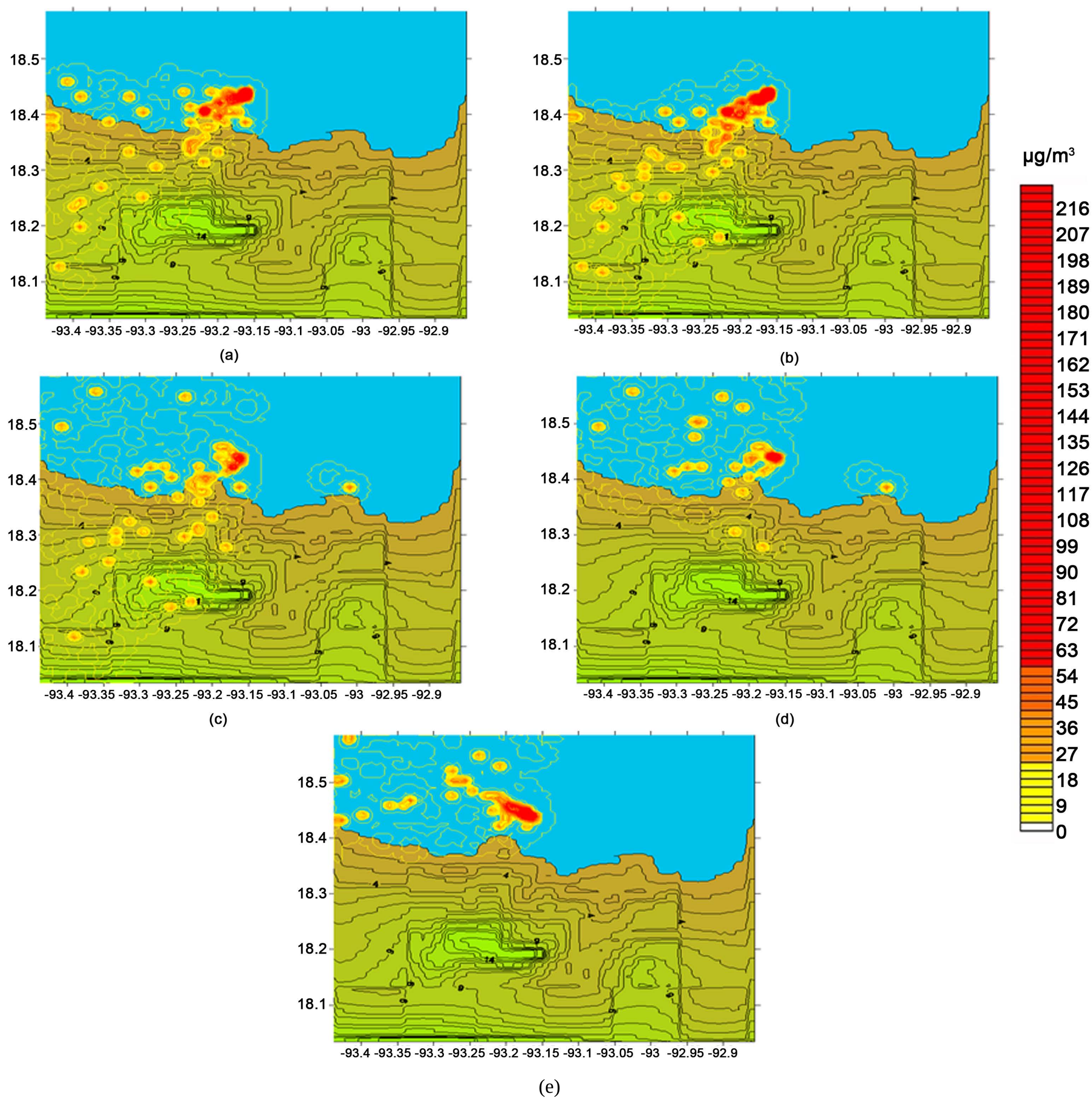


Figure 7. Air pollution dispersion for scenario No 2 in year 2005. (a) June 10, 00 h; (b) June 10, 12 h; (c) June 11, 00 h; (e) June 12, 00 h; (e) June, 00 h.

6. Conclusions

This review makes evident a lack of more recent information and there is not sufficient detail in most of it, therefore it makes difficult to have a proper panorama to be in position to establish appropriate policies and regulations to control air pollution emissions. It is important to homogenize emission factor that can be used systematically for all actors and to make emissions measurement a compulsory activity, so reliable EI could be produced. Dispersion modeling made evident that primary pollutants were not impacting air quality. On the other hand, monitoring results and atmospheric deposition studies demonstrated that SO_2 and sulfate levels could be a severe environmental problem in this region. Consequently, it is important to put more effort in dispersion modeling, which is a less expensive activity. In addition, some attention must be given to acid rain, mercury and carcinogenic organic compounds that are directly produced or might be a secondary transformation product.

It is very important that environmental authorities make a further effort to make public EI as well as results of monitoring air pollution from all sources, especially those who are producing or are suspected to produce an en-

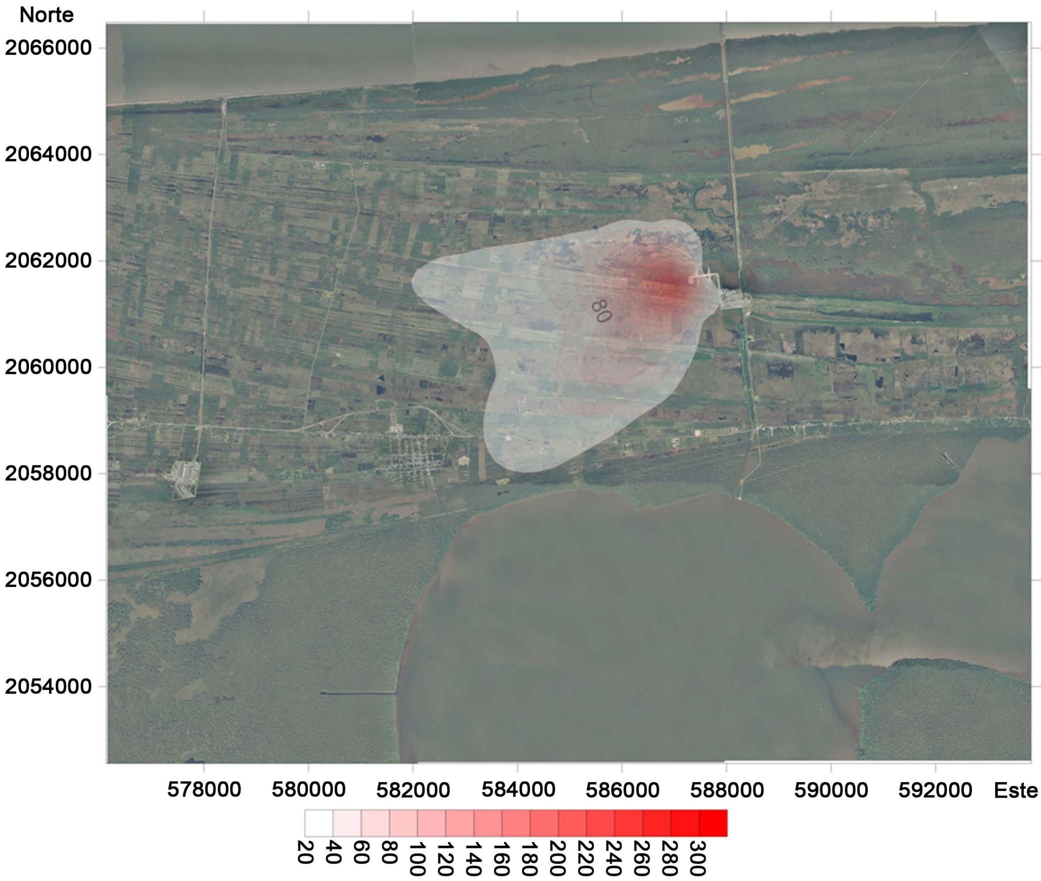


Figure 8. Average SO_2 8 hr. concentration. September 2009.

vironmental impact. Even more, there should be a more complete environmental regulations specifying what to measure, when to measure and where to measure, this will guarantee that available budget is used more efficiently. Authorities, industry, academics and engineers should put more effort in making dispersion modeling a standard tool, similar as it is done in the USA [48]. Contrary to that reported from monitoring studies, at this moment, in the Sound of Campeche, Atasta, and Paraiso it has been demonstrated through dispersion modeling that there is not air pollution impact for the presence of SO_2, NO_X and particles. However, it is necessary to achieve intensive monitoring campaigns that collect criteria pollutants data at a wide scale, to carry out campaigns to obtain full database of surface and upper meteorology, and to increase the number of measuring points, either by purchasing automatic equipment or by using passive or manual samplers. This will allow assessing the air quality in the region, both spatially and temporally, identifying critical points that can be compared with the critical points obtained from models. Integral studies that simultaneously consider both monitoring and modeling are required, so that, those periods where background levels could have a strong regional contribution are identified. From this, it will be possible to obtain a solid base line and sufficient database that allows validating the results obtained from modeling studies.

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