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Organochlorine Pesticides in Ambient Air of Belize, Central America

HENRY A. ALEGRIA

Department of Chemistry & Biochemistry, University of South Carolina, Columbia, South Carolina 29208

TERRY F. BIDLEMAN*

Meteorological Service of Canada, 4905 Dufferin Street, Downsview, Ontario, M3H 5T4 Canada

TIMOTHY J. SHAW

Department of Chemistry & Biochemistry and Marine Science Program, University of South Carolina, Columbia, South Carolina 29208

Air samples were collected for organochlorine pesticides in Belize, Central America, during December 1995−January 1996 and July−August 1996. Concentrations of DDTs and aldrin/dieldrin were greatly elevated relative to levels measured at Great Lakes monitoring stations, suggesting that Central America is a potential source region for emission of these pesticides. Toxaphene concentrations in Belize and at Great Lakes stations were similar, and both were lower than those recently measured in the southern United States. Chlordane levels in Belize were intermediate between Great Lakes and southern U.S. values. On the basis of these limited measurements, Central America does not appear to be a strong source of toxaphene or chlordanes.

Introduction

Most organochlorine pesticides (OCs) have been banned in industrialized countries such as Canada and the United States. However, some OCs continue to be used in tropical and subtropical countries, both in agriculture and in the fight against vector-borne diseases (*1*−*6*). In addition, other OCs were discontinued in tropical and subtropical countries long after their use was stopped in industrialized countries. This is certainly the case in Central America, where some OCs continue to be used in some countries (e.g., DDTs, HCH, chlordane, heptachlor, toxaphene, dieldrin, aldrin) (*1*, *4*). Reports also indicate that some pesticides that are banned or restricted continue to be used illegally in agriculture (*1*, *7*, *8*; Belize Department of the Environment, personal communication).

The quantities of OCs employed in Central America are difficult to estimate since usage inventories are unavailable or incomplete, but they have been considerable in the past and may be substantial even today. For example, 16 million kg of OCs was used in 1974−1975 in Guatemala, Honduras, El Salvador, and Nicaragua (*1*). Toxaphene was produced and used in Nicaragua until 1991 (*9*). Leonard (*10*) reported that application rates of pesticides (including OCs) in Central America were often excessive and that local evidence showed prolific pesticide use throughout the region.

In recent years there have been increased efforts aimed at developing a clearer understanding of transboundary pollution on a regional and global scale. It has now been well-established that persistent organic pollutants (POPs), including OCs, are transported atmospherically from their sites of application and deposited in distant locations (*11*−*19*). OCs and other POPs volatilize from tropical and subtropical areas (*20*) in a process known as "global distillation" (*21*) and are atmospherically transported and deposited in areas with colder temperatures (*19*, *22*−*25*). This may take place through episodic transport events (*12*, *15*, *26*) or in a series of condensation and revolatilization steps (the "grasshopper effect") that lead to fractionation of the compounds according to volatility (*22*−*25*, *27*, *28*). OCs are routinely found in air of the Great Lakes region, where concentrations are slowly declining with half-lives of 2−20 yr (*29*). High episodes of OCs in southern Ontario have been associated with air parcel movements from south of the Canada−United States border, with back trajectories extending to the southern United States and the Caribbean (*15*, *30*). Monitoring stations in the Canadian (*11*) and Norwejian (*12*) Arctic also report OCs in air.

Measurements in source regions are important to understand transboundary pollution on a regional and hemispheric scale and to determine whether pesticides detected in air samples from receptor regions in North America are due to current use or to recycling from "old" sources (i.e., revolatilization from soils). Considering the recent and current use of OCs in Central America, it is possible that emissions from the region contribute to background levels in North America. To our knowledge, no information exists regarding air concentrations and atmospheric transport of pesticides in Central America. In 1995−1996, two sampling trips were carried out to measure ambient air concentrations of OCs in Belize.

Experimental Section

Sampling. Samples were collected during two periods, December 1995−January 1996 and July−August 1996, at two stations in Belize (Figure 1). One station, referred to hereafter as the inland station, was located in Belmopan, (population 5000, elevation 93 m) (Figure 1). The second (coastal) station was in Belize City, the largest urban center (population 80 000, elevation 0−1 m) (Figure 1). Some of the most extensive farmlands in Belize (citrus, bananas, and vegetables) are located just south of Belmopan, while there are no large-scale agricultural enterprises near Belize City. Samples at the inland station were collected from the roof of a private residence (approximately 15 m) located on a small hill. Samples at the coastal station were collected from the roof of the main building of the University College of Belize (approximately 40 m), located about 500 m from the shore.

Samples were collected by pulling air at approximately 0.35 m^3/min (for 18−67 h) through a precombusted round glass fiber filter (GFF, 90 mm diameter Gelman A/E) followed by one or two polyurethane foam (PUF) plugs. Procedures for cleaning and preparation of filters and PUF plugs have been specified elsewhere (*31*). During the first sampling period, daily maximum−minimum temperatures averaged 301−295 K at the inland station and 299−293 K at the coastal station. During the second sampling period, daily maximum−minimum temperatures averaged 304−297 K at the coastal station and 304−298 K at the inland station.

* Corresponding author telephone: (416)739-5730; fax: (416)739-5708; e-mail: terry.bidleman@ec.gc.ca.

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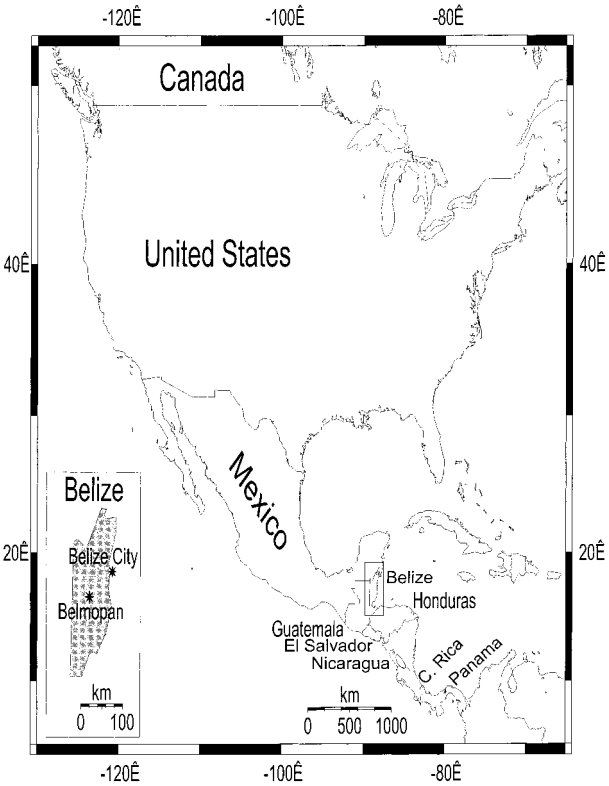

FIGURE 1. Air sampling locations in Belize and relationship to surrounding countries.

Analysis. Samples from both collection periods were shipped to Meterological Service of Canada, Canada, for analysis. OCs were extracted from GFFs and PUF plugs by Soxhlet extraction with 400 mL of petroleum ether for approximately 24 h. GFFs and PUF plugs for each sample were extracted together since this work did not attempt to measure partitioning of pesticides between vapor and particulate phases. The extracts were concentrated first by rotary evaporation and then with a gentle stream of nitrogen to ~1 mL and solvent-exchanged into isooctane. Extracts were cleaned and separated into two fractions on a 1-cm i.d. glass column containing 3 g of 200-mesh silicic acid (deactivated with 3.3% water) overlaid with 2 g of neutral alumina (deactivated with 6% water), and topped with 1 cm of anhydrous granular Na_2SO_4. The column was washed with 30 mL of dichloromethane, followed by 30 mL of petroleum ether. Extracts were applied in ~1 mL of isooctane, and pesticides were split into two fractions by eluting with 18 mL of petroleum ether (F1), followed by 25 mL of dichloromethane (F2). F1 contained heptachlor, *p,p′*-DDE, aldrin, ~30% *o,p′*-DDT, polychlorobiphenyls, and hexachlorobenzene. F2 contained *p,p′*-DDT, ~70% *o,p′*-DDT, *p,p′*-DDD, heptachlor epoxide, chlordanes, nonachlors, HCHs, dieldrin, and toxaphene. Both fractions were concentrated to 1 mL by nitrogen blow-down and solvent-exchanged into isooctane. F2 was split into two subfractions, one of which was treated with 18 M H_2SO_4 for cleanup. The untreated subfraction was used for the determination of dieldrin and heptachlor epoxide. The treated fraction was analyzed for the other pesticides in F2 listed above. Mirex was added as an internal standard just prior to analysis by gas chromatography as described below.

OCs (except toxaphene) were determined by gas chromatography−electron capture detection (GC−ECD) using a Hewlett-Packard 5890II chromatograph with a 60 m × 0.25 mm i.d., DB-5 column, 0.25 μm film thickness (J & W Scientific). Samples of 2 μL were injected splitless (split time 1 min) at 90 °C with 1 min hold. The temperature was programmed at 10 °C/min to 160 °C and then at 2 °C/min to 250 °C with a 6 min hold. Carrier gas was H_2 at 60 cm/s with N_2 as a detector makeup gas at 50 mL/min. Injector temperature was 250 °C, and detector temperature was 280 °C. Pesticides were quantified relative to the internal standard mirex from a calibration plot of 4−5 standards that bracketed the concentrations of pesticides in samples using HP Chemstation software. OCs from the first sampling trip were confirmed, and toxaphene concentrations for both sampling periods were determined by gas chromatography−negative ion mass spectrometry (GC−NIMS). GC−NIMS was carried out using a Hewlett-Packard 5890II GC-5989B MS engine using a 30 m × 0.25 mm i.d., DB-5 capillary column, 0.25 μm film thickness (J & W Scientific Co.). Samples of 2 μL were injected splitless (split time 1.5 min) at 90 °C with 1 min hold. Temperature was then programmed at 20 °C/min to 150 °C, then at 2 °C/min to 240 °C, and finally at 20 °C/min to 270 °C with a 5 min hold. The injector and transfer line were at 250 °C, the ion source was 150 °C, and the quadrupole was 100 °C. Carrier gas was He at a flow rate of 44 cm/s. Methane was the gas reagent at a nominal ion source pressure of 1.0 Torr. The detector was operated in the selective ion mode (SIM) to enhance sensitivity. SIM ions used to quantify OCs were as follows: mirex (404), *p,p′*-DDT and *p,p′*-DDE (316, 318), *o,p′*-DDT (246, 248), *p,p′*-DDD (248, 250), dieldrin (346, 348), aldrin (328, 330), toxaphene (343, 345, 379, 381, 413, 415), HCHs (255, 257), *trans*- and *cis*-chlordane (412, 414), *trans*- and *cis*-nonachlor (444, 446), heptachlor (300, 302), and heptachlor exo-epoxide (386, 388).

Results and Discussion

Quality Control. Eight field spikes (three during the first sampling trip and five during the second sampling trip) were prepared by adding 50 μL of a mixture containing 166−208 ng of OCs to PUFs, pulling air through them for ~1 min, and then analyzing them as field samples. Four laboratory spikes were prepared by adding 50 μL of the same mixture to PUFs and treating them as samples. Five precleaned PUF plugs (two during the first sampling trip and three during the second sampling trip) were shipped to and from Belize and were analyzed as blanks.

The mean percent recoveries of individual OCs were above 70% with relative standard deviations of 3−16% except for heptachlor (58 ± 13%). Concentrations reported in this study were not corrected for recoveries. Blanks were <5% of sample values for most OCs.

Ten samples (denoted with an asterisk in Tables 1 and 2) were collected with two consecutive PUF plugs in the sampler to determine breakthrough for each pesticide. Significant breakthrough was noted only for α-HCH, γ-HCH, and aldrin. Breakthrough increased with the air volume sampled and was consistent in all samples of similar volumes. For α-HCH, there was an average of 70% breakthrough (calculated as PUF2/PUF1) for samples up to 630 m^3 and 150% breakthrough for samples of higher volumes. For γ-HCH, breakthrough in the two volume ranges was 20% and 100%. Breakthrough of aldrin in the two volume ranges averaged 10% and 25%. Due to the high breakthrough values, concentrations of α-HCH are not reported, although it was detected in all samples. For the same reason, concentrations of γ-HCH are not reported for samples of >630 m^3.

As described above, mirex was used as the internal standard to quantify pesticides. However, mirex is used in Central America in relatively small quantities (*1, 32*). During analysis of the second set of samples, background levels of mirex were determined by analyzing three samples (one from the coastal station and two from the inland station) for mirex prior to adding the internal standard. Results indicated that background levels of mirex in sample extracts were only 1−3% of those used as internal standard for quantification (0.097

TABLE 1. Collection Dates and Pesticide Concentrations (pg/m^3) during December 1995–January 1996[a]

sample	collection dates	γ-HCH	HEPT	HEPX	TC	CC	TN	CN	aldrin	dieldrin	*p,p′*-DDE	*p,p′*-DDD	*o,p′*-DDT	*p,p′*-DDT	Tox
							Inland Station								
BMP-1	Dec 13–14 (500 m^3)	88	11	18	15	11	14	4.9	2868	1104	549	122	218	1203	52
BMP-2*	Dec 15–16 (500 m^3)	59	0.3	1.2	19	16	11	5.0	1624	1426	376	9.2	100	457	41
BMP-3	Dec 18–19 (500 m^3)	75	ND	2.1	24	22	14	8.4	652	2060	351	15	165	677	68
BMP-4	Dec 20–21 (500 m^3)	65	4.2	3.3	23	18	12	5.4	386	931	443	8.2	122	330	29
BMP-5	Dec 22–23 (500 m^3)	28	0.5	3.2	8.9	7.1	7.4	2.2	918	1155	360	8.1	106	190	40
BMP-6*	Dec 27–29 (915 m^3)		0.5	2.1	112	117	99	41	662	571	670	47	159	478	40
AM		63	3.3	4.8	34	32	26	11	1185	1208	458	35	145	556	45
SD		22	4.3	6.5	39	42	36	15	926	504	127	45	45	356	13
GM		59	1.3	2.9	23	20	16	6.6	945	1122	445	19	140	473	43
							Coastal Station								
BZE-1*	Jan 3–4 (500 m^3)	37	ND	2.0	31	22	21	11	9.0	55	99	30	54	100	33
BZE-2	Jan 5–6 (500 m^3)	36	0.3	1.3	31	17	6.8	7.8	2.3	53	61	27	32	69	30
BZE-3*	Jan 6–8 (915 m^3)		0.2	3.1	19	11	6.9	2.9	ND	24	35	6.9	17	36	14
AM		36	0.2	2.0	27	17	12	7.3	3.7	44	65	21	34	68	26
SD		0.7	0.1	1	6.9	5.5	8.1	4.0	4.0	17	32	12	19	32	10
GM		36	0.2	1.8	26	16	10	6.4	1.2	41	60	18	31	62	24

[a] ND replaced by LOD (0.1) when calculating means. Abbreviations: TC, *trans*-chlordane; CC, *cis*-chlordane; TN, *trans*-nonachlor; CN, *cis*-nonachlor; Tox, toxaphene; HEPT, heptachlor; HEPX, heptachlor epoxide; AM, arithmatic mean; SD, standard deviation; GM, geometric mean. An asterisk (*) indicates that two PUF traps were used for breakthrough check.

TABLE 2. Collection Dates and Pesticide Concentrations (pg/m^3) during July–August 1996[a]

sample	collection dates	γ-HCH	HEPT	HEPX	TC	CC	TN	CN	aldrin	dieldrin	*p,p′*-DDE	*p,p′*-DDD	*o,p′*-DDT	*p,p′*-DDT	Tox
							Inland Station								
BMP-7*	Aug 3–5 (915 m^3)		0.5	3.4	16	14	14		50	211	139	41	98	368	18
BMP-8	Aug 5–6 (462 m^3)	32	0.3	2.2	22	19	16		125	308	124	41	89	380	24
BMP-9*	Aug 8–9 (500 m^3)	34	0.5	2.2	25	18	22		107	375	299	63	166	499	25
BMP-10	Aug 12–13 (500 m^3)	65	0.3	3.3	40	22	24		133	401	246	59	171	569	28
BMP-11	Aug 13–14 (400 m^3)	42	3.1	1.1	20	20	19		201	373	288	75	177	548	30
BMP-12*	Aug 15–16 (630 m^3)	45	ND	0.2	13	13	12		159	375	221	88	169	421	18
AM		44	0.8	2.1	23	18	18		129	341	220	61	145	464	24
SD		13	1.1	1.2	9.5	3.5	4.7		51	71	74	19	40	87	5.0
GM		42	0.4	1.5	21	17	17		119	333	208	59	140	457	23
							Coastal Station								
BZE-4*	July 15–16 (500 m^3)	58	6.8	9.3	242	140	90		15	74	107	22	78	3737	74
BZE-5	July 16–17 (500 m^3)	30	0.5	8.7	13	14	17		0.3	36	37	17	36	249	23
BZE-6	July 18–19 (500 m^3)	33	ND	6.7	64	16	13		0.2	28	34	15	38	165	18
BZE-7*	July 19–22 (1323 m^3)		ND	7.7	8.7	7.4	9.1		11	21	18	7.6	12	115	50
BZE-8*	July 23–26 (1407 m^3)		ND	3.0	6.0	5.2	3.9		ND	20	14	3.9	12	78	14
BZE-9	July 29–30 (500 m^3)	22	0.5	4.6	9.8	9.1	7.4		ND	20	21	7.0	21	122	23
BZE-10*	July 31–Aug 1 (500 m^3)	20	ND	1.6	6.4	6.3	4.0		ND	14	17	5.6	14	74	28
AM		36	1.2	5.9	50	28	21		3.8	30	35	11	30	648	33
SD		17	2.5	2.9	87	49	31		6.4	20	33	6.7	24	1363	21
GM		30	0.3	5.1	18	13	11		0.5	26	28	9.6	24	199	28

[a] ND replaced by LOD (0.1) when calculating means. Abbreviations: TC, *trans*-chlordane; CC, *cis*-chlordane; TN, *trans*-nonachlor; CN, *cis*-nonachlor; Tox, toxaphene; HEPT, heptachlor; HEPX, heptachlor epoxide; AM, arithmatic mean; SD, standard deviation; GM, geometric mean. An asterisk (*) indicates that two PUF traps were used for breakthrough check.

ng/μL). Therefore, results were not corrected to account for background levels of mirex.

The ratio of GC–ECD:GC–NIMS concentrations obtained from the first sampling trip were as follows: γ-HCH (1.06 ± 0.12), aldrin (1.06 ± 0.06), dieldrin (0.94 ± 0.09), *p,p′*-DDE (1.11 ± 0.12), *o,p′*-DDT (1.07 ± 0.12), *p,p′*-DDT (0.99 ± 0.10), *trans*-chlordane (0.88 ± 0.16), *cis*-chlordane (0.90 ± 0.16), and *trans*-nonachlor (0.81 ± 0.15). Since results by the two methods compared well, these OCs in samples from the second trip were determined only by GC–ECD except for toxaphene, which was determined in both sample sets by GC–NIMS. Values reported were those obtained by GC–ECD (except for toxaphene) to allow comparison between the two sampling periods.

Spatial and Seasonal Trends and Potential Sources. Tables 1 and 2 show the concentrations of OCs measured during the two sampling periods. Because of the wide range of concentrations, both arithmetic and geometric means are given. Aldrin, dieldrin, and ∑DDTs (*p,p′*-DDT, *o,p′*-DDT, *p,p′*-DDE, *p,p′*-DDD) were particularly elevated at the inland station during both seasons. Unpaired *t*-tests at the 95% confidence level were performed on all pesticides using SigmaPlot software. Results indicated that for both seasons means of aldrin, dieldrin, and ∑DDTs (as well as *p,p′*-DDE, *o,p′*-DDT, and *p,p′*-DDT individually) were significantly different at the two stations. Sample BZE-4 showed elevated levels of chlordanes and DDT, and BMP-6 showed elevated levels of chlordanes as compared with other samples taken at these stations during the same period. The high *p,p′*-DDT:*p,p′*-DDE ratio (*35*) for BZE-4 strongly suggests a usage event. However, we could not relate these high samples to any application in Belize. Information from the Belize Public Health Department did not indicate a large spraying event for vector control during the sampling period for BZE-4, nor did inquiries with several large commercial farms regarding an unusual application event. However, we have no information regarding such events from neighboring countries.

Air parcel back trajectories at pressure levels of 850 and 925 hPa (ca. 1.5 and 0.5 km altitude) showed that in the winter sampling period airflow was mainly from NE–NW,

TABLE 3. Comparison of Pesticide Levels in Belize (Geometric Means) and Other North American Locations (Arithmatic Means) (pg/m^3)

Pesticide	Belmopan[a]	Belize City[a]	Lake Superior[b]	Lake Erie[b]	Southern U.S.[c]	Canadian Arctic[d]
∑DDT	992	216	1.6−4.5	5.5−34	10[g]	1.0
dieldrin	728	34	2.4−19	3.0−22	38	1.3
∑chlordanes	57	47	3.3−11	6.0−31	95−308	3.1
γ-HCH	51	33	6.7−20	6.4−25	50	12
toxaphene	33	26	10−40[e,f]		176−189	3−7
HEPT	0.9	0.3	0.7−1.6[e]		19	0.04
HEPX	2.2	3.5	2.6−12[e]		16	1.4

[a] Average of the two sampling periods, geometric means from Tables 1 and 2. [b] OC concentrations (except toxaphene, HEPT, and HEPX) calculated from relationships in ref *29* at representative summer (higher value) and winter (lower value) temperatures of 293 and 273 K. Lake Superior at Eagle Harbor and Lake Erie at Sturgeon Point. [c] Mean values from South Carolina (*41*) and Alabama (*42*) for chlordane and toxaphene, and for Alabama only for other OCs. [d] Annual average, 1994 (*11*). [e] Open lake, summer 1996 and spring 1997 (*37*). [f] Eagle Harbor (*38*). [g] *p,p′*-DDE only.

passing over Cuba, the southern United States, and Mexico. Transport during summer was uniformly from ENE−E, passing over Cuba and other Caribbean islands. No relationship was seen between transport direction and OC concentrations that would explain the differences between the two sampling stations.

Aldrin, dieldrin, and ∑DDTs concentrations tended to be higher during December−January as compared to July−August. In Belize and surrounding regions, the rainy season generally lasts from late July to February, so the August samples were at the beginning of the rain season whereas the December−January samples were more into the period of heavy rain. It is generally the case that pesticide application increases during the rainy season to compensate for loss from rain washoff. The difference in concentrations during the two sampling seasons and between the two sites suggests local sources for aldrin, dieldrin, and DDTs. Concentrations of chlordanes, HEPX, and toxaphene were more similar between sites and seasons and may arise from regional/long-range transport, e.g., from the southern United States where elevated levels of chlordanes and toxaphene have been reported.

DDT is restricted in Belize, Panama, and southern Mexico for use in vector control; was never registered for use in Honduras; and is banned in the rest of Central America (*4*). A goal of the North American Regional Action Plan (NARAP) between Mexico, the United States, and Canada is to reduce usage of DDT for malaria control in Mexico by 80% in 5 yr (*33*). However, there have been reports of widespread and illegal use of DDT in agriculture (*1, 7, 8, 10*). Therefore, it is not surprising that DDT compounds should be found in air of Central America. Aldrin and dieldrin are banned in all Central American countries (*4*). Nevertheless, the high levels of aldrin at the inland station suggest that it still being used in the region. Dieldrin may be present because it is also used or formed by oxidation of aldrin. Technical HCH is restricted in Belize, unregistered in Costa Rica, unregulated in El Salvador, and banned in all other countries in the region (*4*). Lindane is restricted in Belize; banned in Guatemala, Honduras, and Nicaragua; and not banned or restricted in Costa Rica, El Salvador, Panama, and southern Mexico (*4*). Toxaphene use occurred in Central America until the early 1990s (*2, 9*) and resulted in contamination of breast milk in Nicaragua and Honduras (*34*). Chlordane is restricted to nonagricultural uses in Belize and Honduras and banned in all other Central American countries (*4*). It was widely used in Mexico at the time of this study, but a goal of the NARAP was to phase out uses of chlordane there by 1998 (35). Heptachlor is banned in all Central American countries, except Panama, and is unregulated in Mexico (*4*).

Comparison to Other North American Stations. Measurements of OCs in Belize are compared in Table 3 to reported values from the Great Lakes region, the Canadian Arctic, and the southern United States. Atmospheric concentrations and deposition of OCs in the Great Lakes are monitored by the Integrated Atmospheric Deposition Network (IADN) as part of the Great Lakes Water Quality Agreement between the United States and Canada (*29, 36*). OC concentrations at these stations vary seasonally due to temperature and are declining slowly over the long term (*29*). From the published temporal trends (*29*) and at representative summer and winter temperatures of 293 and 273 K, OC concentrations at Eagle Harbor (Lake Superior) and Sturgeon Point (Lake Erie) during 1995 were estimated as shown in Table 3. Other Lake Superior data were taken from refs *37*−*40*. Annual means for 1994 at the Canadian Arctic air monitoring stations are taken from ref *11*. Measurements in the southern United States were made in 1994−1995 (*41, 42*).

DDTs were greatly elevated in Belize at both the inland and coastal stations relative to other North American stations, suggesting that Central America is a source region for atmospheric DDT. Ratios of *p,p′*-DDT:*p,p′*-DDE may indicate the "freshness" of the DDT source. The average ratio in December−January was 1.1 ± 0.6 and did not differ between the two stations. In July−August, the ratios were 2.3 ± 0.5 at the inland station and 5.6 ± 0.9 at the coastal station, excluding the one very high value of 35 for BZE-4. The means are significantly different at $p < 0.01$. The higher DDT:DDE ratio at the coastal station, along with the outlying high value, suggests current DDT usage near the coastal station during this sampling period. By comparison, ratios of *p,p′*-DDT:*p,p′*-DDE are 0.2−0.8 at Great Lakes stations (*29*) and 0.3−0.8 in the Canadian Arctic (*11*).

Dieldrin concentrations at the coastal station in Belize were similar to summer values in the Great Lakes region, but levels at the inland station were greatly elevated. As for DDT, the higher concentrations in Belize suggest that Central America is a potential source region for aldrin/dieldrin.

Lindane (γ-HCH) is still used in Canada and the United States (*43*) as well as in Belize. Atmospheric levels of γ-HCH in the Great Lakes region undergo a strong seasonal cycle that peaks in May−June. During this time, γ-HCH can exceed 100 pg/m^3 due to springtime usage of lindane for seed treatment (*14, 15, 44*). The comparisons in Table 3 show similar γ-HCH levels in Belize, the southern United States, and the Great Lakes region and somewhat lower values in the Canadian Arctic.

In the mid-1970s, toxaphene was the most heavily used insecticide in the United States with a peak production of 37 000 ton/yr (*45*). Most registrations of toxaphene in the United States were canceled in 1982, and the use of remaining stocks was prohibited after 1986 (*46, 47*). Aerial transport has resulted in toxaphene contamination of the Great Lakes (*37, 45, 48*). Toxaphene has also been found in air and water samples from the Canadian Arctic (*11, 13, 49, 50*). Concentrations of toxaphene in Belize during the two sampling

periods were similar to those found in air over Lake Superior in 1996−1997 (*37, 38*) and over the four lower Great Lakes in 1990 (*40*) (Table 3). All of these measurements were done using the same sampling and analytical methods. A lower concentration range (0.9−10 pg/m^3) has been reported for air sampled at Point Petre, Lake Ontario, from 1992 to 1997 (*39*). Toxaphene levels in the Arctic ranged from 3 to 7 pg/m^3 (*13, 49*). Considering the recent and considerable use of toxaphene in Central America (*2, 9, 34*), it is surprising that levels in Belize are similar to those in the Great Lakes region. In fact, toxaphene concentrations in Belize air are considerably lower than those recently found in South Carolina and Alabama (*41, 42*) (Table 3). Soils in Alabama contain toxaphene residues from past usage and may release toxaphene into the ambient air (*51*). These results suggest that Central America may not be a major emission region for toxaphene.

Chlordane is one of the OCs responsible for fish consumption advisories in the Great Lakes and its tributaries (*52*) and is of concern because of its tendency to bioaccumulate, including in humans (*52, 53*). Chlordane compounds have been found in the air (*11, 13*) and water (*50*) of the Canadian Arctic. The ∑chlordanes in the air of Belize was higher than in the Great Lakes region and the Canadian Arctic but lower than the southern United States (Table 3), suggesting that chlordane use in the region may constitute a moderate emission source. Ratios of *trans*-/*cis*-chlordane (TC/CC) averaged 1.2 ± 0.2 and 1.3 ± 0.3 at the inland station during the winter and summer sampling periods, respectively. The ratios at the coastal station in the two seasons averaged 1.7 ± 0.2 and 1.6 ± 1.1. TC appears to be lost relative to CC during atmospheric transport, lowering the TC/CC ratios. Reported ratios are 1.8 in Alabama (*42*), 1.6 in the city of Columbia, SC (*41*), 1.3−1.8 at Eagle Harbor, Lake Superior (*29*), 0.6−0.7 at Sturgeon Point, Lake Erie (*29*), and 0.4−0.6 in the Arctic (*11*).

Heptachlor epoxide (HEPX) is a metabolite of heptachlor. Although two epoxides are known, endo and exo, the exo-form is found exclusively in the environment. Concentrations of heptachlor and HEPX in Belize were higher than those found in the Arctic, below levels in the southern United States, and similar to those reported over Lake Superior (Table 3), suggesting that Central America is probably not a strong emission region for either substance.

In summary, DDTs, dieldrin, and aldrin were quite elevated in the air of Belize (particularly in inland areas) as compared to recently measured levels in the Great Lakes region, supporting the hypothesis that Central America is a potential source region for these pesticides. Despite usage of toxaphene in Central America into the early 1990s, concentrations in Belize were similar to those at the Great Lakes, and lower than values recently measured in the southern United States. The ∑chlordane in Belize air was intermediate between levels in the Great Lakes region and those found in the southern United States. These results indicate that Central America is probably not a strong source of toxaphene nor chlordane.

The measurements presented here represent a first step in obtaining a clearer picture of the importance of the Central America region for pesticide emissions. A more comprehensive sampling program needs to be instituted that would include other countries in the region, particularly Mexico, which has historically been the largest consumer of pesticides. "New" release of pesticides from Central America should be placed in perspective with emissions from "old" sources such as previously contaminated agricultural soils. Recent measurements indicate that OC pesticides are continuing to volatilize from soils in the United States long after they were banned (*54, 55*).

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