Supplementary material to the poster 160 titled "**Study of formaldehyde (HCHO) columns abundance from OMI satellite data in two agricultural regions in the south of Mexico**"

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Introduction: HCHO

- HCHO is an important compound in the atmosphere. It is a proxy of volatile organic compounds (VOCs), its photolysis generates radicals that influence ozone production and secondary organic aerosols, it is a mutagen, and it has been related with nasopharyngeal cancer in humans.
- HCHO has primary source (direct emissions into the atmosphere) and secondary source (from the oxidation of VOCs in the atmosphere). Globally, the secondary source predominates over the primary source.
- HCHO is produced in high amounts when both isoprene (predominantly from biogenic source) and NO_x ($NO + NO_2$, from anthropogenic activity, biomass burning, and soils) are present.

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Introduction: HCHO

- HCHO columns from the Ozone Monitoring Instrument (OMI) and ancillary data have been used in multiple linear regressions to model HCHO columns, establishing controlling factors and seasonality.
- In this work OMI HCHO columns were used along with biogenic, biomass burning, and soil emission inventories from January 2005 to December 2016 in order to determine the driver factors and the principal months of enhancement of HCHO over two agricultural regions, located in the Oaxaca and the Chiapas States, in the south of Mexico.

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Introduction: Characteristics of the regions

- The Oaxaca and the Chiapas regions depend on agriculture, principally rain-fed maize, which is planted predominantly from May and June (total precipitation shows maxima from june to september).
- Agriculture is poorly technified and is predominantly for subsistence purposes because these states are characterized by the highest rates of poverty, marginalization, and illiteracy at national level.
- A widespread technique is slash-and-burn. Oaxaca and Chiapas were the states with the largest total burned area during 1998-2017.
- Jungles, forest, and agricultural land use are the principal land cover types in both regions.

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Introduction: Characteristics of the regions

- High amounts of nitrogen fertilizer are applied to the crops. The rates can be as high as 300 kg ha^{-1}.
- The emission inventories of the Oaxaca and the Chiapas States reported that VOCs are predominantly from natural sources (94.87% in the Oaxaca State, 86.59% in the Chiapas State) because of the abundant vegetation present in these states. NO_x are predominantly derived from soils and forest fires (74.46% in the Oaxaca State, 59.63% in the Chiapas State).

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Methodology

- OMI satellite data: Smithsonian Astrophysical Observatory OMI HCHO level 2 version 003. HCHO columns were filtered, corrected with a linear trend obtained from a remote location, and taken to a regular grid based on a weighting algorithm (the oversampling method).
- Emission inventories:
  - ALBERI-GFWMOD isoprene emission inventory.
  - Global Fire Emissions Database (GFED) version 4.1s (NO_x emissions from biomass burning, NO_{x_bb}).
  - CAMS-GLOB-SOIL inventory for NO_x soil emissions (NO_{x_bio}, NO_{x_fer}, NO_{x_dep}, NO_{x_pul}, and NO_{x_tot} for biomes, fertilizers and manure, deposition of N, pulses, and totals, respectively).

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Results

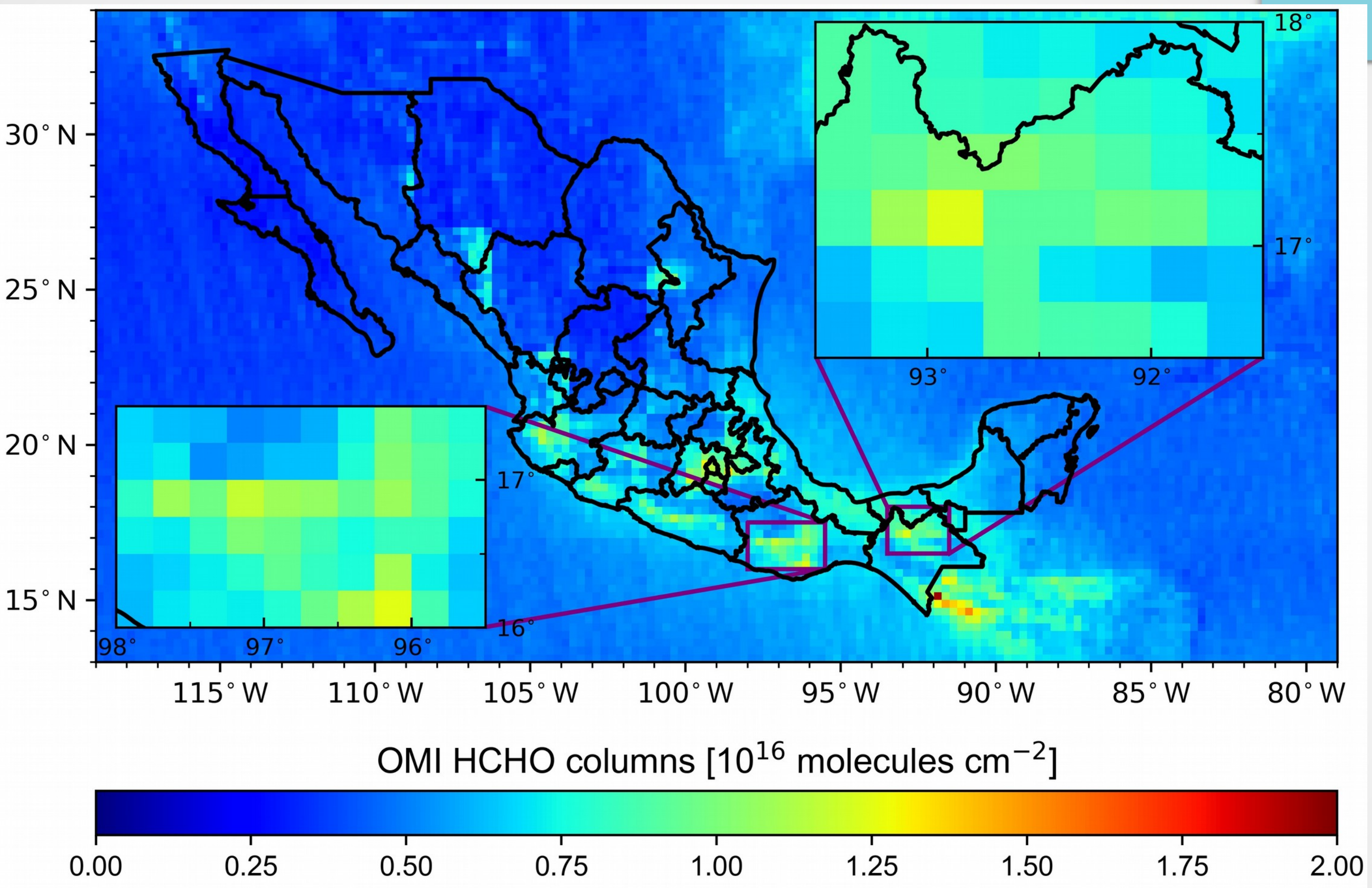

Figure 1. Weighted mean OMI HCHO columns from January 2005 to December 2016 on a 0.25° × 0.25° grid. The lower left and upper right insets zoom-in the abundance and distribution of OMI HCHO columns over the Oaxaca region and the Chiapas region, respectively.

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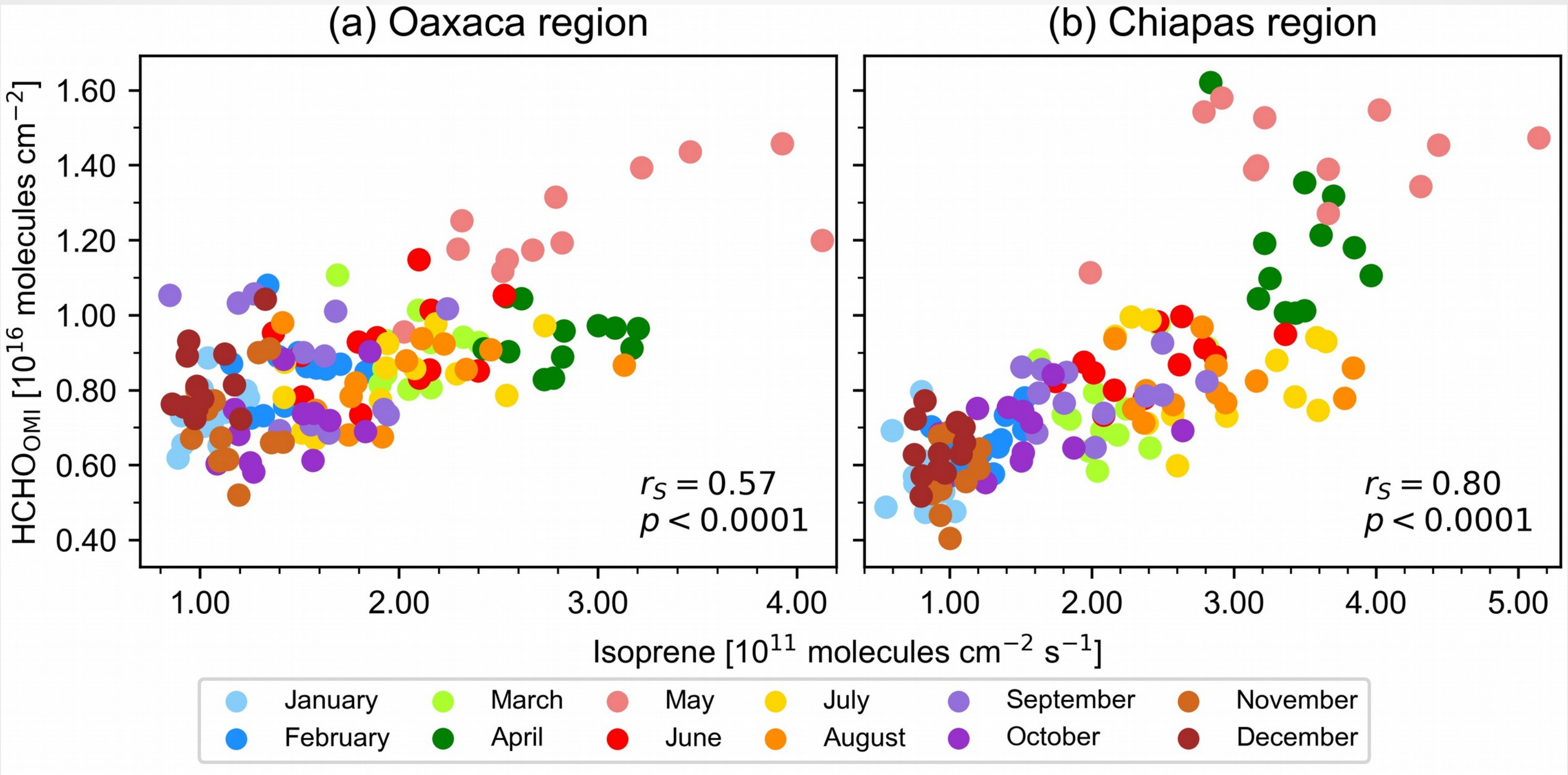

Figure 2. Scatterplot of monthly averaged OMI HCHO columns ($HCHO_{OMI}$) and monthly averaged isoprene emissions (isoprene) in (a) Oaxaca region and (b) Chiapas region. The variables are grouped by month due to their seasonal variations. The Spearman rank correlation coefficient (r_S) and its p-value are also shown.

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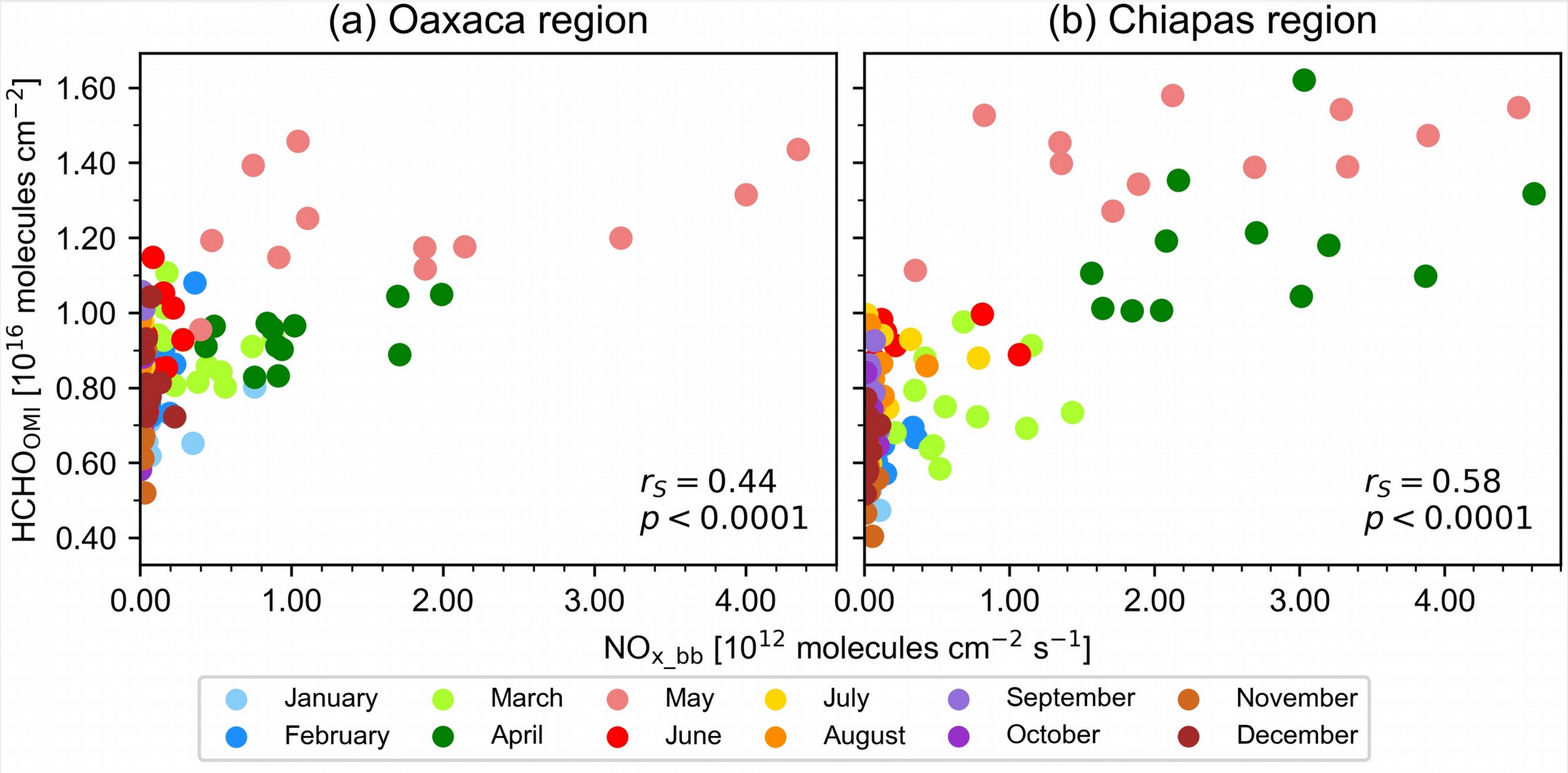

Figure 3. Scatterplot of monthly averaged OMI HCHO columns ($HCHO_{OMI}$) and monthly NO_x emissions from biomass burning (NO_{x_bb}) in (a) Oaxaca region and (b) Chiapas region. The variables are grouped by month due to their seasonal variations. The Spearman rank correlation coefficient (r_s) and its *p*-value are also shown.

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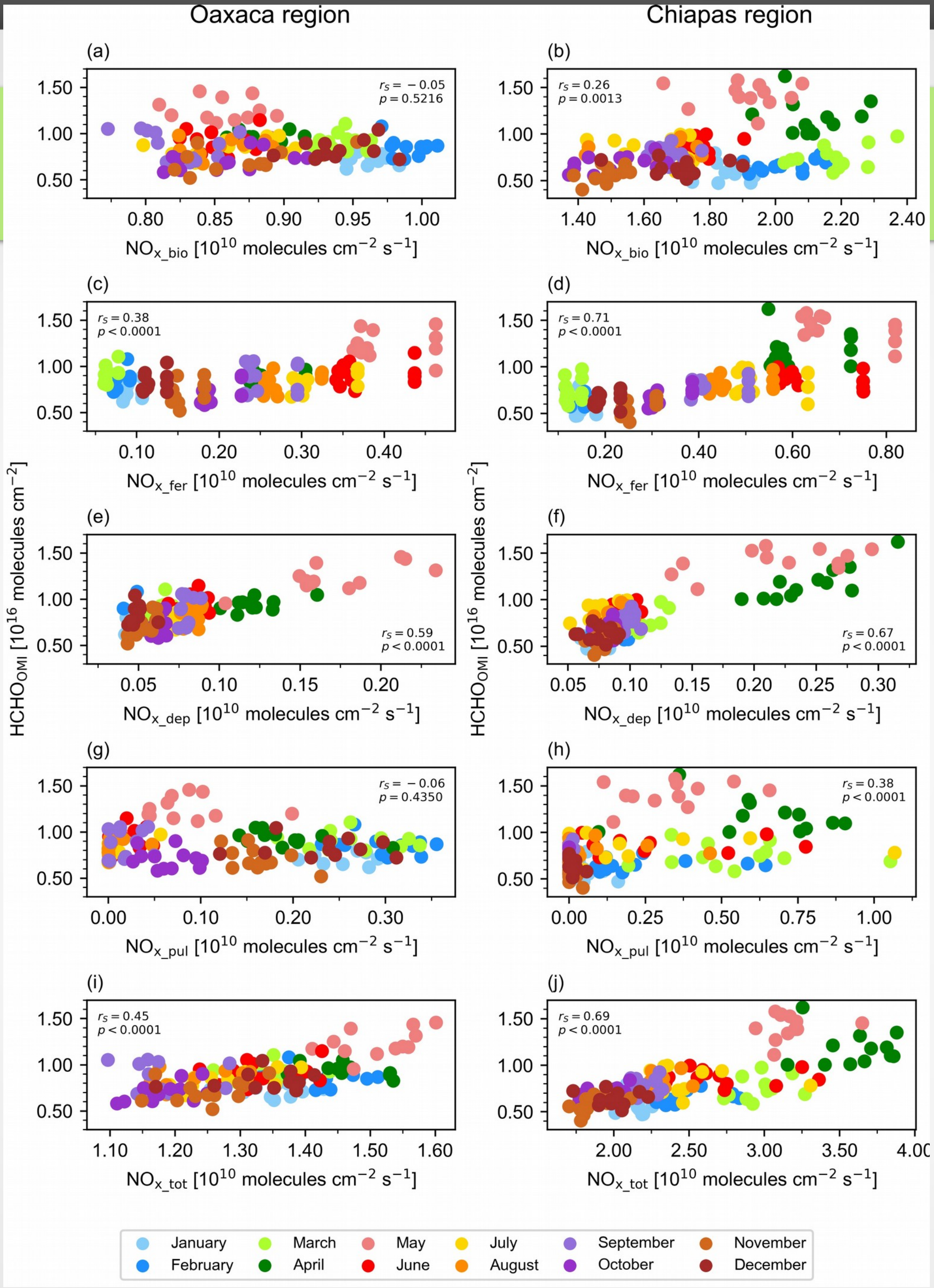

Figure 4. Scatterplots of monthly averaged OMI HCHO columns ($HCHO_{OMI}$) and monthly averaged NO_x emissions from soils from different sources: (a,b) biomes (NO_{x_bio}), (c,d) fertilizers and manure (NO_{x_fer}), (e,f) deposition (NO_{x_dep}), (g,h) pulses (NO_{x_pul}), (i,j) biomes + fertilizers and manure + deposition + pulses (No_{x_tot}) in the Oaxaca region (a, c, e, g, i) and the Chiapas region (b, d, f, h, j). The variables are grouped by month due to their seasonal variations. Spearman rank correlation coefficients (r_S) and *p*-values are also shown.

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Variable	Coefficient	Standard error	t-statistic	p-value
C	2.90×10^{15}	1.14×10^{15}	2.55	0.0121
Isoprene	6.60×10^{3}	2.62×10^{3}	2.52	0.0131
NO_{x_bb}	4.10×10^{2}	1.87×10^{2}	2.19	0.0301
Trend	5.40×10^{12}	2.26×10^{12}	2.39	0.0185
$HCHO_{OMI,t-2}$	3.04×10^{-1}	8.01×10^{-2}	3.79	0.0002
January	1.25×10^{15}	6.34×10^{14}	1.97	0.0511
February	1.80×10^{15}	5.23×10^{14}	3.44	0.0008
March	2.06×10^{15}	5.41×10^{14}	3.81	0.0002
April	1.20×10^{15}	5.23×10^{14}	2.31	0.0232
May	3.65×10^{15}	5.69×10^{14}	6.41	<0.0001
June	1.70×10^{15}	4.36×10^{14}	3.90	0.0002
August	9.54×10^{14}	4.44×10^{14}	2.15	0.0335
September	2.97×10^{15}	5.75×10^{14}	5.16	<0.0001
October	2.76×10^{14}	5.18×10^{14}	0.53	0.5946
November	3.66×10^{14}	5.30×10^{14}	0.69	0.4909
December	2.06×10^{15}	6.40×10^{14}	3.21	0.0017
D2013M10*September	-2.36×10^{15}	6.35×10^{14}	−3.72	0.0003
D2006M09	-2.81×10^{15}	9.65×10^{14}	−2.92	0.0042
D2012M09	-2.92×10^{15}	9.63×10^{14}	−3.03	0.0030
R	0.85	Sum of squared residuals		9.77×10^{31}
R^2	0.76	F-statistic		21.35
Adjusted R^2	0.72	p-value of the F-statistic		<0.0001
Standard error of regression	8.91×10^{14}			

Table 1. Multiple linear regression model with $HCHO_{OMI}$ as dependent variable for the Oaxaca region. The regression coefficients, their standard errors and the significance test are shown for the following variables: isoprene, NO_{x_bb}, a time trend that increases by one for each observation (Trend), the second lag of $HCHO_{OMI}$ ($HCHO_{OMI,t-2}$), the months of the year that shape seasonality (C is the constant term of the model, it represents the coefficient of the months of July. Each of the other months has a value above July, that can be or not be significant depending on the magnitude of the estimated coefficient), a dummy variable (values of 0 and 1 only) that models the structural change of the coefficient of the months of September (D2013M10; values of 0 before October 2013, values of 1 otherwise), and two dummy variables (D2006M09; value of 1 for September 2006, values of 0 otherwise. D2012M09; value of 1 for September 2012, values of 0 otherwise) that model the dates that had high values of standardized residual (−2.6 and −2.4, respectively).

Results

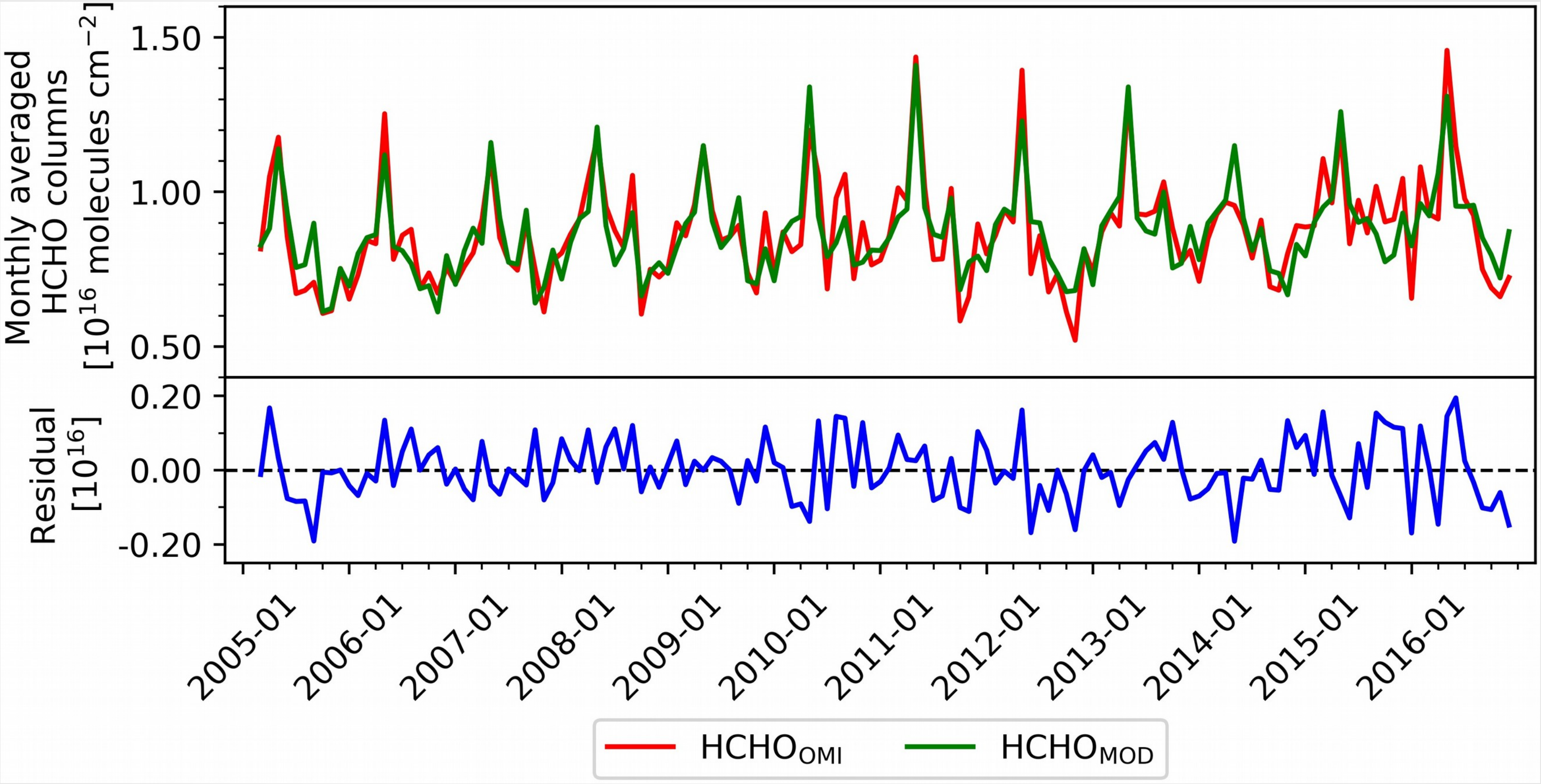

Figure 5. Monthly averaged OMI HCHO columns ($HCHO_{OMI}$), monthly averaged modeled HCHO columns ($HCHO_{MOD}$) based on Table 1, and residuals ($HCHO_{OMI}$ - $HCHO_{MOD}$) in the Oaxaca region.

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Variable	Coefficient	Standard error	t-statistic	p-value
C	4.78×10^{15}	2.15×10^{14}	22.26	<0.0001
Isoprene	4.64×10^{3}	1.51×10^{3}	3.06	0.0027
NO_{x_bb}	2.32×10^{3}	2.11×10^{2}	10.95	<0.0001
NO_{x_fer}	4.73×10^{5}	7.70×10^{4}	6.14	<0.0001
D2006M11*NO_{x_bb}	-1.20×10^{3}	2.19×10^{2}	−5.46	<0.0001
D2012M06*NO_{x_fer}	-1.57×10^{5}	5.16×10^{4}	−3.04	0.0028
D2014M09*NO_{x_fer}	1.94×10^{5}	5.54×10^{4}	3.50	0.0006
D2006M04	-5.41×10^{15}	1.17×10^{15}	−4.61	<0.0001
D2012M05	4.93×10^{15}	1.04×10^{15}	4.74	<0.0001
R	0.93	Sum of squared residuals		1.39×10^{32}
R^2	0.86	F-statistic		101.59
Adjusted R^2	0.85	p-value of the F-statistic		<0.0001
Standard error of the regression	1.01×10^{15}			

Table 2. Multiple linear regression model with $HCHO_{OMI}$ as dependent variable for the Chiapas region. The regression coefficients, their standard errors and the significance test are shown for the following variables: isoprene, NO_{x_bb}, NO_{x_fer}, three dummy variables that model the structural changes of the estimated coefficients of NO_{x_bb} (D2006M11; values of 0 before November 2006, values of 1 otherwise) and NO_{x_fer} (D2012M06; values of 0 before June 2012, values of 1 otherwise. D2014M09; values of 0 before September 2014, values of 1 otherwise), and two dummy variables (D2006M04; value of 1 for April 2006, values of 0 otherwise. D2012M05; value of 1 for May 2012, values of 0 otherwise) that model the dates that had high values of standardized residual (−3.7 and 4.0, respectively). C is the constant term of the model.

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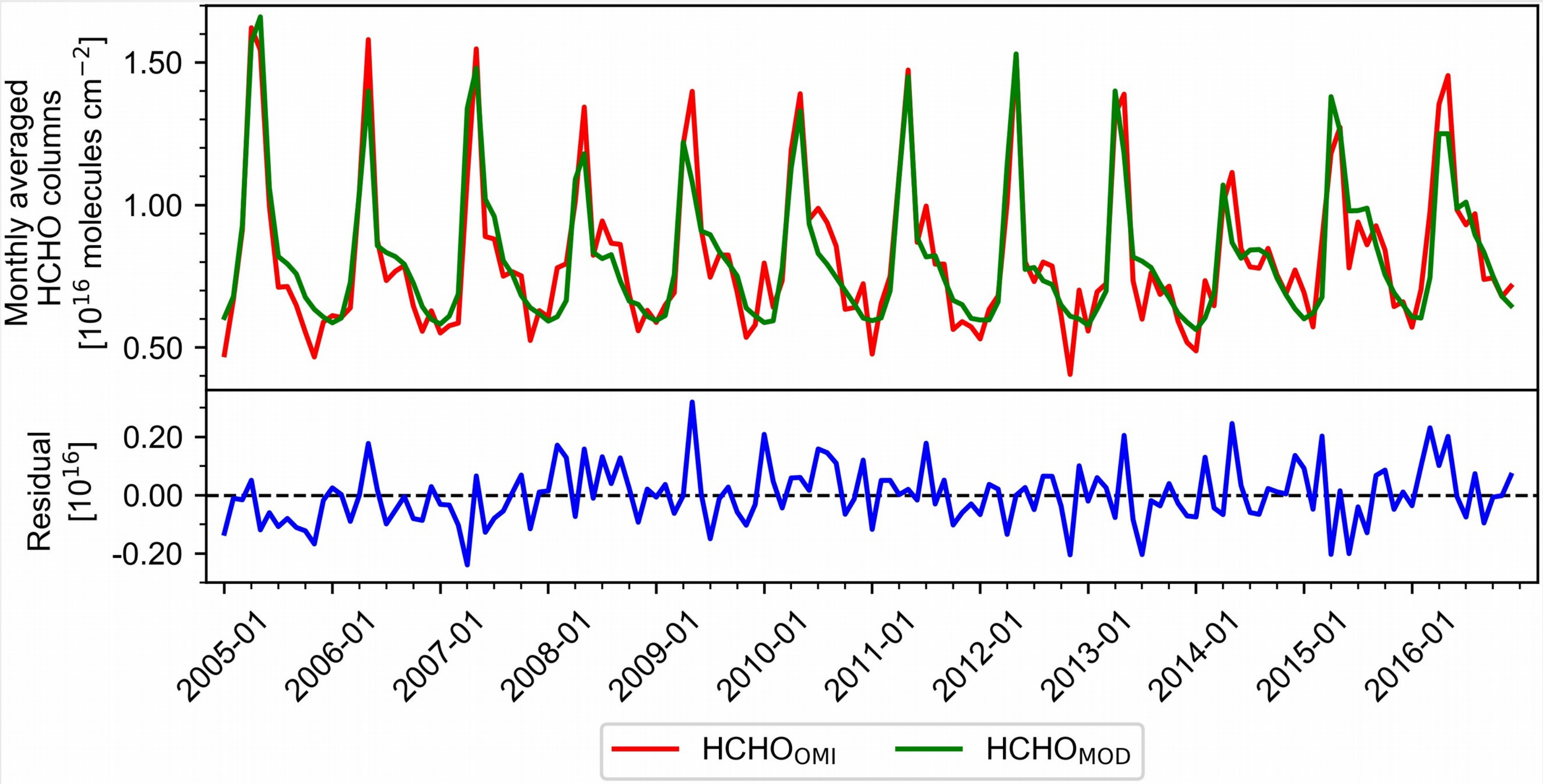

Figure 6. Monthly averaged OMI HCHO columns ($HCHO_{OMI}$), monthly averaged modeled HCHO columns ($HCHO_{MOD}$) based on Table 1, and residuals ($HCHO_{OMI}$ - $HCHO_{MOD}$) in the Chiapas region.

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Conclusions

- Oaxaca region: isoprene was an important driver of $HCHO_{OMI}$, contributing both to its seasonality and its peak months during April and May.
- Chiapas region: both isoprene and NO_{x_fer} were important drivers of the seasonality of $HCHO_{OMI}$ and its peak months during April and May.
- In both regions NO_{x_bb} was predominantly involved in $HCHO_{OMI}$ enhancement during April and May.

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