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Ideas and perspectives: patterns of soil CO_2, CH_4, and N_2O fluxes along an altitudinal gradient – a pilot study from an Ecuadorian neotropical montane forest

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Supplementary information

1 Materials and methods

1.1 Study areas

The fieldwork was carried out along an altitudinal gradient from lowland (400 m a.s.l.) to upper montane evergreen forests (3010 m a.s.l.; Table S2). We selected areas of well-preserved natural forests located on the western flanks of the Andes in northern Ecuador; specifically, in the Sierra region in the provinces of Imbabura and Pichincha. Four study sites (Fig. S1) were selected: Río Silanche at 400 m a.s.l (hereinafter: S_400), Milpe at 1100 m a.s.l. (hereinafter: M_1100), El Cedral at 2200 m a.s.l. (hereinafter: C_2200) and Peribuela at 3010 m a.s.l. (hereinafter: P_3010). All sites experience two rainy seasons (March-April and October-November), with a mean annual precipitation (MAP) that varies on average between 900 and 3600 mm, and an adiabatic lapse rate of approx. -5 °C per 1000 m of altitude (Table S2) (Varela and Ron, 2018).

1.2 Sampling strategy

The sampling campaign took place from August 6th to September 28th, 2018, corresponding to the end of the dry season. One plot (20x20 m) was selected for each site, and within each plot, five polyvinyl chloride (PVC) collars were installed to allow *in-situ* measurements using a static flux chamber method. The collars were inserted at random locations within the plots but guaranteeing at least 7 m distance between each one. The insertion of the collars was performed at least 12 h before the first measurements, by applying even pressure across all points to minimize effects caused by soil disturbance. The chambers consisted of a PVC pipe hermetically sealed on top with a rubber-sealed lid. The chamber area was 0.0191 m^2 and the internal volume ranged between 3.63 and 3.98 L. Each chamber was equipped with sampling ports mounted with three-way valves, and a vent tube was installed to reduce pressure interferences.

Gas samples were collected mid-morning to avoid extreme temperatures and consider them as representative of a whole day (Collier et al., 2014; Luo and Zhou, 2006). Measurement cycles on each site consisted of four consecutive gas measurements once per day for one hour and during five contiguous days. For these measurements, the collars were left in place for the duration of each measurement cycle; thus, the analysis per stratum lasted 1 week (i.e. 1 month for all measurements in the 4 strata). However, in order to assess both short-term and long-term variations mainly related to weather conditions, the gas measurements were done first in August and consequently repeated in the next month (September).

Adjacent to each chamber (~ 1 m), one pit was dug for soil sampling, and intact soil cores were collected using stainless steel cylinders (diameter: 5.08 cm, height: 5.11 cm). The samples were taken at 5 and 20 cm depth once during the first month (August) of measurements. Each soil core was immediately packed into airtight zip-lock bags and once the sampling campaign was over, they were sent to Belgium (Ghent University) for physicochemical soil analysis. Bulk density (ρ_b) was measured by oven drying (75°C for 48 h) and weighing the soil samples. Soil porosity was derived from Eq. (1), assuming a particle density of 2.65 g cm^{-3}. pH was measured by a potentiometric method using a pH-sensitive glass electrode, a standard reference electrode (HI 4222; Hanna Instruments, Bedfordshire, UK), and a volumetric ratio soil:liquid of 1:5 for pH_{water} (distilled water) and pH_{KCl} (1M KCl). NO_3^- and NH_4^+ content was determined colorimetrically (Auto Analyzer 3; Bran and Luebbe, Norderstedt, Germany) after extractions performed with 1M KCl at room temperature and neutral pH. C and N concentrations (%C, %N), along with the stable N isotope signatures ($\delta^{15}N$) of the soil samples, were determined at natural abundance by a Continuous Flow Element Analyzer (Automated Nitrogen Carbon Analyzer), interfaced with an Isotope-Ratio Mass Spectrometer (Sercon 20-20; Sercon, Cheshire, UK). Moreover, the soil samples taken at 5 and 20 cm depth were combined to produce one composite sample associated with each site, and by means of the method described by the International

Organization for Standardization (ISO 11277:2009), soil texture was determined. The classification of the soil was made according to the United States Department of Agriculture (USDA, 2017); and the soil class was determined based on the classification of FAO and UNESCO: World Reference Base for Soil Resources (WRB) (FAO, 2007).

$$Porosity\ [\%] = \left(1 - \frac{\rho_b\ [g\ cm^{-3}]}{2.65\ [g\ cm^{-3}]}\right) \cdot 100\% \qquad (1)$$

Daily measurements of soil moisture, expressed as water-filled pore space (WFPS), were taken per site at 5 and 20 cm depth using soil moisture sensors (EC-5, Meter Environment, Pullman, Washington, USA) and data loggers (ProCheck, Meter Environment, Pullman, Washington, USA). Finally, soil temperature was determined daily for each measurement cycle and per chamber, by means of a thermometer inserted at 5 cm depth and approximately 10 cm from each chamber.

1.2.1 Soil-atmosphere exchange

Each day, the chambers were closed for a period of 1 h. Samples of 20 mL were taken with disposable syringes from the headspace air every 20 minutes: $T_1 = 0$, $T_2 = 20$, $T_3 = 40$ and $T_4 = 60$ min; T_1 or time-zero indicates the sample taken immediately after the chamber was closed. Before each sample collection, the syringe was flushed twice with the air of the chamber to mix the chamber headspace and to avoid any possible stratification of gases.

The 20 mL samples were injected in pre-evacuated 12 mL exetainer vials (over-pressurized), and once the sampling campaign was over, the samples were sent to Belgium (Ghent University) for gas chromatography analysis. For CH_4 and CO_2 analysis, a gas chromatograph (Finnigan Trace GC Ultra; Thermo Electron Corporation, Milan, Italy) equipped with a flame ionization detector (FID) and a thermal conductivity detector (TCD) was used, respectively. For N_2O, another gas chromatograph equipped with an electron capture detector (ECD) (Shimadzu GC-14B; Shimadzu Corporation, Tokyo, Japan) was used.

1.3 Data analysis

The fluxes for each gas (CO_2, CH_4 and N_2O) were calculated by means of linear regressions using the four consecutive measurements of each measurement cycle. The slope of the regressions represented the flux. Thus, following the ideal gas law, and considering the headspace volume of the chamber and the chamber area, the net gas flux was calculated by Eq. (2) (Collier et al., 2014; Dalal et al., 2008; Kutzbach et al., 2007):

$$F_c = \left(\frac{\Delta c\ [ppm]}{\Delta t\ [min]}\right) \cdot \left(\frac{P\ [atm]}{R\ [L\ atm\ mol^{-1}\ K^{-1}] \cdot T\ [K]}\right) \cdot (MW\ [g\ mol^{-1}]) \cdot \left(\frac{V_{ch}\ [L]}{A_{ch} [m^2]}\right) \qquad (2)$$

where Fc corresponds to the net gas flux (CO_2, CH_4 or N_2O), $\Delta c/\Delta t$ is the rate of change of the gas concentration within the chamber or the slope of the regression line [ppm min^{-1} or µL L^{-1} min^{-1}], P/RT corresponds to the ideal gas law used to convert concentration from volumetric to mass fraction at local temperature and pressure, R = gas law constant (0.08206 L atm mol^{-1} k^{-1}); MW is the molecular weight of the gas (CO_2-C and CH_4-C: 12.01 g mol^{-1}, N_2O-N: 14.01 g mol^{-1}), V_{ch} is the headspace volume of the chamber, and A_{ch} the area of the chamber. The goodness-of-fit was evaluated for every linear regression using the adjusted coefficient of determination (R^2), and time series (concentration vs time) with $R^2 < 0.65$ were excluded from further analysis.

2. Results

2.1 Physicochemical soil properties

All soils along the altitudinal gradient are Andosols and the soil texture was classified (USDA) between loam and sandy loam at all sites (WRB; Table 2). All sites had a relatively acidic soil; pH_{water} ranged from strong to medium acidic (4.6 - 5.7), with an increase in acidity with depth, except at P_3010 (Table 2). The most acidic soil was found at S_400 at 5 cm, although not significantly different from M_1100 and C_2200; whereas the least acidic one at P_3010 at 5 cm depth, and only significantly different from M_1100. Except for P_3010, NO_3-N concentrations were 2-4 times higher at 5 cm compared to 20 cm depth; the highest variability was observed at S_400, and in comparison to the other sites, P_3010 seems to be depleted in NO_3-N at both depths (0.8 – 3.6 µg g^{-1}). In contrast, the highest concentration of NH_4-N was obtained at P_3010 at 20 cm, followed by S_400 at 5 cm. However, at all sites, NH_4-N concentrations at 5 cm were not significantly different from each other. Such as NO_3-N, NH_4-N also decreased with depth, except at P_3010 where the increase at 20 cm with respect to 5 cm was almost doubling. Higher N contents were measured at 5 cm compared to 20 cm depth at all sites; and S_400 exhibited the highest content at both depths, 1.3-1.4 times higher than any other N percentage at the same depth, and even 4 times higher than any other N percentage at 20 cm depth. The C content showed a general decrease with depth at all sites, with the highest percentage at S_400 at 5 cm, and the lowest one at M_1100 at 20 cm. Higher $\delta^{15}N$ signatures were obtained at 20 cm compared to 5 cm depth; at S_400 the soil was most enriched in ^{15}N, and P_3010 showed the most depleted one.

Soil temperature decreased with altitude with a gradient of -4.2 °C per 1000 m, with no statistical difference between months (Fig. S2). WFPS increased significantly with depth at all sites during both months (Fig. S3), except at C_2200 in September. The lowest WFPS at 5 cm depth was obtained at C_2200 (16.8% ± 2.5) and P_3010 (14.4% ± 0.3) in August and September, respectively, whereas the highest one at M_1100 at 20 cm in both months (August: 75.9% ± 0.3; September: 71.9% ± 6.3).

2.2 Greenhouse gas fluxes

In general, all sites were sources of CO_2 (Fig. 1a, Table 1). Except for P_3010, mean CO_2 emissions were higher in September compared to August, but due to the high variability in the measurements, there was no significant difference between months at M_1100, C_2200 and P_3010 ($P > 0.05$). The lowest and highest emissions were observed at C_2200 (August and September) and P_3010 (August), respectively. All mean CH_4 fluxes were negative, indicating a net flux from the atmosphere to the soil (Fig. 1b, Table 1). Although the mean CH_4 fluxes (except for P_3010) were higher in September compared to August, there was no significant difference ($P > 0.05$) between months at any site. Finally, the mean N_2O fluxes showed a general negative trend with increasing altitude (Fig. 1c). A marked net N_2O consumption was observed at the sites located at 2200 and 3010 m a.s.l.; however, there was no significant difference ($P > 0.05$) in any plot between months. The highest consumption was observed in September at C_2200, followed by P_3010 in August, while the highest emission was in September at M_1100 (Table 1).

Although only monthly average fluxes were discussed, the large variability observed with most of the gas fluxes (Table 1 and Fig. 1) are the result of the spatial (i.e. differences in GHG fluxes between chambers) and temporal (i.e. differences in GHG fluxes per day) variability within each site.

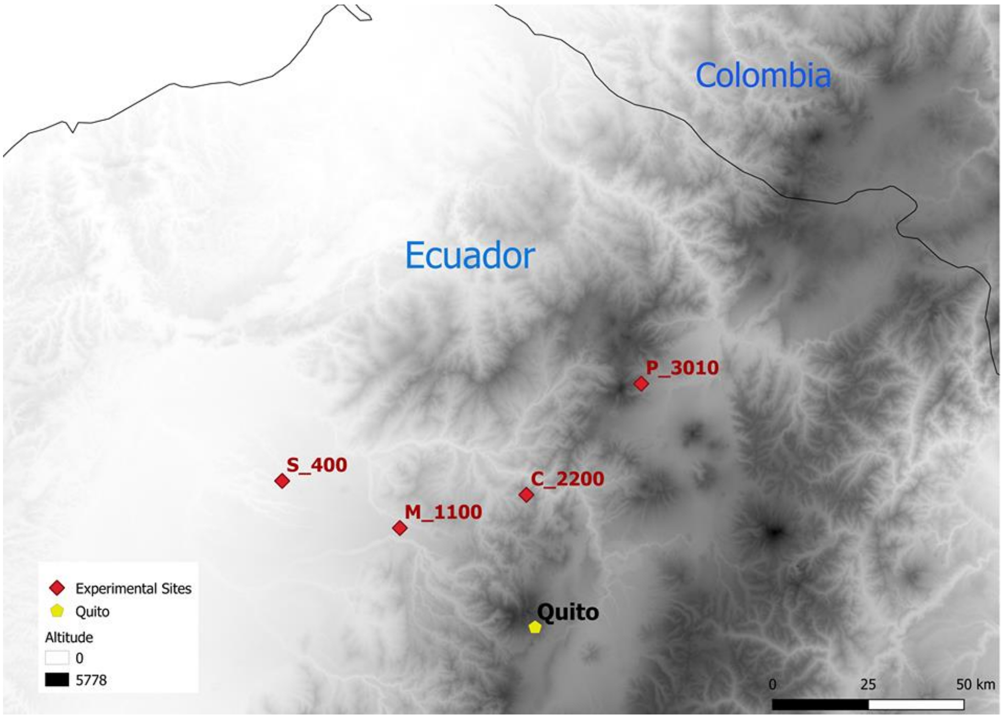

Fig. S1. Overview map with the location of the study areas: Río Silanche (400 m a.s.l.; S_400), Milpe (1100 m a.s.l.; M_1100), El Cedral (2200 m a.s.l.; C_2200) and Peribuela (3010 m a.s.l.; P_3010). Study areas projected on a DEM based on SRTM data (Jarvis et al., 2008).

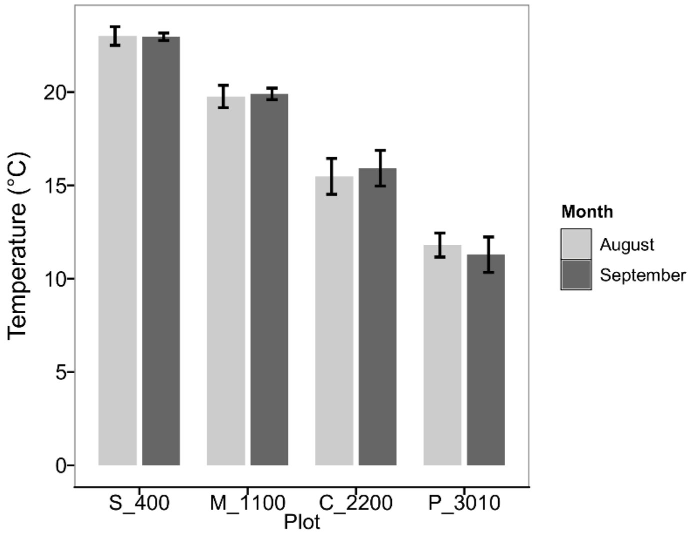

Fig. S2. Monthly average soil temperature (°C)±standard deviations (SD) at Río Silanche (400 m a.s.l.; S_400), Milpe (1100 m a.s.l.; M_1100), El Cedral (2200 m a.s.l.; C_2200) and Peribuela (3010 m a.s.l.; P_3010). Light grey: average soil temperature in August; dark grey: average soil temperature in September.

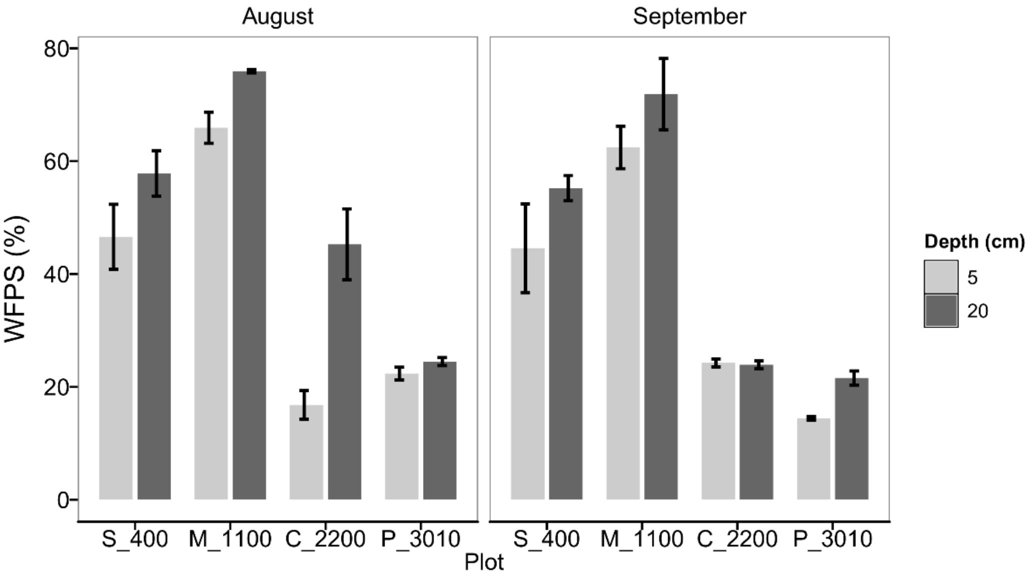

Fig. S3. Monthly average water-filled pore space (WFPS)±standard deviations (SD) at Río Silanche (400 m a.s.l.; S_400), Milpe (1100 m a.s.l.; M_1100), El Cedral (2200 m a.s.l.; C_2200) and Peribuela (3010 m a.s.l.; P_3010) at 5 and 20 cm depth. Light grey: average WFPS at 5 cm, dark grey: average WFPS at 20 cm.

Table S1. Measured and estimated annual CO_2, CH_4 and N_2O fluxes from tropical forest soils of South America including elevation, mean annual precipitation (MAP), mean annual temperature (MAT) and period of measurement. N.R. stands for not reported.

Country	Elevation (m a.s.l.)	MAP (mm) MAT (°C)	Measured CO_2 flux (g CO_2-C $m^{-2}h^{-1}$) and period of measurement	Estimated annual CO_2 flux (Mg CO_2-C $ha^{-1}y^{-1}$)	Measured CH_4 flux (µg CH_4-C $m^{-2}h^{-1}$) and period of measurement	Estimated annual CH_4 flux (kg CH_4-C $ha^{-1}y^{-1}$)	Measured N_2O flux (µg N_2O-N $m^{-2}h^{-1}$) and period of measurement	Estimated annual N_2O flux (kg N_2O-N $ha^{-1}y^{-1}$	Reference
Brazil	50	2000 -	N.R.	N.R.	-11.5 April 1983	N.R.	43.6 April 1983	N.R.	(Keller et al., 1983)
Brazil	50	2000 -	N.R.	N.R.	0.7; -22.3 December 1983, and March 1984	N.R.	13.1; 31.0 December 1983, and March 1984	N.R.	(Keller et al., 1986)
Brazil	54	2200 -	N.R.	N.R.	N.R.	N.R.	15-35 April 1987-April 1988	1.9	(Luizão et al., 1989)
Brazil	130	1750 -	Dry season: 240±20 November 1992^3; Wet season: 290±20 May 1992^3	N.R.	N.R.	N.R.	N.R.	N.R.	(Davidson and Trumbore, 1995)
Brazil	150	2200 25.5	N.R.	N.R.	-3.42 to -5.93 kg CH_4-C $ha^{-1}y^{-1}$ June 1992-December 1993^1		N.R.	N.R.	(Steudler et al., 1996)
Brazil	130	1850 N.R.	N.R.	N.R.	N.R.	N.R.	***Fazenda Vitória – Primary forest*** Dry season: 10.4±0.8 Wet season: 52.3±4 February 1995-May 1996	2.43	(Verchot et al., 1999)
							Fazenda Vitória – Secondary forest Dry season: 6.9±1.1 Wet season: 16.2±1.3 February 1995-May 1996	0.94	

			N.R.	N.R.	N.R.	N.R.	***Fazenda São José*** 5.4±1.6 July 1996	N.R.	
			N.R.	N.R.	N.R.	N.R.	***Fazenda São Sebastião*** 2.0±0.7 July 1996	N.R.	
Brazil	130	1800 N.R.	N.R.	20	N.R.	N.R.	N.R.	N.R.	(Davidson et al., 2000)
	130	1800 N.R.	N.R.	18	N.R.	N.R.	N.R.	N.R.	
Brazil	130	1850 N.R.	Dry season: 181±9 Wet season: 299±14 April 1995-May 1996	20	Dry season: -30.6±6.6 Wet season: 0.9±6.6 April 1995-May 1996	-1.6	N.R.	N.R.	(Verchot et al., 2000)
	130 (Secondary forest since 1976)	1850 N.R.	Dry season: 174±10 Wet season: 245±10 April 1995-May 1996	17.9	Dry season: -10.6±5.6 Wet season: -6.2±2.5 April 1995-May 1996	-0.7	N.R.	N.R.	
Brazil	145	2200 25.6	N.R.	N.R.	N.R.	N.R.	1.94±0.22 kg N_2O-N ha^{-2}y^{-1} June 1992-January 1996		(Melillo et al., 2001)
Brazil	150	2270 18.8-25.6	N.R.	N.R.	N.R.	N.R.	Dry season: 1.3 August-September 1998 Wet season: 76.4, February-March 1998; 67.0 March 1999	N.R.	(Garcia-Montiel et al., 2001)
Brazil	150	2270 25.6	129.21± 31.93 November 2001	N.R.	N.R.	N.R.	13.13± 3.75 November 2001	N.R.	(Garcia-Montiel et al., 2003)
Brazil	200	2000 25	N.R.[2]	N.R.	N.R.[2]	N.R.	185 (clay soil), 15 (sandy soil) June-August 2000	N.R.	(Varner et al., 2003)
Brazil	150	2090-2270	***Nova Vida 1*** 148.1±9.7	N.R.	N.R.	N.R.	***Nova Vida 1*** 27.3±4.6	N.R.	

		18.8-25.6	1992-1999				1992-1999		(Garcia-Montiel et al., 2004)
			Nova Vida 2 155.5±18.5 1992-1993	N.R.	N.R.	N.R.	***Nova Vida 2*** 19.2±7.0 1992-1993	N.R.	
			Proto Velho 163.92 October 1993 and March 1994	N.R.	N.R.	N.R.	***Proto Velho*** 25.2 October 1993 and March 1994	N.R.	
			Jamari 151.09 October 1993 and March 1994	N.R.	N.R.	N.R.	***Jamari*** 34.5 October 1993 and March 1994	N.R.	
			Cacaulândia 159.01 October 1993 and March 1994	N.R.	N.R.	N.R.	***Cacaulândia*** 34.3 October 1993 and March 1994	N.R.	
			Ouro Preto 144.7 October 1993 and March 1994	N.R.	N.R.	N.R.	***Ouro Preto*** 30.5 October 1993 and March 1994	N.R.	
			Vilhena 161.4 October 1993 and March 1994	N.R.	N.R.	N.R.	***Vilhena*** 28.1 October 1993 and March 1994	N.R.	
Brazil	200	2000 21 - 23	10.0±0.9 Mg CO_2-C ha^{-1}y^{-1} September 1998-December 2002[1]		-0.8±0.7 kg CH_4-C ha^{-1}y^{-1} September 1998-December 2002[1]		2.6±1.0 kg N_2O-N ha^{-2}y^{-}1 September 1998-December 2002[1]		(Davidson et al., 2004)
Brazil	200	2000 25	138.4±4.3 (clay soil), 160.0±8.6 (sandy soil) June 2000-May 2001	N.R.	-11.2±4.4 (clay soil), N.R. (sandy soil) June 2000-July 2011	N.R.	130±10 (clay soil), 14±2 (sandy soil) June 2000-July 2011	N.R.	(Silver et al., 2005)
Brazil	200	2000 21 - 23	12.8±1.0 Mg CO_2-C ha^{-1}y^{-1} September 1998-April 2005[1]		-1.2±0.7 kg CH_4-C ha^{-1}y^{-1} September 1998-April 2005[1]		2.1±0.7 kg N_2O-N ha^{-2}y^{-1} September 1998-April 2005[1]		(Davidson et al., 2008)
Brazil	100	3050	N.R.	13.3	-2.7±0.5 kg CH_4-C ha^{-1}y^{-1}		3.4±0.4 kg N_2O-N ha^{-2}y^{-}1		

		19.1 - 25.5			September 2006-August 2007^1		September 2006-August 2007^1		(Sousa Neto et al., 2011)
	400	3050 19.1 - 25.5	N.R.	13.6	-4.9±8.0 kg CH_4-C ha^{-1}y^{-1} September 2006-August 2007^1		0.9±0.1 kg N_2O-N ha^{-2}y-1 September 2006-August 2007^1		
	1000	2300 19.1 - 25.5	N.R.	12.9	-4.4±0.3 kg CH_4-C ha^{-1}y^{-1} September 2006-August 2007^1		0.8±0.2 kg N_2O-N ha^{-2}y-1 September 2006-August 2007^1		
Ecuador	400	4500 -	171.6 August 1984	N.R.	19.4 August 1984	N.R.	7.5 August 1984	N.R.	(Keller et al., 1986)
	400 (Secondary forest of 5-10 years old)	4500 -	117.0 August 1984	N.R.	-25.1 August 1984	N.R.	7.4 August 1984	N.R.	
Ecuador	1000	2230 19.4	N.R.	N.R.	N.R.	N.R.	0.2±0.1 (lower slope), 0.3±0.1 (mid-slope), 0.4±0.1 (ridge) kg N_2O-N ha^{-2}y^{-1} May 2008-May 2009^1		(Wolf et al., 2011)
	2000	1950 15.7	N.R.	N.R.	N.R.	N.R.	1.3±0.2 (lower slope), 0.3±0.1 (mid-slope), 0.1±0.1 (ridge) kg N_2O-N ha^{-2}y^{-1} May 2008-May 2009^1		
	3000	4500 9.4	N.R.	N.R.	N.R.	N.R.	1.1±0.1 (lower slope), 0.1±0.1 (mid-slope), -0.05±0.1 (ridge) kg N_2O-N ha^{-2}y^{-1} May 2008-May 2009^1		
Ecuador	1000	2230 19.4	10.3±0.8 (lower slope), 10.3±0.1 (mid-slope), 9.8±0.9 (ridge) Mg CO_2-C ha^{-1}y^{-1} May 2008-May 2009^1		-5.5±0.7 (lower slope), -5.4±0.9 (mid-slope), -5.9±1.0 (ridge) kg CH_4-C ha^{-1}y^{-1} May 2008-May 2009^1		N.R.	N.R.	(Wolf et al., 2012)
	2000	1950 15.7	8.8±0.4 (lower slope), 7.6±0.6 (mid-slope), 6.7±0.7 (ridge) Mg CO_2-C ha^{-1}y^{-1} May 2008-May 2009^1		-2.3±0.3 (lower slope), -4.3±0.9 (mid-slope), -2.7±0.3 (ridge) kg CH_4-C ha^{-1}y^{-1} May 2008-May 2009^1		N.R.	N.R.	
	3000	4500 9.4	6.4±0.4 (lower slope), 5.7±0.7 (mid-slope), 3.7±0.5 (ridge) Mg CO_2-C ha^{-1}y^{-1} May 2008-May 2009^1		-0.6±1.2 (lower slope), -1.6±0.4 (mid-slope), -1.0±0.1 (ridge) kg CH_4-C ha^{-1}y^{-1} May 2008-May 2009^1		N.R.	N.R.	
Ecuador	1000	2230 19.4	N.R.	N.R.	N.R.	N.R.	0.2±0.1 (2008), 0.5±0.1 (2009) kg N_2O-N ha^{-2}y^{-1} January 2008-September 2009^1		(Martinson et al., 2013)

	2000	1950 15.7	N.R.	N.R.	N.R.	N.R.	0.2± 0.03 (2008), 0.1±0.2 (2009) kg N_2O-N ha^{-2}y^{-1} January 2008-September 2009		
	3000	4500 9.4	N.R.	N.R.	N.R.	N.R.	-0.03± 0.1 (2008), -0.3±0.3 (2009) kg N_2O-N ha^{-2}y^{-1} January 2008-September 2009		
Ecuador	1000	2230 19.4	N.R.	N.R.	N.R.	N.R.	0.57±0.26 kg N_2O-N ha^{-1}y^{-1} November 2010-August 2012[1]		(Müller et al., 2015)
	2000	1950 15.4	N.R.	N.R.	N.R.	N.R.	0.17±0.06 kg N_2O-N ha^{-1}y^{-1} November 2010-August 2012[1]		
	3000	4500 9.4	N.R.	N.R.	N.R.	N.R.	0.05±0.04 kg N_2O-N ha^{-2}y^{-1} November 2010-August 2012[1]		
French Guiana	49	2200 26	99.4 July-September 1994	N.R.	N.R.	N.R.	N.R.	N.R.	(Janssens et al., 1998)
French Guiana	30	2771.2±628.8 27.3±0.5	N.R.	N.R.	N.R.	N.R.	15.83±2.1 April 2010-April 2011	1.32 [5]	(Petitjean et al., 2015)
French Guiana	147-194	2990-3041 25.7	***Nouragues forest*** Dry season: 92.6±34.3 (top hill), 89.9±37.8 (middle slope), 131.0±64.2 (bottom slope) October 2015 Wet season: 159±36.5 (top hill), 191.7±66.5 (middle slope), 188.8±50.2 (bottom slope) May 2016	N.R.	***Nouragues forest*** Dry season: -64.0±69.7 (top hill), 6.6±237.9 (middle slope), -49.9±50.1 (bottom slope) October 2015) Wet season: -19.9±70.3 (top hill), 43.2±274.0 (middle slope), 9.4±64.9 (bottom slope) May 2016	N.R.	***Nouragues forest*** Dry season: -20.4±15.0 (top hill), -20.1±17.4 (middle slope), -32.5±21.6 (bottom slope) October 2015 Wet season: -30.7±30.9 (top hill), -31.9±15.5 (middle slope), -55.4±47.6 (bottom slope) May 2016	N.R.	(Courtois et al., 2018)

			Paracou forest Dry season: 165.2±50.2 (top hill), 131.7±34.3 (middle slope), 189.6±96.8 (bottom slope) October 2015 Wet season: 161.6±62.9 (top hill), 138.3±88.7 (middle slope), 94.8±57.4 (bottom slope) May 2016	N.R.	***Paracou forest*** Dry season: -44.0±139.7 (top hill), -19.9±79.5 (middle slope), 6.6±103.7 (bottom slope) October 2015 Wet season: 3.7±40.1 (top hill), -1.9±41.2 (middle slope), 23.9±34.6 (bottom slope) May 2016	N.R.	***Paracou forest*** Dry season: -31.2±27.5 (top hill), -41.4±54.5 (middle slope), -35.7±21.8 (bottom slope) October 2015 Wet season: -49.7±49.8 (top hill), -19.3±45.1 (middle slope), -18.0±70.9 (bottom slope) May 2016	N.R.	
French Guiana	40.	2929[4] 27	Dry season: 99.6±7.9 Wet season: 111.3±5 May 2011-November 2014	N.R.	Dry season: -12.9±10.8 Wet season: -12.1±9.2 May 2011-November 2014	N.R.	Dry season: 8.3±2.1 Wet season: 12.9±1.7 May 2011-November 2014	N.R.	(Petitjean et al., 2019)
Peru	180	2200 26	N.R.	N.R.	-29.0 to -32.1 October 1997-October 1999	-2.6	8.1 to 18.8 October 1997-October 1999	0.80	(Palm et al., 2002)
Peru	200	2700 26.4	Dry season: 0.19±0.01[6] 2007	N.R	N.R	N.R	N.R	N.R	(Zimmermann et al., 2009)
	1000	3100 21.3	Dry season: 0.18±0.007[6] 2007	N.R	N.R	N.R	N.R	N.R	
	1500	2600 18.3	Dry season: 1.17±0.007[6] 2007	N.R	N.R	N.R	N.R	N.R	
	3030	1700 12.5	Dry season: 0.18±0.008[6] 2007	N.R	N.R	N.R	N.R	N.R	
Peru	600 - 1200	5318	N.R.	N.R.	Dry season: -13.3±4.6	-0.14±0.12	Dry season: 40.0±19.6	0.54±0.32	

		23.4			Wet season: 21.3±17.1 July 2011 – December 2011		Wet season: -6.3±17.9 July 2011 – December 2011		
	1200 - 2200	2631 18.8	N.R.	N.R.	Dry season: -35.0±2.9 Wet season: -20.4±5.4 December 2010 - December 2011	-0.69±0.09	Dry season: 40.8±9.6 Wet season: 6.7±5.4 December 2010 - December 2011	0.50±0.13	(Teh et al., 2014)
	2200 - 3200	1706 12.5	N.R.	N.R.	Dry season: -50.8±1.7 Wet season: -22.5±4.6 December 2010 - December 2011	0.80±0.08	Dry season: 7.9±7.1 Wet season: 0.8±9.2 December 2010 - December 2011	0.12±0.13	
Peru	1070 - 1088	5300 23.4	Dry season: 216.7±12.5 Wet season: 212.5±12.5 July 2011-June 2013	N.R.	Dry season: -8.3±4.2 Wet season: -4.2±4.2 July 2011-June 2013	N.R.	N.R.	N.R.	(Jones et al., 2016)
	1532 - 1769	2600 18.8	Dry season: 179.2±12.5 Wet season: 170.8±12.5 February 2011-June 2013	N.R.	Dry season: -45.8±4.2 Wet season: -1.34±4.2 February 2011-June 2013	N.R.	N.R.	N.R.	
	2811 - 2962	1700 12.5	Dry season: 210.8±12.5 Wet season: 166.7±12.5 February 2011-June 2013	N.R.	Dry season: -66.7±4.2 Wet season: -45.8±4.2 February 2011-June 2013	N.R.	N.R.	N.R.	

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[1] Measured mean annual fluxes.

[2] Soil-atmosphere fluxes of CO_2 and CH_4 were measured weekly during June-August 2000, but average values are not reported.

[3] Measured CO_2 fluxes from the soil surface.

[4] Average of the annual rainfall measured at the experimental site during 4 years.

[5] Cumulative N_2O fluxes from the 11/05/2010 to the 09/05/2011

[6] Values for undistrubed “native” soil. This study evaluated the climate dependence of heterotrophic soil respiration from a soil-translocation experiment. As a matter of comparison with the others studies, only control cores are depicted, i.e. soil cores re-installed at the same site.

Table S2. Characteristics of the study areas Río Silanche (400 m a.s.l.; S_400), Milpe (1100 m a.s.l.; M_1100), El Cedral (2200 m a.s.l.; C_2200) and Peribuela (3010 m a.s.l.; P_3010), including mean annual precipitations (MAP) and mean annual temperatures (MAT) extracted from the Worldclim data set, using average monthly data from 1970-2000 with a spatial resolution of ~1 km^2 (Fick and R.J. Hijmans, 2017). Forest classification has been done based on the system used by the country (FAO, 2017; Ministerio del Ambiente, 2015).

Study area	**Forest type**	**Coordinates**		**Altitude (m a.s.l.)**	**MAP (mm)**	**MAT (°C)**
		Latitude	Longitude			
S_400	Lowland evergreen forest of Choco	00°08’45.58’’ N	79°08’34.22’’ W	400	3633	23.0
M_1100	Andean foothill evergreen	00°02’07.17’’ N	78°51’59.72’’ W	1100	2856	21.1
C_2200	Andean montane evergreen	00°06’47.87’’ N	78°34’10.88’’ W	2200	1464	16.8
P_3010	Upper montane evergreen	00°22’27.35’’ N	78°18’0.36’’ W	3010	956	12.8

Note: the coordinates were taken at the center of the plots.

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