1 Contribution of advection to nighttime ecosystem 2 respiration at a mountain grassland in complex terrain

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10 Abstract

11 Net ecosystem carbon dioxide (CO₂) exchange (NEE) at FLUXNET sites
12 is typically evaluated by means of the eddy covariance technique using a set of
13 instruments on a single tower. However, in complex terrain, such as mountain
14 areas, and during nighttime atmospheric conditions, with low turbulent mixing
15 and stable stratification, this approach is known to underestimate the night-
16 time NEE and thus bias longer-term carbon balances. This study reports on
17 the quantification of advection at a subalpine grassland site in Northern Italy
18 (2160 m asl) situated in complex mountainous terrain. We show that different
19 published methods for indirectly or directly accounting for advection resulted
20 in a large divergence in the annual carbon balance. Advection, and in particu-
21 lar the horizontal term, reached non negligible values during nighttime and its
22 inclusion in the CO₂ conservation equation increased NEE by a factor of two.
23 NEE calculated by taking into account all terms (NEE_{acmb}), i.e. turbulent ex-
24 change, change in storage and advection of CO₂, matched the approach based
25 on the after-sunset maximum in the vertical turbulent flux and change in the
26 storage of CO₂ and ecosystem respiration measured by automated chambers.
27 Accounting for advection led to a 169% change in the annual carbon budget,
28 turning the ecosystem from a sink (-108 gCm⁻²y⁻¹) to a source (75 gCm⁻²y⁻¹)
29 of CO₂.

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31 covariance, advection

32 1. Introduction

33 The increase in the atmospheric concentration of carbon dioxide (CO₂) since
34 1750 is the major factor responsible for the observed global warming (Stocker
35 et al., 2013). Since a percentage (~40-45%) of the anthropogenically emitted
36 CO₂ remains in the atmosphere, while a part is captured by ocean and land
37 sinks (Le Quéré et al., 2009), particular attention of the scientific community
38 has been devoted to assessing the role of several ecosystems to the global carbon
39 cycle (Baldocchi, 2014).

40 A widely used method to quantify the net exchange of CO₂ (NEE) between
41 ecosystems and the atmosphere is the eddy covariance (EC) technique, which
42 operates at the appropriate spatial scale of the ecosystem and covers temporal
43 scales from hours to decades (Baldocchi, 2003). These characteristics make the
44 EC method an invaluable tool for studying the long-term gas exchange processes
45 and to determine if an ecosystem acts as a sink or a source of CO₂ and how
46 this role could be modified by climate change. Nevertheless, the EC method
47 is prone to some critical issues (Aubinet, 2008), which must be taken into ac-
48 count, primarily when the aim of the study is to determine the net amount of
49 carbon that is sequestered or emitted by an ecosystem during a given timespan.
50 The EC method assesses the source/sink term of the CO₂ conservation equation
51 assuming that it can be inferred from the vertical turbulent exchange and the
52 change in the storage term, thereby considering the remaining components, i.e.
53 the vertical and horizontal advection and the divergence of the turbulent flux,
54 negligibly small (Finnigan 1999; Aubinet et al. 2000). This approach relies on
55 the assumption that the mass balance of CO₂ mixing ratio of an ecosystem can
56 be approximated by a single point measurement when the requirements of sta-
57 tionary conditions, high turbulent mixing, flat, and horizontally homogeneous
58 terrain are satisfied (Baldocchi et al. 2000; Aubinet et al. 2003; Marcolla et al.

2005; Etzold et al. 2010; Foken et al. 2012). During stable and calm nighttime conditions, and in particular in complex terrain these requirements are however likely to be violated and the advective terms of the conservation equation become non-negligible, resulting in an underestimation of the nocturnal NEE (Baldocchi et al. 2000; Aubinet et al. 2010; Vickers et al. 2012). Since the daily net exchange of CO_2 is composed by net uptake during daytime, when plant photosynthesis exceeds respiration, and net emission of CO_2 during nighttime due to ecosystem respiration, the unaccounted advective fluxes may potentially bias the net daily and longer-term flux measurements towards a systematically overestimated net CO_2 sequestration (Goulden et al. 1996; Moncrieff et al. 1996).

Common approaches to overcome the nighttime underestimation are based on the rejection of data measured when the theoretical requirements are not fulfilled. The widely used engineering-type approach consists in discarding data measured during calm conditions, i.e. below a site-specific threshold of friction velocity (u^*) and replacing these with values estimated from an empirical relationship between the remaining NEE data (under windy conditions) and environmental parameters (Falge et al. 2001a,b; Reichstein et al. 2005; Papale et al. 2006). Acevedo et al. (2009) pointed to uncertainties related to this threshold and proposed the use of the standard deviation of the vertical wind velocity (w) instead of u^* . van Gorsel et al. (2007) presented another alternative method, which takes advantage of the early evening maximum in the vertical turbulent flux and change in the storage of CO_2 , resulting from the interval between sunset and the onset of advection. The authors proposed to derive an empirical model based on the early evening maximum in NEE and independent variables, such as air and soil temperature, which is then used to estimate nighttime respiration. However, since substituting nighttime NEE measured during calm conditions with NEE estimated using observations made under windy periods potentially propagates errors, each of the described methods may increase NEE uncertainty (Baldocchi 2003; Acevedo et al. 2009). Alternatively, all terms contributing to the nighttime carbon exchange can be measured, making corrections during non-turbulent periods unnecessary. This approach, coined *advection completed mass*

90 *balance* (ACMB) by [Aubinet et al. \(2010\)](#), requires additional measurements of
 91 wind speed and horizontal/vertical CO₂ gradients. Since natural ecosystems,
 92 and in particular mountain sites, are often located in complex terrain, the eval-
 93 uation of the full CO₂ mass balance has recently received increasing attention
 94 (e.g. [Marcolla et al. 2005](#); [Aubinet et al. 2010](#); [Feigenwinter et al. 2008](#); [Montag-](#)
 95 [nani et al. 2010](#)). However, multiple towers and complex arrays of instruments
 96 are generally required for running these measurements, which are costly and
 97 difficult to be maintained with a long-term perspective ([Aubinet et al. 2010](#);
 98 [Marcolla et al. 2014](#)). Previous advection experiments have been conducted
 99 almost exclusively in forest ecosystems and, to our knowledge, only little infor-
 100 mation exists for low statured vegetation where advection is often supposed to
 101 play a minor role ([Hiller et al., 2008](#)). However, grasslands may have a large
 102 practical advantage compared to forests, since measurements of advection can
 103 be realised with smaller infrastructure and thus with less experimental and eco-
 104 nomical effort. Reporting on the role of neglected advective fluxes in grassland
 105 ecosystems is of foremost importance to contribute towards reducing the un-
 106 certainty of current NEE global estimates and on the surface energy imbalance
 107 problem ([Leuning et al., 2012](#)), as these ecosystems cover 40% of land surface
 108 ([White et al., 2000](#)). In addition, grassland ecosystems are characteristic ele-
 109 ments of worldwide mountain areas, which, with their global distribution and
 110 the sensitivity to both human and environmental changes represent invaluable
 111 reference points in climate change research ([Körner, 2003](#)). Because mountain
 112 terrain with its complex orography and fragmented nature is prone to the de-
 113 velopment of adverse conditions for micrometeorological studies ([Rotach et al.,](#)
 114 [2014](#)), such as nocturnal gravity flows, EC measurements in these locations
 115 have been historically discouraged. Nevertheless, previous studies ([Etzold et al.,](#)
 116 [2010](#)) demonstrated that the typical bi-directional wind pattern, such as diurnal
 117 slope or valley winds ([Whiteman 2000](#); [Hammerle et al. 2007](#); [Wohlfahrt et al.](#)
 118 [2016](#)), makes the set-up of advection studies less challenging than in some flat
 119 area (e.g. [Aubinet et al. 2010](#)).

120 Advances in respiration chambers technology allow to compare EC-based

121 nighttime NEE with independent measurements of ecosystem respiration. How-
 122 ever, uncertainties exist when upscaling observations from leaf to canopy or
 123 ecosystem scale or if temporally discrete manual measurements are performed.
 124 Automated chambers are easier to use in low canopies, where the main sources
 125 of uncertainty could be represented by the system design and the small-scale
 126 spatial variability in the sources/sinks of CO₂ (Baldocchi 2014; Görres et al.
 127 2015).

128 In this paper we present a proof-of-concept study, which aims at illustrat-
 129 ing the first quantification of the contribution of advective fluxes to the CO₂
 130 budget measured by EC at a subalpine grassland in the Alps. The specific ob-
 131 jectives of the study were: *i*) to quantify the advective fluxes with a simplified
 132 2-D approach, *ii*) to illustrate the comparison among different EC-based and
 133 chamber-based NEE calculations to obtain the nocturnal respiration at our site
 134 and *iii*) to extrapolate advection data to years not covered by direct measure-
 135 ments.

136 2. Materials and Methods

137 2.1. Study site

138 The Torgnon site (FLUXNET site name IT-Tor) is a subalpine unmanaged
 139 grassland located in the northwestern Italian Alps at an elevation of 2160 m asl
 140 (45°50'40" N, 7°34'41" E). Dominant vegetation mainly consists of matgrass,
 141 (*Nardus stricta*) with *Arnica montana*, *Trifolium alpinum* and *Carex semper-*
 142 *virens* as co-dominant species. During the growing season, the peak value of
 143 leaf area index (LAI) is on average 2.2 m²m⁻² and maximum canopy height is
 144 20 cm. The site is characterized by a mean annual temperature of 3.1 °C and
 145 mean annual precipitation of about 880 mm. On average, the site is covered by
 146 snow (up to 90-120 cm of snow depth) from the end of October to late May,
 147 which limits the growing season to an average of five months. While the aver-
 148 age terrain slope is less than 5°, with a total difference in altitude of 22 meters,
 149 the site is characterized by undulating terrain with slopes at various angles and

150 expositions (Fig. 1). Regular eddy covariance (EC) measurements of CO₂ flux
151 are carried out continuously since June 2008 (Galvagno et al. 2013). In this
152 study, data of the years 2010, 2011, 2012 and 2014 were used for the analysis.

153 2.2. Permanent and experimental EC setups

154 The permanent instrumental setup at the site consists of an eddy covari-
155 ance system (hereinafter labeled EC-1, Fig. 1) composed by a CSAT3 three-
156 dimensional sonic anemometer (Campbell Scientific, Inc.) for measurement of
157 wind speed in the three components (u , v , w) and the sonic temperature, and
158 a LI-7500 open-path infrared gas analyzer (LI-COR, Inc.) for measurements of
159 CO₂ and H₂O air densities. Instruments were placed 1.65 m above the ground
160 and measurements were performed at a frequency of 10 Hz. A weather station
161 provided 30-min averaged records of different meteorological parameters, includ-
162 ing air and soil temperature (HMP45, Vaisala Inc. and therm107, Campbell
163 Scientific, Inc.), and global radiation (CNR4, Kipp and Zonen Corp.). Further
164 details on the site instrumental system are found in Galvagno et al. (2013).

165 To evaluate the contribution of advection to the carbon balance of this grass-
166 land, in summer 2012 an additional eddy covariance system (EC-2) and mea-
167 surements of wind speed and CO₂ concentrations (see section 2.3) were set up.
168 EC-2 was equipped with sensors equivalent to EC-1, and an additional two-
169 dimensional sonic anemometer (WindSonic, Gill) placed at 0.90 m above the
170 ground. EC-2 was sequentially (from 31 July to 10 August and from 10 to 21
171 August) placed at two different locations of the site, to account for potential
172 spatial differences in the contribution of advection (Fig. 1).

173 2.3. CO₂ concentration profiles and automated chambers

174 The LI-8100/8150 profiling system (LI-COR, Inc.) was used to obtain hori-
175 zontal and vertical profiles of CO₂ concentrations. In detail, CO₂ concentration
176 was measured over two vertical profiles with three sample points each (0.30,
177 0.90, 1.65 m), installed 30 meters uphill and downhill the EC-2 tower with the
178 following scheme: 1. uphill 1.65 m - downhill 1.65 m; 2. uphill 0.90 m - downhill

179 0.90 m; 3. uphill 0.30 m - downhill 0.30 m. The transect was aligned NE-SW
 180 (45-200°), the main wind direction (Fig. 1). The 6 inlets were consecutively
 181 sampled for CO₂ concentration with an observation length of 1 min using an
 182 air flow of 3 lmin⁻¹. A purging period of 15 seconds was set in order to pre-
 183 vent contamination between two sequential measurements. In any measurement
 184 cycle each point was sampled twice and then averaged to a half-hourly value.

185 In order to obtain independent measures of ecosystem respiration, four au-
 186 tomated opaque CO₂ flux chambers (model 8100-104, LI-COR, Inc.) were in-
 187 stalled near the advection transects during the advection campaign and near
 188 EC-1 in all the other years. Being applied in a low-canopy site, this enclosure
 189 system allows estimating ecosystem respiration directly without the need for
 190 upscaling component CO₂ flux measurements (Görres et al., 2015). CO₂ flux
 191 from the automated chambers was derived as the rate of change of CO₂ mixing
 192 ratio in the measurement chamber according to the manufacturer software, and
 193 data were considered as outliers and removed when the coefficient of determi-
 194 nation of the gradient fit was lower than 0.99. The instrument was calibrated
 195 prior to the field campaign. Because each chamber sampled a small area, differ-
 196 ences between chambers can occur due to small-scale spatial variability in the
 197 sources/sinks of CO₂ fluxes. The coefficient of variation (CV) was quantified
 198 taking into account standard deviations among the four chambers for the whole
 199 study period, and averaged to 18% (mean standard deviation, 1.1 $\mu\text{molm}^{-2}\text{s}^{-1}$,
 200 for further details refer to the Appendix).

201 2.4. EC data processing

202 Half-hourly eddy fluxes (EC-1, EC-2) were calculated by computing the
 203 mean covariance between vertical wind speed and CO₂ densities (Baldocchi,
 204 2003), and following the standard procedures as reported by the Euroflux method-
 205 ology for both raw data processing and quality check (Aubinet et al. 2000;
 206 Mauder and Foken 2004). The planar-fit method was performed for each loca-
 207 tion of the experimental campaign to correct the anemometer tilt with respect
 208 to the mean wind streamlines (Wilczak et al., 2001). The density effect on flux

209 measurements due to heat and water vapor fluctuations was corrected using the
 210 method described in Webb et al. (1980), while frequency response corrections
 211 were applied in order to account for spectral loss in the high frequency and
 212 low frequency range following Moore (1986) and Aubinet et al. (2010). In this
 213 study the term F_c represents the vertical turbulent CO₂ flux and F_s is the stor-
 214 age term. F_s was computed as the time rate of change of the CO₂ mixing ratio
 215 at the measurement height for EC-1 and from the profiling system for EC-2 as
 216 described in section 2.5. In this study the convention by which negative fluxes
 217 correspond to a net CO₂ movement from the atmosphere to the biosphere and
 218 positive values the reverse was used. Commonly applied tests (i.e. integral tur-
 219 bulence characteristics and stationarity tests, Foken and Wichura (1996)) were
 220 applied to check the quality of the vertical turbulent flux and combined to an
 221 overall flag to filter the flux dataset.

222 2.5. Mass balance terms

223 For the theoretical background underlying the advection calculation and
 224 further details concerning the following paragraph we refer to the specific bibli-
 225 ography (Baldocchi et al. 2000; Finnigan 1999; Massman and Lee 2002; Aubinet
 226 et al. 2003).

227 We took advantage of the bi-directional wind pattern and simple canopy
 228 at this site to calculate advection in a simplified two-dimensional (2D) form
 229 (Feigenwinter et al., 2004), as previously applied in other studies (e.g. Aubinet
 230 et al. 2003; Marcolla et al. 2005; Etzold et al. 2010). The CO₂ mixing ratio
 231 measured by the profiling system along the vertical and horizontal transects
 232 were combined with wind speed data from the 3D and 2D EC-2 anemometers
 233 to compute the advection terms by means of a 5-point Gaussian quadrature
 234 rule. Wind speed was extrapolated at the 5 gaussian heights (0.08, 0.38, 0.83,
 235 1.27, 1.57 m) by applying a logarithmic wind profile above the canopy and
 236 an exponential equation below the canopy following the method described in
 237 Wohlfahrt et al. (2000). CO₂ mixing ratios were extrapolated at the same
 238 heights by applying a linear fitting. Horizontal advection (F_{ha}) was computed

239 as:

$$F_{ha} = \int_0^{1.65} \bar{u}(z) \frac{\partial \bar{c}(z)}{\partial x} dz \quad (1)$$

240 where, $\bar{u}$ is the along transect mean wind component, z represents the measure-
 241 ment and integration height and $\frac{\partial \bar{c}}{\partial x}$ is the horizontal gradient of CO₂ mixing
 242 ratio. By restricting our observations to conditions where the $\bar{u}$ direction does
 243 not exceed the profile alignment (45-200°) by more than 18°, we limited the
 244 uncertainty on the gradient measured by the proposed 2D approach to less than
 245 5%, based on the trigonometrical calculations derived from [Etzold et al. \(2010\)](#).
 246 The vertical advection term (F_{va}) was computed as the product of the mean
 247 vertical wind component, $w_{h1.65}$ at the measurement height $h_{1.65}$, and the dif-
 248 ference between the CO₂ mixing ratio at 1.65 m, $c_{h1.65}$ and the mean CO₂
 249 concentration in the control volume, c ([Lee 1998](#); [Feigenwinter et al. 2004](#)):

$$F_{va} = \bar{w}_{h1.65} (\bar{c}_{h1.65} - [\bar{c}]) \quad (2)$$

250 where,

$$[\bar{c}] = \frac{1}{h} \int_0^{1.65} \bar{c}(z) dz \quad (3)$$

251 Finally the storage term (F_c) for EC-2 was computed as follows:

$$F_s = \int_0^{1.65} \frac{\partial \bar{c}}{\partial t} dz \quad (4)$$

252 where $\frac{\partial \bar{c}}{\partial t}$ represents the time rate of change of CO₂ mixing ratio.

253 In order to quantify the measurement uncertainty related to our advection
 254 measurement system, the standard errors of half-hourly CO₂ mixing ratio and
 255 wind components, the accuracy of the instruments and the 5% error related to
 256 the transect alignment, were computed. The individual uncertainties were prop-
 257 agated into the advection calculations to obtain the F_{ha} and F_{va} measurement
 258 errors following error propagation rules ([Hughes and Hase, 2010](#)).

259 2.6. NEE calculation

260 In this study we tested the contribution of different calculation options on
 261 nighttime NEE measured during the 2012 campaign. NEE was firstly computed

as the sum of F_c and F_s measured by EC-2:

$$NEE = F_c + F_s \quad (5)$$

Different NEE calculations were then obtained in accordance with the following different approaches:

- NEE_{u^*} : nighttime NEE was filtered according to the u^* threshold of 0.05 ms^{-1} (Galvagno et al., 2013), computed based on Papale et al. (2006). Nighttime hours were selected using a global radiation (R_g) threshold of 20 Wm^{-2} .
- NEE_{σ_w} : nighttime NEE was filtered as described above, but using the turbulence scale of σ_w instead of u^* (Acevedo et al., 2009) with a threshold value of 0.09 ms^{-1} .
- R_{max} : nighttime NEE computed from the maximum value of $F_c + F_s$ after sunset as suggested by van Gorsel et al. (2008).
- NEE_{acmb} : in this approach the “*advection completed mass balance*” was estimated by adding the measured advective terms (section 2.5) to nighttime NEE, as follows:

$$NEE_{acmb} = F_c + F_s + F_{ha} + F_{va} \quad (6)$$

- NEE_{Fmod} : we investigated the relation of $F_{ha} + F_{va}$ with u^* in order to derive an estimation of advection (F_{mod}), related to turbulence conditions independent from direct measurements. F_{mod} was then summed to $F_c + F_s$ to obtain NEE_{Fmod} .
 - R_{cham} : nighttime NEE derived from the opaque chambers.
- To obtain continuous NEE time-series each dataset was gap-filled according to Reichstein et al. (2005). Furthermore, two independent and standard estimates of filtered and gapfilled NEE were derived from the FLUXNET2015 dataset (<http://fluxnet.fluxdata.org/data/fluxnet2015-dataset/>)
- NEE_{u*50} : NEE filtered using 50-percentile of u^* thresholds from bootstrapping. The u^* threshold is variable for each year.
 - NEE_{REF} : NEE filtered using the u^* threshold extracted from the model efficiency approach and variable for each year.

289 Finally, we considered the uncertainty related to the u^* threshold determina-
 290 tion available from the FLUXNET2015 dataset, and expressed it as interquantile
 291 range, IQR (i.e. the difference between NEE filtered using the 75th percentile
 292 and 25th percentile of u^* thresholds).

293 Since incorporating the advection terms in the CO_2 mass balance equation
 294 is still an issue (Aubinet et al., 2010), the eight described approaches were in
 295 addition applied to the full available EC-1 yearly datasets (2010, 2011, 2012,
 296 2014) to evaluate the impact that individual methods, and in particular the
 297 unaccounted advection, may have on the annual budgets. To this aim our ap-
 298 proaches were firstly tested on two independent validation datasets, i.e. different
 299 from the experimental one, the growing seasons of 2010 (128 days) and 2014 (168
 300 days), during which also chamber measurements were available. Yearly NEE_{u^*} ,
 301 $\text{NEE}_{\sigma w}$, R_{max} were computed for each year separately, NEE_{u^*50} and NEE_{REF}
 302 were directly obtained from the FLUXNET2015 dataset, while NEE_{Fmod} was
 303 estimated on the basis of data collected during the field campaign in 2012 and
 304 extrapolated to other years. Since the presence and transformation of snow-
 305 cover change the physical properties of the atmosphere-vegetation interface,
 306 thereby influencing the above fluxes (Armstrong and Brun, 2008), with the cur-
 307 rent dataset it was not possible to obtain information on the advective processes
 308 during the winter season, consequently, only the snow-free period was corrected,
 309 while winter NEE data was not corrected for all the datasets, except for NEE
 310 derived from FLUXNET2015, which was used precisely as provided from the
 311 database.

312 **3. Results**

313 *3.1. Atmospheric conditions*

314 In this section the average atmospheric conditions at the site are presented
 315 considering both the entire study period (growing season) from 2010 to 2014 and
 316 the data of the 2012 experimental campaign. The prevailing wind directions at
 317 the site (Fig. 1, 2) showed a typical bi-directional pattern, with SE ($180\text{-}220^\circ$)

and NW (20-70°) winds dominating during daytime (65%) and nighttime (83%), respectively. The shift from South-East to North-West winds was sharp at the transition from day to night hours (Fig. 2). This time of the day (around 19.00 CET) indicated the transition to reduced turbulence with low wind speeds and u^* , which showed values below 1.2 and 0.1 ms^{-1} respectively, and an increase of atmospheric stability ($z/L > 0$, Monin-Obukhov parameter), indicating that stable stratification dominated during nighttime. Conversely, during daytime both wind speed and u^* showed high values around 2 and 0.3 ms^{-1} respectively, and z/L was lower than 0, indicating well-developed convective turbulence.

3.2. Advection data and correction approaches

Wind and CO_2 profiles sampled during the advection campaign in 2012 indicated a good turbulent mixing during daytime when wind velocity is generally high and CO_2 mixing ratio is invariable in the vertical (height above the ground) and horizontal (uphill, downhill) space (Fig. 3). Conversely, during nighttime the accumulation of CO_2 in the air column and the difference between the uphill and downhill profiles (~ 4 ppm), associated with lower wind speed, set the conditions for the non-turbulent transport processes. The mean diurnal variation of each term of Eq. (6), is shown in Figure 4. Advection data confirmed that the CO_2 mass balance was influenced by nocturnal horizontal flows that moved CO_2 out from the control volume. The daily pattern of advection closely reflected that of the wind speed, u^* and z/L presented in Figure 2. The turbulent term $F_c + F_s$ showed a nighttime efflux of 3 $\mu\text{molm}^{-2}\text{s}^{-1}$ and diverged from the automated chambers, which, with an average flux of 6 $\mu\text{molm}^{-2}\text{s}^{-1}$, exceeded $F_c + F_s$ values by almost 100%. During nighttime F_{ha} clearly exceeded F_{va} which fluctuated around zero, while both advection terms were close to zero during daytime. An average horizontal advective flux of 3 $\mu\text{molm}^{-2}\text{s}^{-1}$ was observed during the night hours from around 20.00 to 06.00 CET, similar in magnitude to $F_c + F_s$. Around sunset (19.00 CET), just before the set up of calm conditions, F_{ha} showed minimum values, concurrent with high values of F_s . When summing $F_{ha} + F_{va}$ to $F_c + F_s$, the new term corresponded with

348 chamber records during the night hours and with $F_c + F_s$ during daytime (Fig.
 349 4). Since the campaign was conducted in two different locations sequentially,
 350 shaded areas in Figure 4 represent for each term the combined temporal and
 351 spatial variability during the study period, expressed as 95% confidence intervals
 352 (i.e. CI, 1.96 times the standard error of the mean of measurements carried on
 353 in the two periods and locations). Even if in some cases the temporal/spatial
 354 variability is large (e.g. for $F_c + F_s + F_{ha} + F_{va}$), the CI of the different terms
 355 traced the described differences and similarities and showed the same diurnal
 356 course among calculations, indicating that the variability is mainly related to
 357 changing environmental/phenological conditions during the study period. A
 358 presentation of measurements conducted in the first and the second location
 359 (and period), separately, can be found in the Appendix, confirming that spatial
 360 variability played a minor role.

361 Both turbulent and advective terms showed constant values (slope not signif-
 362 icantly different from zero) with the variation of u^* as an indication of mechan-
 363 ical turbulence (Fig. 5). Based on these results the term NEE_{Fmod} , introduced
 364 in section 2.6 was calculated as the sum of $F_c + F_s$ and the average of $F_{ha} + F_{va}$
 365 (i.e. $3 \mu\text{molm}^{-2}\text{s}^{-1}$). Figure 6 shows the effect of the different processing ap-
 366 proaches on the nighttime CO_2 efflux. The two filtering methods NEE_{u*} , and
 367 $NEE_{\sigma w}$ resulted in mean nocturnal fluxes of 3, and $3.7 \mu\text{molm}^{-2}\text{s}^{-1}$, respec-
 368 tively, that did not significantly differ (Tukey HSD, $p < 0.05$) from uncorrected
 369 NEE data ($3 \mu\text{molm}^{-2}\text{s}^{-1}$) and were lower than those of the standard filtering
 370 methods $NEE_{50\%}$ and NEE_{REF} ($4.0 \mu\text{molm}^{-2}\text{s}^{-1}$), R_{max} ($5.7 \mu\text{molm}^{-2}\text{s}^{-1}$),
 371 the advection methods (NEE_{acmb} , NEE_{Fmod} , 5.7 and $5.8 \mu\text{molm}^{-2}\text{s}^{-1}$) and
 372 the automated chambers ($6 \mu\text{molm}^{-2}\text{s}^{-1}$). The use of $NEE_{50\%}$ and NEE_{REF}
 373 provided NEE estimates, which were higher than NEE_{u*} and $NEE_{\sigma w}$, but dif-
 374 fered significantly from the advection methods and the automated chambers.
 375 R_{max} was closer to both the advection methods and R_{cham} , however, it did
 376 not significantly differ from the previous terms $NEE_{50\%}$ and NEE_{REF} . Taking
 377 into account direct advection measurements resulted in nighttime CO_2 fluxes
 378 (NEE_{acmb}) which significantly deviated from all the filtering methods but agreed

379 with R_{max} and the independent chambers measurements. Figure 6 shows that
 380 NEE_{Fmod} successfully performed in providing good agreement with direct ad-
 381 vection measurements (NEE_{acmb}) and consequently with R_{max} and R_{cham} .

382 3.3. Contribution of advection to annual budgets and uncertainty

383 F_{mod} was fixed to $3.3 \mu\text{molm}^{-2}\text{s}^{-1}$ during the 2012 summer campaign, how-
 384 ever this value is likely to overestimate the true advective flux at the edges of
 385 the season when CO_2 efflux from the ecosystem is lower. In order to account
 386 for the seasonal variability of the fluxes, NEE_{Fmod} for the annual analysis was
 387 computed as the sum of NEE and the percentage of F_{mod} to NEE measured
 388 during the field campaign. The comparison of the approaches to calculate NEE
 389 in years different from the experimental one (2010, 2014; Table 1) indicates that
 390 the methods separated into two groups with regard to the nighttime values, the
 391 first with NEE, NEE_{u*} , $NEE_{\sigma w}$, $NEE_{50\%}$ and NEE_{REF} yielding lower sums
 392 compared to the second represented by R_{max} , NEE_{Fmod} and R_{cham} . The sea-
 393 sonal course of nighttime NEE observed during the two growing season (Fig.7)
 394 highlights the good agreement between NEE_{Fmod} and R_{cham} . Conversely, even
 395 though R_{max} closely matched NEE_{Fmod} and R_{cham} when integrated over the
 396 whole growing season, this approach was weaker in representing the amplitude
 397 of short-term variations in ecosystem respiration. The Taylor diagram in Figure
 398 8 shows that the different approaches correlated in a similar fashion ($R \sim 0.75$)
 399 with R_{cham} , but only NEE_{Fmod} showed an amplitude of variations in fluxes
 400 similar to chambers (standard deviation equal to $2.1 \mu\text{molm}^{-2}\text{s}^{-1}$).

401 Table 2 shows the contribution of the different NEE correction approaches
 402 to the annual budgets of the grassland ecosystem from 2010 to 2014. For all
 403 the considered years the NEE_{u*} method ($-107 \text{ gCm}^{-2}\text{y}^{-1}$) did not significantly
 404 affect the annual budget as compared to uncorrected NEE ($-108 \text{ gCm}^{-2}\text{y}^{-1}$),
 405 while all the other approaches led to less negative or positive annual sums. The
 406 yearly $NEE_{\sigma w}$ diverged from uncorrected NEE on average by $32 \text{ gCm}^{-2}\text{y}^{-1}$,
 407 $NEE_{50\%}$ and NEE_{REF} with a mean difference of $70 \text{ gCm}^{-2}\text{y}^{-1}$, led the annual
 408 carbon balance close to neutrality, while R_{max} and NEE_{Fmod} added to the

original NEE on average 168 and 183 $\text{gCm}^{-2}\text{y}^{-1}$ respectively. The use of the last two methods thus shifted the ecosystem from a sink to a source in all the considered years but 2011, which was an extremely productive year (Galvagno et al., 2013). The interquartile range of standard NEE estimates for the seasonal and annual sums (Tables 1, 2) was on average 48 and 58 $\text{gCm}^{-2}\text{y}^{-1}$, respectively, consequently the use of the 75th percentile of u^* thresholds could lead to greater sums, however the budgets obtained with R_{max} , NEE_{Fmod} and R_{cham} were placed outside the upper limit of this range. Detailed information about seasonal and annual sums obtained with different percentile of u^* thresholds is given in table A.1 of the Appendix.

Though each of the methods tested generated a different quantity of gaps related to the specific filtering strategy, the comparison of mean and distribution of the various NEE calculations before and after the gap-filling, revealed that the role of the latter made a minor contribution compared to the within-methods difference (not shown).

4. Discussion

Quantification of advection in a short-statured canopy with a 2D approach

The study reports on the first attempt of quantifying advection of CO_2 in a short-statured canopy ecosystem, an unmanaged grassland of the Italian Alps. Grassland canopies are often assumed to be less affected by advection due to their short stature and, for this reason, little information exists on the potential underestimation of nighttime CO_2 fluxes measured with the eddy covariance technique in these ecosystems (Twine et al. 2000; Hiller et al. 2008).

The main findings of this study (Figs. 4-8) can be summarised as follows: (i) the sum of the vertical turbulent flux and the storage terms ($F_c + F_s$) were considerably smaller compared to independent estimates of nighttime ecosystem respiration as measured by chambers; (ii) during nighttime horizontal (F_{ha}) advection was an important term of Eq. (6); (iii) NEE calculated by taking into account all terms of Eq. (6) was similar to nighttime ecosystem respiration

438 estimated by the approach put forward by van Gorsel et al. (2007, 2008) and the
 439 chambers; (iv) different published methods for indirectly and directly accounting
 440 for advection resulted in a large divergence in the annual carbon balance; (v)
 441 accounting for advection generally turned the site from a sink to a source; and
 442 (vi) common approaches of filtering for periods of supposed advection (u^* or σ_w)
 443 agreed with each other to within 20% during the growing season and increased
 444 the annual NEE by 1-70% depending on the method used (Table 1)

445 The latter point suggests the potential challenges (e.g. [Vickers et al. 2012](#);
 446 [van Gorsel et al. 2007](#); [Kutsch et al. 2008](#)), in selecting an objective threshold
 447 useful to exclude periods when advection dominates at our site. At Torgnon
 448 the constantly low u^* values ($0.01\text{-}0.1\text{ ms}^{-1}$) during nighttime revealed that
 449 common atmospheric conditions (Fig. 2) are such that the site never reaches
 450 a turbulence regime which is high enough for CO_2 gradients to vanish, finally
 451 explaining the lack of the relationship between u^* and the fluxes ($F_c + F_s$ and
 452 $F_{ha} + F_{va}$).

453 Despite our site being located in complex terrain, the observed steady at-
 454 mospheric nocturnal pattern and the very constant bi-directional wind system
 455 enabled us to measure horizontal and vertical advection in a simplified 2D tran-
 456 sect, with a reasonably low (9 and 20 %) measurement error, as successfully
 457 accomplished at other mountain sites ([Marcolla et al. 2005](#); [Etzold et al. 2010](#)).
 458 Since our measurements were conducted at two different locations but were
 459 temporally separated, our set-up did not allow to provide an accurate estimate
 460 of spatial uncertainty in advection measurements (e.g. [Marcolla et al. 2014](#)),
 461 however the small differences between measurements in the first and the second
 462 locations (Fig. 4, Fig. A.1) suggested that spatial representativity is a minor
 463 issue in this specific experiment.

464 Finally, the low and homogeneous canopy of the grassland had a large advantage
 465 compared to forest ecosystems, as we could also compare our estimation of the
 466 ACMB and other NEE correction methods with independent measurements of
 467 ecosystem respiration carried out at an appropriate temporal (half-hourly) and
 468 spatial (ecosystem) scale by automated respiration chambers. We are aware

469 that also the chamber method are prone to some errors (e.g. [Riederer et al.](#)
 470 [2014](#)), but little and contrasting information exist on its potentials and pitfalls
 471 ([Görres et al. 2015](#); [Koskinen et al. 2014](#)). Indeed, only few studies used auto-
 472 mated chambers, especially on the whole ecosystem scale, and a standardised
 473 procedure for checking the quality of data as for EC still does not exist ([Vargas](#)
 474 [et al., 2011](#)). [Riederer et al. \(2014\)](#) concluded that depending on atmospheric
 475 conditions, during nighttime chambers are biased compared to EC. Based on
 476 a intercomparison campaign, [Görres et al. \(2015\)](#) demonstrated instead that
 477 the modern design and operation of automatic chambers has the potential of
 478 providing reliable nighttime CO₂ flux data. However, since the actual ecosys-
 479 tem CO₂ fluxes can never be known in environmental conditions, [Görres et al.](#)
 480 [\(2015\)](#) also concluded that it is not possible to test whether the LI-8100 night-
 481 time measurements are overestimated or not. In the present study we showed
 482 that chamber measurements at our site agreed with EC-NEE when the latter is
 483 corrected using the R_{max} approach or the quantification of the ACMB.

484 *Evaluation of correction methods*

485 Horizontal advection amounted to significant values during nighttime, up to
 486 100% of uncorrected NEE, and accounting for advection in the CO₂ conservation
 487 equation increased NEE by a factor of two. We found that directly account-
 488 ing for advection allowed agreement between NEE_{acmb} and two of the other
 489 methods tested: R_{max} and R_{cham} . Since direct advection measurements are
 490 not feasible for long time periods, a method to estimate and extrapolate advec-
 491 tion data to years without advection measurements was tested and resulted in a
 492 high correspondence to both NEE_{acmb} , R_{max} and R_{cham} . This correspondence
 493 relies on the systematic pattern of nighttime wind direction and turbulence in-
 494 tensity, which allowed to estimate F_{mod} with a simple approach. However, in
 495 the estimation of the term F_{mod} some assumptions were made, i.e. a constant
 496 relationship between NEE and advection in space and time, which is not possi-
 497 ble to be verified with the current set-up. Indeed, with the available data these
 498 assumptions can only be supported by the small variability observed in Figure

4, which includes observations made in two different locations (Fig. A.1, A.2), and the systematic accordance between the F_{mod} and R_{max} approaches through years. The method introduced by van Gorsel et al. (2007) agreed with direct and estimated advection methods and, as for NEE_{acmb} and NEE_{Fmod} significantly matched also R_{cham} . Being based on the assumption that there are different temporal scales for the decline of the turbulent flux, the storage flux, and the build up of advection (van Gorsel et al., 2007), this method captures values of $F_c + F_s$ in a short period just after sunset when the turbulent flux is dominant and the advection terms are still negligible. In this period (19.00 CET) $F_c + F_s$ can be considered as representative of the unbiased CO_2 efflux as demonstrated by the comparison with R_{cham} (Figs. 4, 6).

Impacts on annual estimates

We also tested our approach in years different from the experimental one and evaluated the contribution of directly accounting for advection on the uncertainty of the yearly CO_2 budget. R_{max} and NEE_{Fmod} gave similar results in terms of seasonal and annual sums, and consequently R_{max} could be considered a good indirect method for accounting of advection at our site. Nevertheless, differences between R_{max} and NEE_{Fmod} were found when looking at the seasonal course of nighttime fluxes (Fig. 7). Indeed, NEE_{Fmod} , being based on direct measurement of NEE plus a percentage of unaccounted CO_2 flux, well represented the short-term variation of respiration, as demonstrated by the comparison with the variation of flux pattern measured by chambers (Fig. 7). Since R_{max} is based on the rejection of a large fraction of data, requiring appropriate replacement with an empirically derived ecosystem respiration model, together with the filtering methods, it showed a dampened seasonal course which resulted in a lower representativeness of the temporal variation of the fluxes (Fig. 8). On the yearly time span, our results showed that the use of NEE_{u*} led to a non significant ($< 1\%$) change in uncorrected NEE, conversely, $NEE_{\sigma w}$, NEE_{u*50} and NEE_{REF} moved the net carbon balance towards less negative values on average by $68 \text{ gCm}^{-2}\text{y}^{-1}$, since these methods allowed the determination of a

529 higher threshold. The highest departures from annual uncorrected NEE were
 530 found using both R_{max} and NEE_{Fmod} which added to the former on average 168
 531 and 183 $\text{gCm}^{-2}\text{y}^{-1}$ respectively. By increasing the CO_2 loss from the ecosys-
 532 tem on average by 155-169% (R_{max} - NEE_{Fmod}), during all the years but 2011,
 533 the use of both R_{max} or NEE_{Fmod} turned the ecosystem from a weak sink to
 534 a weak source. Considering all the tested approaches, the mean annual car-
 535 bon balance of this ecosystem could range from -108 (NEE) to 75 (NEE_{Fmod})
 536 $\text{gCm}^{-2}\text{y}^{-1}$. Therefore, for such an ecosystem, close to carbon-neutral, account-
 537 ing for advection may have a crucial impact on the definition of its source/sink
 538 role compared to stronger sinks, e.g. vigorously growing forests. Indeed, during
 539 an anomalously productive year ([Galvagno et al., 2013](#)) as 2011, the net balance
 540 remained negative, also when accounting for advection.

541 5. Conclusion

542 Lately, it appears that the interest in quantifying advection has decreased
 543 (but see e.g. [Siebicke et al. 2012](#)), probably reflecting the demanding experi-
 544 mental effort that such measurements require as well as the discouraging results
 545 obtained in some studies ([Aubinet et al., 2010](#)). However, the current practice
 546 of accounting for the supposed contribution of advection to nighttime CO_2 ex-
 547 change (i.e. u^* -filtering) could prove problematic in complex mountainous sites
 548 when the nighttime turbulent regime is continuously low. Accounting for advec-
 549 tion caused NEE at our grassland site to increase on average by 183 $\text{gCm}^{-2}\text{y}^{-1}$
 550 and turned the site from a sink to a source. We advocate that continuing ef-
 551 forts need to be made towards quantifying the contribution of advection to NEE
 552 and to further develop approaches for diagnosing and, if possible, accounting
 553 for advective flux contributions. Recently, [Campioli et al. \(2016\)](#) evaluated the
 554 convergence between eddy-covariance and biometric methods in the quantifi-
 555 cation of the carbon budget of forests and found that the correspondence is
 556 poor for sites where the fluxes are lower, but that these discrepancies are not
 557 related to the inaccuracy of EC measurements and processing. Since all the

558 methods considered in this study have potential issues, future work will be also
 559 directed towards a comparison with biomass and soil carbon inventories at the
 560 site, which, given the simple ecosystem, could provide key details on the unac-
 561 counted fluxes.

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574 **Appendix A. Considerations on uncertainty**

575 *Field campaign measurements in different locations/periods*

576 The 2012 experimental campaign was composed by two sequential periods,
 577 from 31 July to 10 August and from 10 to 21 August, in which turbulent flux and
 578 advection measurements were conducted in two different locations of the study
 579 site (Figure 1). Figure A.1 shows the mean diurnal variation of all terms of Eq.
 580 6, separately for the first and the second locations (and periods). Figure A.2
 581 shows the comparison between measurements carried out with the permanent
 582 (EC-1) and the experimental (EC-2) station in the two locations.

583 *Chamber measurements variability*

584 Respiration chambers sampled a small area, and differences between cham-
585 bers can lead to uncertainty in the measurements, however, the CV quantified
586 during the study period appears to be quite low (18% on average). Figure
587 A.3 shows the observed variability in chamber measurements during the field
588 campaign (2012) and the validation years (2010, 2014).

589 *FLUXNET2015 derived uncertainty*

590 The additional table A.1 reports growing season nighttime (a) and yearly
591 (b) NEE filtered using different percentiles of u^* thresholds as derived from
592 the FLUXNET2015 dataset. The use of a very high u^* threshold (NEE_{u^*95})
593 potentially lead to greater annual sums compared to uncorrected NEE, $NEE_{\sigma w}$,
594 NEE_{u^*50} and NEE_{REF} , but overall the budgets still remained below the upper
595 limit of the range obtained using R_{max} or NEE_{Fmod} . Moreover, it must be
596 noticed that the FLUXNET2015 yearly data were filtered for the whole year,
597 while yearly sums obtained with the other methods were corrected only for
598 the snow-free period as described in section 2.6. Indeed, when considering the
599 seasonal values in table A.1, the highest percentile showed a lower deviation
600 from uncorrected NEE.

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774 **Tables**

775 Table 1: Growing season nighttime ($R_g < 20 \text{ Wm}^{-2}$) sums of NEE (gCm^{-2}) com-
776 puted with different correction approaches and derived from independent chamber measure-
777 ments (R_{cham}) for two validation years: NEE, uncorrected fluxes, NEE_{u*} , u^* -filtered data,
778 $NEE_{\sigma w}$, σw -filtered data, NEE_{u*50} and NEE_{REF} , independent u^* -filtered data derived from
779 FLUXNET2015, R_{max} data modeled on the basis of maximum value of after-sunset $F_c + F_s$,
780 NEE_{Fmod} , NEE computed including advection. For NEE_{u*50} and NEE_{REF} the IQR is re-
781 ported (i.e. the difference between NEE filtered using the 75th percentile and 25th percentile
782 of u^* thresholds). Growing season is referred to the period during which chamber data were
783 available for a given year, i.e. 127 days in 2010 and 168 days in 2014.

Year	NEE	NEE_{u*}	$NEE_{\sigma w}$	NEE_{u*50}	NEE_{REF}	R_{max}	NEE_{Fmod}	R_{cham}
2010	129	129	149	158 (32)	156 (32)	236	264	293
2014	208	204	239	252 (65)	246 (65)	362	409	406

784 Table 2: Annual sums of NEE ($\text{gCm}^{-2}\text{y}^{-1}$) computed with different correction approaches:
785 NEE, uncorrected fluxes, NEE_{u*} , u^* -filtered data, $NEE_{\sigma w}$, σw -filtered data, NEE_{u*50} and
786 NEE_{REF} , independent u^* -filtered data derived from FLUXNET2015, R_{max} data modeled
787 on the basis of maximum value of after-sunset $F_c + F_s$, NEE_{Fmod} , NEE computed including
788 advection. For NEE_{u*50} and NEE_{REF} the IQR is reported (i.e. the difference between NEE
789 filtered using the 75th percentile and 25th percentile of u^* thresholds)

Year	NEE	NEE_{u*}	$NEE_{\sigma w}$	NEE_{u*50}	NEE_{REF}	R_{max}	NEE_{Fmod}
2010	-58	-58	-34	2 (41)	15 (41)	81	92.5
2011	-236	-234	-191	-156 (73)	-151 (73)	-60	-51
2012	-23	-19	-1	47 (48)	54 (48)	145	147
2014	-116	-119	-80	-57 (69)	-48 (69)	74	112
Average	-108	-107	-76	-40 (58)	-32 (58)	60	75

790 Table A. 1: FLUXNET2015 derived uncertainty. NEE filtered using different percentiles of
791 u^* thresholds for both the growing season nighttime (a) and the yearly (b) sums (gCm^{-2}) of
792 NEE

(a)				
Year	NEE _{u^*05}	NEE _{u^*25}	NEE _{u^*75}	NEE _{u^*95}
2010	123	146	179	198
2014	162	206	272	296
(b)				
Year	NEE _{u^*05}	NEE _{u^*25}	NEE _{u^*75}	NEE _{u^*95}
2010	-29	-6	35	60
2011	-224	-187	-114	-89
2012	20	34	82	100
2014	-139	-108	-38	-19

794 Figure 1: The Torgnon study site. Colours represent altitude. The EC permanent (EC-1)
 795 and EC-2 experimental towers are marked. Arrows indicate location and orientation of the
 796 EC-2 transects. Right top figure shows the main wind pattern at the EC-1 site.

797 Figure 2: Median diurnal variation of a) wind direction ($^{\circ}$), b) wind speed (ms^{-1}), c) global
 798 radiation (Wm^{-2}), d) Monin-Obukhov stability parameter (z/L), e) friction velocity u (ms^{-1})
 799 during the 2012 field campaign (black solid line) and the whole study period (2010-2013, dark
 800 grey dashed line) with its variability range (10% and 90% inter quantile grey solid lines). The
 801 red line indicates the time of the day when calm conditions build up.

802 Figure 3: Wind and CO₂ profiles during the 2012 field campaign. Left panel: mean horizontal
 803 wind speed, u (ms⁻¹), at different heights above the ground, pooled by day (dashed line) and
 804 night (solid line) hours. Right panel: Mean CO₂ concentrations (ppm) at the same heights
 805 pooled by day (dashed line) and night (solid line) and by uphill (black) and downhill (red)
 806 measurement points.

807 Figure 4: Mean diurnal variation of measured vertical turbulent CO₂ flux plus the storage
 808 term $F_c + F_s$ (blue line), horizontal advection, F_{ha} (yellow line), vertical advection F_{va} (green
 809 line), the full mass balance $F_c + F_s + F_{ha} + F_{va}$ (black line), the storage term F_s (grey line,
 810 right axis), and the CO₂ flux from automated chambers (red solid line is used for nighttime
 811 and red dashed line for daytime), during the 2012 field campaign (note that chambers were
 812 opaque, and thus did not measure any photosynthetic CO₂ uptake during daytime). Shaded
 813 areas represent for each method the combined temporal and spatial variability during the
 814 study period, expressed as 95% confidence intervals (i.e. CI, 1.96 times the standard error of
 815 the mean.

816 Figure 5: Relationships of nighttime vertical turbulent flux plus the storage term $F_c + F_s$
817 (blue), horizontal advection F_{ha} (orange) and vertical advection F_{va} (green) to classes of
818 friction velocity u^* , during the 2012 field campaign.

819 Figure 6: Distribution and mean of nighttime values of NEE computed with different cor-
 820 rection methods: uncorrected NEE, u^* -filtered NEE_{u^*} , σ_w -filtered NEE_{σ_w} , independent u^* -
 821 filtered data derived from FLUXNET2015, NEE_{u^*50} and NEE_{REF} , data modeled on the basis
 822 of maximum value of after-sunset turbulent and storage terms, R_{max} , NEE computed includ-
 823 ing advection, NEE_{Fa} , NEE computed including the estimated advection F_{mod} , NEE_{Fmod}
 824 and records of chambers R_{cham} . Different letters indicate significant differences ($p < 0.05$)
 825 between the investigated methods based on the Tukey HSD test. The dark line represents
 826 the mean, boxes extend to the 25th and 75th percentiles, whiskers represent 1.5 times the
 827 interquartile distance. Points lying beyond the extremes of the whiskers are represented by
 828 open circles.

829 Figure 7: Gap-filled time series of nighttime NEE computed with different correction ap-
 830 proaches for two validation years (summer period), 2010 and 2014: uncorrected NEE (grey),
 831 u*-filtered NEE_{u*} (cyan) and independent u*-filtered data derived from FLUXNET2015,
 832 NEE_{u*50} and NEE_{REF}, (purple), σ_w -filtered NEE _{σ_w} (blue), data modeled on the basis of
 833 maximum value of after-sunset turbulent and storage terms R_{max} (green), NEE computed
 834 including the estimated advection F_{mod} , NEE _{F_{mod}} (orange), and records of chambers R_{cham}
 835 (red)

836 Figure 8: Taylor diagram presenting the relative skills with which each NEE calculation
 837 method matches chamber observations R_{cham} . The similarity between a given calculation
 838 approach and the chamber patterns is quantified by means of their correlation, the amplitude
 839 of their variations, i.e. their standard-deviation (represented by radial distance from the origin,
 840 black arc represents the reference R_{cham} standard deviation) and their centered root mean
 841 square difference (grey contours). Data are relative to the summer period of the validation
 842 years 2010 and 2014

843 Figure A. 1: Mean diurnal variation of all term of Eq. (6) measured in the two locations of
844 Figure 1, during the first and the second period of the experimental campaign.

845 Figure A. 2: CO₂ turbulent flux measurements carried on with the permanent (EC-1) and
846 the experimental station (EC-2) in the two locations. Red line represents R_{Cham} , the mean
847 nocturnal respiration by chambers

848 Figure A. 3: Nighttime time series of chambers CO₂ fluxes during the field campaign in 2012,
849 and in 2010 and 2014. Black points represent the half-hourly mean between the chambers and
850 the grey bars their standard deviations