CHAPTER-2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1. CO_2 emission a global problem:

Over the last century the atmosphere and biosphere of the earth has been experiencing remarkable changes in climate [1, 2, 3] caused by the anthropogenic emissions of greenhouse gases. Agricultural activities have also contributed by about 20% to the present GHG concentration in the atmosphere [4]. As per the measurements of Mauna Loa observatory, atmospheric CO_2 concentration has crossed 400 ppm which has increased by about 24% since 1950 [5, 6]. As predicted by Intergovernmental panel on climate change (IPCC) the atmospheric concentration might get doubled towards the end of the next century [7, 8].

After the disclosure of increasing trend of CO_2 concentrations in the atmosphere [9], the analysis on global warming process through greenhouse effect has received attention of the world community. The role of human activities on causing this global climate change is undisputable [10]. Although the measurements indicating rise of atmospheric CO_2 concentration per year are very precise and reliable [11, 12, 13] but those estimates cannot be used for global level comparison due to unavailability of the quantified uptake rate of land and ocean [14, 12, 15]. Estimation of natural sinks with high precession and accuracy is necessary to understand the process which is causing the difference between anthropogenic CO_2 emission and atmospheric CO_2 concentration level [12]. The Kyoto protocol has given importance on identification and accurate quantification of sources and sinks of atmospheric CO_2 [16]. It is very much essential to picturize the variation and distribution of terrestrial carbon cycle to address the “missing sink” in global carbon cycle [17, 18, 19].

2.2. CO_2 as greenhouse gas:

The major greenhouse gases whose increasing concentrations are considered to be the major threat to the earth’s atmosphere are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Over the last 100 years the estimated global warming potential of CH_4 and N_2O relative to CO_2 are 28 and 298 respectively [8]. CO_2 contributes about 77% to the total anthropogenic greenhouse gas emission and is reported to have the highest contribution on climate change [3, 7].The causes of increasing CO_2 concentration in the atmosphere are well known now, among which burning of fuels to power advanced industrial economics and clearing of forest cover and woodlands are being often discussed [10, 20]. About half of the anthropogenic CO_2 emitted remains in the atmosphere and the rest amount is absorbed by natural sinks like terrestrial biosphere and ocean [14, 15, 21].

2.3. Greenhouse gases and climate change:

Increasing concentration of greenhouse gases in the atmosphere is a matter of concern for global scientific community and the policy makers because of the ability of greenhouse gases to trap the outgoing longwave radiation which increases earth’s surface temperature [22, 23]. Some of the potential major consequences of increasing atmospheric CO_2 concentration are earth’s surface warming, polar ice caps melting, rising of the sea level and change in physiological activity of plant and ecosystem [24, 25, 26, 27]. Over the years oceanic warming was reported to be one of the key consequences of anthropogenic climate change [28]. Observational efforts are essential to understand the response of ecosystems to the warming process [29].

2.4. Sources and sinks of CO_2:

The global carbon cycle is the combination of three major components [30] which includes (i) Land (vegetation, soil and geological objects) (ii) Atmosphere and (iii) Ocean.

2.4.1. Emission of CO_2 from fossil fuels and Industry:

Combustion of fossil fuels has been considered as one of the major anthropogenic sources responsible for increase in atmospheric CO_2 concentration [31]. Globally CO_2 emission from fossil fuel and industry can be divided in to following sources: fossil fuel combustion at national level, gas flaring from industry and wells, production of cement, oxidation process of hydrocarbons and fuels used by international bunkers [7, 32]. Emissions of CO_2 from fossil fuel and industry are about 90% of total CO_2 emitted from human activity [33]. In city area, CO_2 emission is contributed by fossil fuel burning for transportation, to fulfill the house hold energy demand as well as in different industries. In the fastest growing transport sector, burning of gasoline or diesel fuels can result in direct emission of CO_2 to the atmosphere. The rate of production and uses of cement is growing every year [34], which is a significant source of CO_2 emission by carbonate decomposition. Production process of one ton of cement could release 900 kg of CO_2 to the atmosphere [35]. Production of cement releases CO_2 to the atmosphere by two ways, first by the chemical reaction in production of the necessary components, which could contribute about 5% of the anthropogenic CO_2 emission [36]. Large amount of CO_2 is also released in the combustion process of fossil fuels in energy generation for heating the raw ingredients during cement production [37]. Thus, cement industry can contribute about 8 % of global carbon dioxide emission [38].

2.4.2. Emission of CO_2 from land use change:

CO_2 emission from land use change can be considered as second largest source of anthropogenic CO_2 emissions. Land use change contributes to increasing atmospheric CO_2 concentration by changing the structure of terrestrial ecosystems and by soil CO_2 emission [39]. The processes like deforestation, burning of biomass, conversion of any natural ecosystem to agricultural ecosystem and soil cultivation can lead to increase in atmospheric CO_2 level [40]. Along with the land use change both the vegetation type and management practices gets altered [41], which in turn can change above ground biomass, microbial properties of soil, organic matter present in soil and microenvironment responsible for plant growth [42]. The CO_2 added to the atmosphere due to the change of land use and land cover is the most uncertain flux in the global carbon budget because of uncertainties in deforestation or afforestation rates and due to uncertainties in carbon densities of lands undergoing change [43]. It was reported that 1.6–1.7 Pg C/year was emitted in to the atmosphere due to deforestation and conversion of tropical rain forests to agricultural ecosystems [44]. On annual basis an amount of 1.3 ± 0.7 Pg C year^{-1} has been estimated due to tropical land use change [21]. In a study Wang et al., [45] reported about the increase in annual soil respiration by 3-22% after the transformation of a grassland ecosystem to woodland. It was reported that in tropical zone the deforestation process is getting lower than earlier which contributed about 10 % to the total anthropogenic CO_2 emission [46]. The CO_2 emissions due to land use change are getting lower as a result of strict legal action taken against deforestation in different parts of the country [47].

2.4.3. Soil as a source of CO_2:

The role of soil in global carbon cycle is very important as it can absorb and release CO_2 [48, 49]. Carbon dioxide can be released to the atmosphere by the process of soil respiration. Soil respiration is mainly combination of two processes heterotrophic respiration and autotrophic respiration [50]. Soil respiration depends on temperature and moisture content of soil [51]. On annual basis approximately 70 Gt of carbon was reported to be respired back to the atmosphere by soil which is nine times greater than the global annual fossil fuel emissions [52, 53]. Accurate estimation of soil respiration in different ecosystems is very important for forecasting future CO_2 concentration in the atmosphere [54]. Soils of agricultural ecosystem can also act as source of CO_2 depending on management, climate and C saturation [55]. A small change in soil respiration may have a large impact on the carbon cycle of the forest and a carbon sink may turn in to source [56].

2.4.4. Ocean as a sink of CO_2:

Significant amount carbon released from anthropogenic activities can be absorbed by the ocean. Ocean absorbs about one third of the CO_2 released from fossil fuel burning and deforestation activities [57]. It was reported that from year 1800 to 1994 approximately 118 ± 19 Pg C had been removed from the atmosphere by ocean [58], this value is nearly equal to 50% of the CO_2 emitted to the atmosphere by fossil fuel burning [59, 60].Ocean has the higher CO_2 storage capacity than the terrestrial ecosystems [61]. Ocean contains nearly 38000 Gt of Carbon and it absorbs around 1.7 ± 0.5 Gt of carbon from the atmosphere annually [62].

2.4.5. Terrestrial biosphere as a sink of CO_2:

One of the important strategies to mitigate the ongoing human induced climate change is the carbon sequestration in terrestrial biosphere which includes the management process to increase the carbon stock in biomass and soil [63]. The estimated carbon sequestration potential of the terrestrial system is 5-10 Gt C year^{-1} [62]. In a study of European carbon cycle, Janssens et al., [64] reported that about 7-12 % of industrial carbon emission was sequestered by terrestrial ecosystems. Since 1960s terrestrial ecosystems has sequestered about 30% of CO_2 emitted to the atmosphere due to anthropogenic activities [53].

2.4.5.1. Forest ecosystem:

Forests are considered as important component of global carbon cycle due to its capacity of storing large amount of carbon in forest biomass [65, 66]. The amount of carbon stored in forest ecosystem is twice than the atmosphere [67]. Globally, around 25 % of the land surface is covered by forests [68]. In Northern hemisphere about 2×10^7 km^2 of area are covered by boreal and temperate forests and they are acting as carbon sink by sequestering 0.6 -0.7 PgC per year [69]. Globally, the carbon stock of tropical forest is approximately one fourth of the total forest carbon stock [21, 70]. In an earlier publication forest ecosystem is reported to sequester 359 billion tons of carbon [71]. Old growth forests are also acting as significant sinks of carbon dioxide [72, 73]. In a study Luyssaert et al., [74] reported that forests of age between 15 to 800 years show positive net ecosystem productivity. The carbon sequestration potential of forest ecosystems might get affected by increasing global surface temperature, changes in rainfall pattern and nitrogen deposition [75]. Thus, the change in climate can affect the forest carbon dynamics and may have influence on global carbon cycle. In a study conducted over 23 different forest ecosystems of Europe and USA between 1995 to 2011 by Fernandez-Martinez et al., [76] 1 % increase in annual gross primary production and net primary production has been reported.

2.4.5.2. Soil as sink of CO_2:

Out of all terrestrial ecosystems only soil can store carbon for a long period of time [77]. Soil carbon sequestration intensifies the pool of soil organic matter and secondary carbonates of the soil [78]. Globally soil carbon pool has been reported to contain 2500 Gt of carbon including both soil organic and inorganic carbon [79]. The soil carbon pool is 3.3 times bigger than the atmospheric pool and 4.5 times greater than the biotic pool [79]. Soil can store 1500-2000 Gt of organic carbon [80] and the carbon storage capacity of the soils boreal and temperate forest is 33% more than the total carbon stored in tropical forests [81]. The average carbon sequestration potential of the soils of United States was estimated as 288 Tg C yr^{-1} [78].

2.5. CO_2 flux measurement by eddy covariance:

Earlier CO_2 fluxes were measured and reported by various researchers [82, 83, 84, 85] over forest ecosystems using the flux gradient technique, but flux gradient techniques have certain disadvantages and encountered from various practical difficulties. Although CO_2, H_2O and energy fluxes were being measured since late 1950s and early part of 1960’s, the development of new technology (eddy covariance) for continuous measurement of the above parameters is very recent [86]. The micrometeorological eddy covariance method computes the rate of CO_2 exchange between the interface of canopy and surrounding atmosphere. Earlier this method was used for short time periods to measure the flux in agricultural fields under ideal measurement conditions. During the last decade eddy covariance has become a standard tool for monitoring the exchange to CO_2 and water vapor between ecosystem and atmosphere in time scales starting from hours to year after year [86, 87, 88].

Fluxnet is a global network and its goal is to measure CO_2, water vapor and energy fluxes between biosphere and atmosphere continuously. Under the umbrella of Fluxnet, fluxes over diverse of vegetation and ecosystem [1] are being measured viz., broadleaved forest, temperate forest, boreal and tropical forest ecosystem, grasslands, agricultural ecosystem, wetlands, tundra etc. There are several regional networks under Fluxnet with more than 400 towers are in operation around the globe such as CarboEuroflux, Ameriflux, Ozflux, Asiflux etc. Routine EC measurement has been started after 1980s along with the availability and development of sonic anemometer, infrared spectroscopy and digital computers [1].

2.6. Global CO_2 flux studies:

Initially, Verma et al., [89] reported about the computed CO_2 fluxes over deciduous forest on Oak Ridge, Tennessee using eddy correlation technique. From early part of 1990s, EC technique and instrumentation developed further and became more efficient for long term use in the field. First long term measurement of CO_2 fluxes using eddy correlation technique was reported by Wofsy et al., [90] in a mid-latitude deciduous forest of central Massachusetts. The net annual uptake by the forest as reported by them was around 3.7 metric tons of C ha^{-1} yr^{-1}. In Netherlands Vermetten et al., [91] made a comparative study between the results of observational flux and model estimated results and reported good agreement between the two techniques during summer months.

In a study over Harvard forest of northeastern United States Goulden et al., [92] reported about aggregated carbon sequestration of 2.1 t C ha^{-1} yr^{-1} in the year 1994. In New England, CO_2 uptake of a deciduous forest was reported to be in the range (1.4 -2.8) metric tons of carbon per hectare between1991 – 1995 by Goulden et al., [93].

After the above pioneering efforts the process of establishment of more and more flux tower was started. In a study over a deciduous forest of Oak Ridge, TN Greco and Baldocchi [94] reported net annual CO_2 flux of -525 g C m^{-2} yr^{-1} using EC data from the period April 1993 to April 1994. In a beech forest ecosystem of Italy, Valentini et al.,

[95] monitored the seasonal variation of CO_2 fluxes and reported about the net annual productivity of 472 g C m^{-2} yr^{-1}. In a study over a temperate forest of Japan Yamamoto et al., [96] reported the results of seasonal and inter annual variation of CO_2 exchanges using three years (1993-1996) flux data. They reported large inter annual variability in CO_2 uptake rate, the net annual CO_2 uptake by the forest was reported to be 1.8 t C ha^{-1} yr^{-1} which indicated substantial sink capacity of the temperate forest.

Berbigier et al., [97] used two years EC data under the Euro flux over a maritime pine plantation site and recorded average carbon sequestration of about 11.5 t C ha^{-1} yr^{-1}. Two years CO_2 flux data were used by Granier et al., [98] under Euro flux network over a young beech forest of France. The annual net ecosystem exchange of the forest were reported to be -218 g C m^{-2} in 1996 and -257 g C m^{-2} in 1997 [98]. In a comparison of two years eddy covariance data by Pilegaard et al., [99] over a beech forest of Denmark under Euro flux network observed contrasting results between two years of observation. Annual sums of ecosystem CO_2 exchange were 223g C m^{-2} in 1996-1997 and144g C m^{-2} in 1997-1998 respectively.

In Canada Lee et al., [100] monitored CO_2 exchange between atmosphere and temperate deciduous forest ecosystem and reported net ecosystem productivity of -1 t C ha^{-1} yr^{-1} to - 2.8 t C ha^{-1} yr^{-1} during the period 1995 to 1997. In a comparative analysis of net annual CO_2 exchange of 15 European forest site during 1996 to 1998, Valentini et al., [101] reported net uptake and release as 6.6 t C ha^{-1} yr^{-1} and 1 t C ha^{-1} yr^{-1} respectively. Their analysis indicated that the most of the European forests are substantial carbon sink with large variability between the forests. Increment in the CO_2 uptake by the ecosystems with decreasing latitude was a significant finding reported by these authors.

Micrometeorological eddy covariance method also used for quantification of CO_2 fluxes over a tropical rain forest of central Amazonia by Malhi et al., [102] for a complete year cycle. Their results depicted active day time photosynthesis rate between 24 -28 µmol m^{-2} sec^{-1} and respiration between 6-8 µmol m^{-2} sec^{-1}. In central Sweden Lindroth et al., [103] measured CO_2 fluxes over a boreal forest ecosystem and revealed that the forest acted as a source of CO_2 from June, 1994 to May, 1996. The accumulated CO_2 flux was reported to be in the range 480 g m^{-2} to 1600 g m^{-2} for the full two years of measurements. From 1997-1999, EC flux measurements were carried out over a scots pine forest in southern Finland and the results were reported by Markkanen et al., [104].

Their estimated annual net ecosystem exchange for 3 consecutive years from 1997 to 1999 ranged between -262 g C m^{-2} yr^{-1} to -191 g C m^{-2} yr^{-1}. In Maine of USA, CO_2 and energy fluxes were measured over a boreal forest dominated by spruce, the forest was found to be a carbon sink [105] which stored about 2.1 t C ha^{-1} in 1996. Eddy covariance technique was used above a ponderosa pine forest of central Oregon. The net carbon gained by the forest as reported by Anthoni et al., [106] for the years 1996 and 1997 were 320 g C m^{-2} $year^{-1}$ and 270 g C m^{-2} $year^{-1}$ respectively. Eddy covariance technique was used by the researchers [107] of Southern Africa over semi-arid deciduous mopane woodland and found strong influence of seasons on CO_2 fluxes. During their period of observation from 1999 to 2000, the woodland was nearly carbon neutral with net annual carbon uptake of 1 mol C m^{-2} $year^{-1}$. A comparative study of CO_2 exchanges between an old growth forest and a mature forest has been done by Desai et al., [108] in Midwest (upper) of USA. They reported that the carbon sink strength of the mature forest was significantly higher than the old growth forest. In southwestern China, EC measurements were conducted over a tropical rain forest and the results were compared with biometric measurements [29]. The findings reported by them revealed that the rain forest acted as a sink with annual uptake of 1.19 Mg C ha^{-1} $year^{-1}$. In a study of CO_2 flux over a Scots pine forest of Brasschaat using 8 years EC data , Gielen et al., [109] found annual uptake of 2.4 t C $ha^{-1}$$year^{-1}$. The range of day time CO_2 uptake of a mangrove forest ecosystem of coastal Florida Everglades were found between -20 to -25 µmol CO_2 m^{-2} sec^{-1} [110].

2.7. Indian study on CO_2 flux:

Terrestrial ecosystems of India are expected to depict vast spatial and temporal variation on carbon cycle due its monsoon based climate, mixed land use and land cover pattern [111].

In India for the first time a network to monitor CO_2 and energy fluxes over terrestrial, coastal and oceanic ecosystems was proposed by Sundareshwar et al., [112]. Only few literatures are available from Indian subcontinent quantifying the net CO_2 exchange of forest or manmade ecosystem. In Betul district of Madhya Pradesh, Jha et al., [113] measured CO_2, water vapour and energy fluxes over a teak mixed deciduous forest for summer and winter seasons with the help of Eddy covariance method. They reported strong influence of changing leaf phenology on CO_2 and energy fluxes due to presence of deciduous vegetation around the study area. Peak CO_2 (monthly average of -

25 µmol m^{-2} sec^{-1}) was found to be sequestered during winter months ,whereas very less amount monthly average of -2 µmol m^{-2} sec^{-1} was sequestered during summer season [113]. After that, monthly variation of CO_2 and water vapour fluxes are reported by Watham et al., [114] over a mixed forest plantation located in Nainital district of Uttarakhand. They observed that the ecosystem was a source of CO_2 during the leafless period and it turned in to a sink from the beginning of leaf onset up to growing period. They recorded maximum uptake and release of CO_2 by the ecosystem in the month of July. Maximum uptake of -29.5 µmol m^{-2} sec^{-1} by the ecosystem from the atmosphere are reported [114]. In a recent study variation of CO_2 and water vapor fluxes over Indian tropical Mangroves in Sundarbans, India are reported by Rodda et al., [115]. They observed that half hourly CO_2 flux varied in the range between -6 µmol m^{-2} sec^{-1} to -10 µmol m^{-2} sec^{-1}. The high point of the study is that the Mangrove ecosystem acted as a net carbon sink over an annual cycle.

2.8. Different factors affecting the CO_2 flux:

The seasonal and inter annual variation in the carbon cycles of the terrestrial ecosystem is the interplay between climate and ecosystem variables [116]. Climate can control the carbon cycles of terrestrial ecosystems by regulating the physiological activity of plants and its phenology [117]. The carbon uptake capacity and the period of carbon uptake of any ecosystem can be affected by climate [118].

2.8.1. Heat fluxes and energy balance:

The absorbed net radiation by any ecosystem gets converted to Latent heat, sensible heat and soil heat fluxes. In energy partitioning analysis over an Indian tick mixed deciduous forest of Madhya Pradesh more energy was reported to be partitioned in to latent heat (LE) during winter whereas in summer inverse partitioning was reported [113]. They observed diurnal peak values of sensible and latent heat fluxes during 1200 to 1300 hours. In Sundarbans over a tropical Indian mangrove forest ecosystem a linear relationship between net radiation and heat fluxes (sensible heat and latent heat) was observed by Rodda et al., [115]. The average annual evapotranspiration over a tropical Indian mangrove forest ecosystem was estimated as 1.96 ± 0.33 mm day^{-1} [115].

The quality check of Eddy covariance data can be done by calculating surface energy balance closure [119, 120]. Most of the sites running under FLUXNET individually reported and accepted the energy balance closure of their site as a standard measure to access the quality of their EC data [105, 106, 121, 122, 123, 124]. The total of net radiation (Rn) received by any ecosystem for each half hour should be nearly balanced by sum of latent and sensible heat flux (LE+H), soil heat flux (G) and canopy heat storage (C_s) [123].

A comprehensive study of energy balance across 22 different FLUXNET sites indicated lack of energy balance closure at almost all the sites [125]. They reported average imbalance between available net radiation and surface fluxes of around 20 %, which is basically the violation of first law of thermodynamics [126]. Many researchers reported energy imbalance even from the sites which were considered ideal for eddy covariance measurement (homogeneous and flat terrain) and the ecosystems having only small vegetation [120, 127,128, 129]. From Saskatchewan of Canada Barr et al., [130] reported about the energy balance closure of three boreal forest ecosystems. Energy imbalance of 11%, 14% and 15% are reported over aspen, jack pine and black spruce forest respectively [130]. In Japan Saigusa et al., [131] made a comparative study of energy balance closure calculated from half hourly fluxes and daily averaged fluxes over a cool temperate forest. They reported better energy balance closure using daily averaged fluxes of the parameters.

Eder et al., [132] reported that the observed energy imbalance on the eddy covariance sites was mainly caused by the underestimation of latent heat and sensible heat fluxes. The energy imbalance in the sites having sloping terrain is explained as the net radiation measured by the radiometer does not represent the radiative energy experienced by the surface [133, 134]. To get some new ideas on energy imbalance of eddy covariance sites, Sanchez et al., [135] analyzed eddy covariance data of a boreal forest in Finland. They reported that the closure improved by 6 % after including the heat storage term in the energy balance equation. Exclusion of storage term in the energy balance equation is the major cause of energy imbalance of flux stations [136, 137].

Many of the sites reported that the energy balance closure improved with the increase in friction velocity [125, 135, 138]. Energy balance closure is reported to improve after considering the data of only unstable conditions [135].

2.8.2. Net radiation:

Forests ecosystems are known to be optically dark compared to other short vegetation as a result it can trap more solar energy which can enhance evaporation process and primary productivity [139, 140, 141]. Several researchers have reported that day time CO_2 uptake between biosphere and atmosphere are regulated by solar radiation [142, 143, 144, 145, 146]. Using data from 20 FLUXNET sites Niu et al., [147] reported radiation as the one of the main drivers responsible for seasonal variation in CO_2 flux.

2.8.3. Photosynthetically active radiation (PAR):

PAR is the incident photosynthetically active radiation and its wave length lies between 400 nm- 700nm [148], plants use this energy for photosynthesis [149]. In Uttarakhand of India, Watham et al., [114] reported daily mean of PAR in the range 302.78 µmol m^{-2} sec^{-1} to 492.16 µmol m^{-2} sec^{-1}. It was reported in previous studies that CO_2 uptake rate increases along with the increase in incident light intensity until it reached a saturation point [150]. In a study on tropical forest of south-west Amazonia Grace et al., [151] tried to work out a relationship between PAR and CO_2 flux and found that CO_2 uptake rate of the ecosystem had a hyperbolic relationship with PAR, several other researchers also reported rectangular hyperbola to be the best fit between the two parameters [115, 144,152, 153, 154].

2.8.4. Leaf area index:

Leaf area index is defined as the ratio between areas of one side of the leaf to ground surface area [155, 156]. Leaf area index is a quantitative indicator of the present leaf amount and it determines the biological productivity of plants [157]. Leaf area index of plants determines photosynthate assimilation ability and stomatal density [158]. The seasonal phenology of LAI in interpreting the fluxes of the carbon, water vapor and energy between biosphere and atmosphere is basic and crucial [159, 160, 161]. Increase in LAI also increases the carbon uptake ability of plants from the atmosphere [162]. The leaf area of canopy plays the most vital role in photosynthesis, transpiration, exchange of energy with the atmosphere and in many other ecosystem processes [162,163, 164]. Change in LAI affects the light capturing ability and the nitrogen supply to the plants which can affect net photosynthesis of any ecosystem [165]. The ecosystem productivity of a forest was reported to be modulated by the timing of leaf emergence and senescence

[131, 160, 166]. Studies over deciduous boreal and temperate forests ecosystem showed strong correlations between leaf phenology and CO_2 uptake [167, 168, 169].

2.8.5. Air temperature:

The plant metabolism rate and phenology depends on temperature, which in turn affects the photosynthesis of the plants [166, 170, 171]. Increasing air temperature may raise the vapour pressure deficit of the air which may regulate stomatal openings responsible for the exchange of CO_2 and water between biosphere and atmosphere [170]. The relationship between air temperature and photosynthesis in different ecosystems was found to be nonlinear [172]. In a study of CO_2 exchange in Japan between temperate forest ecosystem and atmosphere Yamamoto et al., [96] observed that inter annual variability of annual CO_2 uptake was a function of summer air temperature. Studies over tropical rain forest by Grace et al., [151], boreal forest ecosystems by Lindroth et al., [103] and temperate deciduous forest by Goulden et al., [93] indicated high sensitiveness of ecosystem CO_2 flux with temperature. According to Lindroth et al., [103] boreal forest ecosystem could change to a net source of CO_2 with the change of temperature. The carbon cycle of savanna ecosystem in China is reported to be strongly affected by the increase in air temperature [173].

2.8.6. Rainfall:

Rainfall plays an important role in controlling seasonal variations in terrestrial carbon cycle [174, 175, 176]. In the years having higher rainfall, the ecosystems receive low radiation which might decrease the photosynthesis rate [177]. Precipitation rate can regulate soil water content and thus influences the carbon gaining capacity of plants [147, 178]. Precipitation played a significant role in carbon exchange processes of boreal and temperate ecosystems [116]. Precipitation controls the status of root zone soil water, which in turn effects the productivity of plants and thus effects the CO_2 fluxes [179, 180]. Soil in wet condition can release more CO_2 to the atmosphere [81, 181] due the higher microbial activities [182]. Over a broad-leaved savanna woodland ecosystem in Southern Africa Veenendaal et al., [107] reported the occurrence of CO_2 release events after rainfall. The carbon dynamics of the ecosystems in Mediterranean climate is mostly affected by the amount of rainfall received during the growing season than the total annual rainfall [183].

2.8.7. Vapour pressure deficit:

The deficit between the vapour pressure at saturated stage and the real vapour pressure can be termed as vapour pressure deficit (VPD). VPD controls the interaction mechanisms between biosphere and atmosphere through stomata [113, 184]. It was reported that in sunny conditions the rate of photosynthesis in leaves depends on the amount of moisture present in the atmosphere [185, 186]. In a study of net ecosystem exchange (NEE) over a mixed temperate forest of Belgian, the authors reported about the better correlation of net CO_2 flux with vapour pressure deficit than the air temperature [167].

2.8.8. Soil carbon dynamics:

The role of forest soil in global carbon cycle is very critical as forest soil covers a large area of the earth [187, 188]. Both plant biomass and soil is responsible for carbon capture and storage. The determination of carbon storage capacity of forest soils is a very important research activity. It is very much essential to understand biological principles involved in carbon exchange process between land surface and atmosphere [189]. Literatures related to soil carbon dynamics are reviewed below.

2.8.8.1. CO_2 efflux:

Soil carbon has been reported to be the largest organic carbon stocks in terrestrial ecosystems [190] which is about two-thirds of terrestrial C [191] out of which 75 Pg C year^{-1} is respired back to atmosphere [192]. Minor changes in CO_2 efflux from soil can have significant impact on increasing atmospheric CO_2 concentration and temperature [192, 193]. The release of CO_2 (efflux) from soil is a complex process which includes respiration from roots of the plants, soil fauna and microorganisms as well as soil organic matter decomposition [194, 195]. The CO_2 efflux is a result of the oxidation process of soil organic matter during the litter decomposition by heterotrophic microorganisms and respiration from roots [196]. Bacteria to fungi ratio in soil and their community composition can be altered by the precipitation and changes in soil moisture [197, 198]. Hence, the population of soil microorganisms in soil along with abiotic factors related to soil like temperature, moisture and soil organic matter etc. plays a vital role in emissions of CO_2 from soil [199, 200]. Soil CO_2 efflux is also contributed by photo degradation [201] or carbonate weathering [202] in some ecosystems. Sometimes magnitude and direction of net ecosystem exchange (NEE) may vary with the variability in soil respiration [101, 203]. Although soil respiration is a common process of all the ecosystems but its magnitude and speed may vary considerably among various ecosystems depending upon geographical location, climate and vegetation and soil characteristics [204]. In a study conducted over various forests of China reveled that soil respiration is highly sensitive to temperature in forests of high latitude and altitude [205]. Significant impact of soil temperature and precipitation on controlling the microbial populations in the natural Oak forest in the northeastern Himalayan region of Manipur, India are reported by Pandey et al., [196]. Presence of fungal population as main driver of soil CO_2 flux in the natural Oak forest has been highlighted in the above study. In a recent study by Jeong et al., [204] over a temperate deciduous forest of Korea the annual average of soil respiration was estimated as 405.1 mg CO_2 m^{-2} h^{-1}. The relative contributions of soil, stem and leaves on CO_2 efflux is reported to be about 56, 8 and 36% respectively in a mediterranean beech forest of Italy [206].

2.8.8.2. Soil organic carbon (SOC):

A portion of the total carbon fixed by the ecosystems through the process of photosynthesis is generally transferred below ground and can stay for long period of time in the soil organic carbon pool [207]. The SOC sequestration mainly depends on the amount of carbon input, stabilization process in the soil, and inputs from the roots and rhizosphere [208]. The depth wise distribution of SOC inside the soil varies depending on climate, vegetation and soil types [209]. Soil organic carbon is the largest terrestrial reservoir of carbon which plays an important role in carbon cycle and is an important part of global climate models [210, 211, 212]. The SOC pool is about 50 % of the total forest carbon pool and in boreal and temperate forests the SOC pool is greater than the carbon content in the forest biomass [63]. The role of SOC is very important in controlling the biological productivity of soil [213]. It is very much essential to understand the variation of SOC and its feedback to the atmosphere in different ecosystems as well as its natural controls in different time frames and different zones [214]. Significant variation of SOC pools in space and time was observed as it depends on the net available carbon resulted from the balance between primary production and respiration due to organic matter decomposition, respiration from roots, leaching of dissolved soil carbon and soil erosion [215]. The estimation of SOC pool is generally done with the help of total organic carbon content, bulk density of soil, rock content and the depth of soil [208]. Soil microbes are very important organisms in ongoing global climate research, due to their important role in controlling soil carbon dynamics [208]. Also abiotic factors can regulate gaseous diffusion process as well as metabolic activity of soil microorganisms which in turn can control the metabolic activity of microorganism within the sites [216]. The rate of decomposition of SOC mainly depends on its chemical composition [217]. Small change in decomposition rate of SOC might have significant influence on the atmospheric CO_2 concentration [218]. In Austrian pine forest, Sevgi and Tecimen [219] found higher soil organic carbon in the natural forest ecosystem as compared to other ecosystems which indicates the presence and decomposition of higher amount of litter in natural ecosystems. In Uttrakhand, India, Salim et al., [220] conducted a comparative study among different ecosystems to observe the seasonal change in soil nutrients and SOC and reported presence of higher organic carbon in winter as compared to other seasons. Negative correlation between SOC and soil CO_2 emission has been observed by Dutta et al., [221] in a paddy filed of Northeast India. SOC accounted for about 55 to 70 % of total ecosystem carbon among different temperate forest types of Northern China [222].

2.8.8.3. Bulk density of Soil:

Bulk density (BD) is one of the most essential parameters which can be used along with soil organic carbon (SOC) and soil organic matter (SOM) for estimation of soil carbon pools [223, 224, 225]. BD is the ratio between the total mass of the material and its total volume, considering the mass of both air and water [226]. The change in BD of soil can alter the dielectric properties of both wet and dry soils [227]. Bulk density of soil can influence nutrient storage, gas exchange rate and water holding capacity [228]. Several researchers reported about the negative correlations between SOC and BD [229, 230].

2.8.8.4. Soil C/N ratio:

The biological productivity of soil depends on the status of carbon and nitrogen in soil [213]. The atmospheric concentration of C and N can be regulated by the amount of carbon and nitrogen present in the soil [231, 232]. Soil is a major reservoir of terrestrial nitrogen, which can store approx.133–140 Pg N in top layer [233]. Thus a small change in soil nitrogen can cause significant changes in global biogeochemical cycle [234]. The amount of carbon and nitrogen present in soil is an indicator of soil fertility which can have profound impact on global climate change [235]. The understory vegetation of any ecosystem plays a significant role in the regulation of the carbon and nitrogen status of soil [236]. Understory vegetation of any ecosystem can also regulate soil moisture and temperature status of soil [237], microbial properties [238, 239] and C/N ratio [240, 241]. In a study over Eucalyptus plantations in south China Wu et al., [242] reported that removal of understory vegetation decreased the root biomass and organic matter input to the soil which together altered the structure of microbial community. Both carbon and nitrogen content of soil are modulated by the change of seasons, hence it is very important to understand the seasonal variation of the carbon cycle with respect to the changes in soil carbon and nitrogen for accurate prediction of future climate change [243]. Xie et al., [244] reported strong influence of seasons on soil carbon and nitrogen status in a temperate forest ecosystem.

2.8.8.5. Soil temperature:

Soil temperature is an important abiotic factor which controls the variation of soil respiration [245]. Positive correlations between soil respiration and temperature is reported from a Taiwanese forest plantation [246]. Using global dataset, Hursh et al., [247] also reported that soil temperature along with soil water content to be the most important drivers of the CO_2 emissions from the soil. Increase of temperature can stimulate the process of soil respiration by accelerating autotrophic respiration and by rapid heterotrophic decomposition of soil organic matter [248]. In some studies neutral or in fact negative impact of soil temperature on respiration has been observed which indicated the existence of multiple drives of soil respiration other than soil temperature, such as soil moisture [249, 250], change in microbial composition of soil [251, 252], C substrate availability and nutrient status [253]. The temperature dependence of respiration varies significantly in different ranges of temperature, in very warm condition the temperature sensitivity of soil respiration was found to be low [254]. Thus, still there are lots of prevailing uncertainties on the response of soil respiration with the ongoing climate warming [255, 256].

2.9. Partitioning of net ecosystem exchange (NEE):

Net ecosystem exchange is a terrestrial flux which represents the net exchange of CO_2 between atmosphere and biosphere [257]. The net CO_2 flux measured over an ecosystem is primarily the interplay between gross CO_2 uptake by an ecosystem (GPP) for photosynthesis and the ecosystem respiration (Re) [258]. The direct measurement of net

CO_2 flux over any ecosystem is possible with the help of eddy covariance method or it can be assessed from repeated inventories and can be estimated with the help of different models [259]. It is impossible to directly partition NEE in to GPP and Re as during daytime both the fluxes mask each other in net CO_2 flux [260]. Therefore, many indirect methods has evolved for partitioning of NEE, out of which the flux partitioning algorithms proposed by Lasslop et al., [258] and Reichstein et al., [261] are the most common method and being used by global FLUXNET community.

2.9.1. Gross primary production:

Gross primary production (GPP) is the basic and most important parameter which determines the amount of CO_2 assimilated by an ecosystem from the atmosphere through the process of photosynthesis [262]. Ecosystem researchers highlighted terrestrial GPP as the largest global CO_2 flux and its approximate magnitude has been reported as 123±8 Pg C year^{-1}. In recent study by Ma et al., [263] the global annual GPP of the forests is estimated as 53.71± 4.83 Pg C yr^{-1}. The GPP of forest ecosystems is higher compared to other ecosystems [264]. Therefore, accurate GPP estimation of forest ecosystems is necessary for accurate prediction of atmospheric CO_2 concentration [265]. The influence of terrestrial GPP on the atmospheric CO_2 concentration level has been documented by some researchers [266, 267]. The available photosynthetically active radiation and leaf area index of the canopy influences the gross primary productivity of a forest ecosystem [268]. GPP is primarily a function of irradiation during the growing season along with presence of suitable temperature for plant growth [167]. Water availability in the ecosystems was also reported as one of the key drivers of the GPP [174]. Inter annual variations in climate parameters can cause significant changes in the gross primary productivity of forest ecosystems [269]. In the year 2003, the GPP over Europe was reported to reduce by about 30% as an effect of the heat wave occurred in that year [270]. In East Asia annual GPP values were reported to be modulated by average air temperature [271]. The productivity of temperate forest was reported to be positively affected by moderate increase of temperature [272]. In a study by Janssens et al., [273] over 18 European forest ecosystems reported mean annual gross primary productivity (GPP) of 1380 ± 330 g C m^{-2} year^{-1}. A distinct seasonal relationship between GPP and absorbed photosynthetically active radiation (APAR) over a cool temperate deciduous forest of Japan is reported by [131].

2.9.2. Ecosystem respiration:

The amount of CO_2 released to the atmosphere by ecosystems is considered as the second largest flux after the ecosystem gross primary production [8]. Ecosystem respiration is about 70 to 85 % of annual GPP [274]. Ecosystem respiration is the key flux which controls the variation of net ecosystem exchange in forest ecosystems [101]. The accurate understanding of carbon dynamics of any ecosystem is possible only after identification of the biotic and abiotic processes which controls the CO_2 efflux of an ecosystem [275]. Respiration from soil is the principal component of total ecosystem respiration [167]. The total ecosystem respiration is the combination of soil respiration and aboveground autotrophic respiration [276]. The amount of CO_2 absorbed by the plants during photosynthesis stays inside the plants only for a small period of time and about 25-70 % of the captured carbon is immediately returned to the atmosphere by the process of autotrophic respiration [277]. Soil respiration or CO_2 efflux is the combination of belowground autotrophic respiration and heterotrophic respiration [50, 81]. The increase of total ecosystem respiration with temperature can give positive feedback to the global warming [217]. Ecosystem respiration of any forest ecosystem was reported to be a function of temperatures of soil and air [167, 278]. Many researchers found temperature and moisture conditions to be the major driver of soil and ecosystem respiration [279, 280, 281]. Studies from East Asia have revealed an existence of a clear exponential relation between mean annual air temperature and annual ecosystem respiration [271]. Carbon loss from an ecosystem can occur throughout the year and soil respiration is the dominating component [273]. Some studies revealed a close relationship between ecosystem respiration and gross primary production [273, 282]. In European forest ecosystems net ecosystem exchange of CO_2 is primarily determined by ecosystem respiration [101]. Sink strengths of different ecosystem are modulated by ecosystem respiration [108]. In Northern hemisphere the carbon cycle during the winter season is reported to be regulated by the ecosystem respiration [228]. Guidolotti et al., [206] carried out a study on carbon balance of Mediterranean beech forest of Italy and reported about strong seasonal variability of ecosystem respiration. They also reported about significant reduction in ecosystem respiration during summer drought.

2.9.3. Net ecosystem productivity:

Net ecosystem productivity (NEP) is the difference between gross primary productivity (GPP) and ecosystem respiration (Re) [283]. In an ecosystem for short time period NEP is approximately equal to negative of net ecosystem exchange(NEP= -NEE) [115]. The seasonal variation in the amplitude and phase of the net carbon flux of an ecosystem is determined by the interplay between assimilation and respiration [167]. Conventionally positive NEP represents carbon gain by an ecosystem whereas negative NEP is an indicator of carbon loss by the ecosystem [115]. The role of forest ecosystems in the regulation of global and regional carbon dynamics is very important due to its large carbon storage capacity and higher productivity [284]. Climatic impact, length of the growing season, species composition and age might change a forest from a carbon sink to carbon source [74, 285, 286]. In a comparative analysis of annual NEP among different forest ecosystems of East Asia, Yamamoto et al., [287] reported annual NEP in the range 2 to 8 t C ha^{-1} yr^{-1}. According to Yamamoto et al., [287] the difference in annual NEP among different forests was caused by variation in mean annual temperature and tree species. In southern England Thomas et al., [288] estimated cumulative NEP over broadleaved deciduous woodland and reported as 1.2 Mg C ha^{-1} $year^{-1}$. Ross et al., [289] reported that change in rainfall pattern could lead to the change in productivity of the forest ecosystems of northern hemisphere. In a study over 26 different forests of Canada , Coursolle et al., [290] found that NEP of matured forests were mainly controlled by climate whereas in young forests NEP was a function of canopy leaf area index and climate. They also reported that mature forests act as nearly carbon neutral. The inter annual variability of NEP was reported to be influenced by various factors such as amount of rainfall during spring season [291], phenology of the land surface [292], temperature of air [293], drought during summer season [294], various disturbances in the forest [285] and variability in CO_2 flux phenology in autumn [295]. In Canada Zha et al., [296] made a study over 18 different temperate and boreal forests stands to study and interpret the variations of NEP among different forest types. They found strong influence of species on the net productivity of the ecosystems. The annual net productivity of boreal forests were approximately half as compared to temperate stands and NEP is reported to be controlled by absorbed photosynthetically active radiation, LAI, soil nitrogen, annual air temperature and annual rainfall amount [296]. Highest NEP of 328 g C m^{-2} yr^{-1} by a Korean pine plantation ecosystem followed by 311.9 g C m^{-2} yr^{-1} by an old growth forest ecosystem has been observed by Cai et al., [222] in a study of NEP among different temperate forest types of Northern China. In a recent study over tropical Indian Mangrove forest, annual NEP of 249±20 g C m^{-2} $year^{-1}$ is reported by Rodda et al., [115].

References

[1] Baldocchi, D., Falge, E., Gu, L., Olson, R., Hollinger, D., Running, S., Anthoni, P., Bernhofer, C., Davis, K., Evans, R., Fuentes, J., Goldstein, A., Katul, G., Law, B., Lee, X., Malhi, Y., Meyers, T., Munger, W., Oechel, W., Paw, K.T., Pilegaard, K., Schmid, H. P., Valentini, R., Verma, S., Vesala, T., Wilson, K., and Wofsy, S. FLUXNET: A New Tool to Study the Temporal and Spatial Variability of Ecosystem-Scale Carbon Dioxide, Water Vapor, and Energy Flux Densities. *Bulletin of the American Meteorological Society,* 82(11): 2415-2434, 2001.

[2] Le Quere, C., Rodenbeck, C., Buitenhuis, E.T., Conway, T.J., Langenfelds, R., Gomez, A., Labuschagne, C., Ramonet, M., Nakazawa, T., Metzl, N., Gillett, N., and Heimann, M. Saturation of the Southern Ocean CO_2 Sink Due to Recent Climate Change. *Science,* 316:1735-1738, 2007.

[3] Peters, G.P., Andrew, R.M., Boden, T., Canadell, J.G., Ciais, P., Quere, C.L., Marland, G., Raupach, M.R., and Wilson, C. The challenge to keep global warming below 2°C. *Nature Climate Change,* 3:4-6, 2012.

[4] Hutsch, B.W. Methane oxidation in non-flooded soils as affected by crop production. *European Journal of Agronomy,* 14:237-260, 2001.

[5] Keeling, C.D. and Whorf, T.P. Atmospheric CO_2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. *Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory,* 1999.

[6] Showstack, R. Carbon dioxide tops 400 ppm at Mauna Loa, Hawaii. *Eos Transactions American Geophysical Union,* 94:192-192, 2013.

[7] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[8] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge

University Press, Cambridge, United Kingdom and New York, NY, USA.

[9] Keeling, C.D. The concentration and isotopic abundance of carbon dioxide in the atmosphere. *Tellus,* 12:200–203, 1960.

[10] Malhi, Y. and Grace, J. Tropical forests and atmospheric carbon dioxide. *Trends in Ecology and Evolution,* 15:332–337, 2000.

[11] Conway, T.J., Tans, P.P., Waterman, L.S., and Thoning, K.W. Evidence of interannual variability of the carbon cycle from the NOAA/CMDL global air sampling network. *Journal of Geophysical Research,* 99:22831-22855, 1994.

[12] Le Quere, C., Raupach, M.R., Canadell, J.G., Marland, G., Bopp, L., Ciais, P., Conway, T.J., Doney, S.C., Feely, R.A., Foster, P., Friedlingstein, P., Gurney, K., Houghton, R.A., House, J.I., Huntingford, C., Levy, P.E., Lomas, M.R., Majkut, J., Metzl, N., Ometto, J.P., Peters, G.P., Prentice, I.C., Randerson, J.T., Running, S.W., Sarmiento, J.L., Schuster, U., Sitch, S., Takahashi, T., Viovy, N., Van Der Werf, G.R., and Woodward, F.I. 'Trends in the sources and sinks of carbon dioxide. *Nature Geoscience,* 2, 831-836, 2009.

[13] Huber, M. and Knutti, R. Anthropogenic and natural warming inferred from changes in Earth’s energy balance. *Nature Geoscience,* 5:31-36, 2012.

[14] Gurney, K.R., Law, R.M., Denning, A.S., Rayner, P.J., and Pak, B. TransCom 3 L2 modelers. Transcom 3 inversion inter comparison: control results for the estimation of seasonal carbon sources and sinks. *Global Biogeochemical Cycles,* 18:GB1010, 2004.

[15] Raupach, M.R. Carbon cycle: Pinning down the land carbon sink. *Nature Climate Change,* 1:148-149, 2011.

[16] Kowalski, A.S., Serrano-Ortiz, P., Janssens, I.A., Sanchez-Moral, S.M., Cuezva, S., Domingo, F., Were, A., and Alados-Arboledas, L. Can flux tower research neglect geochemical CO_2 exchange? *Agricultural and Forest Meteorology,* 148:1045-1054, 2008.

[17] Bolin, B. Changes of land biota and their importance for the carbon cycle. *Science,* 196:613–615, 1977.

[18] Woodwell, G.M., Whittaker, R.H., Reiners, W.A., Likens, G.E., Delwiche, C.C., and Botkin, D.B. The biota and the world carbon budget. *Science,* 199:141-146, 1978.

[19] Houghton, R.A., Davidson, E.A., and Woodwell, G. M. Missing sinks, feedbacks, and understanding the role of terrestrial ecosystems in the global carbon balance. Global *Biogeochemical Cycles,* 12(1):25-34, 1998.

[20] Davis, W.J. The Relationship between Atmospheric Carbon Dioxide Concentration and Global Temperature for the Last 425 Million Years. *Climate,* 5:76, 2017.

[21] Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S., and Hayes, D. A Large and Persistent Carbon Sink in the World's Forests. *Science,* 333(6045):988-993, 2011.

[22] Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M., and Dorland, R.V. Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

[23] Bhattacharya, S.K., Borole, D.V., Francy, R.J., Allison, C.E., Steele, L.P., Krummel, P., Langenfelds, R., Masarie, K.A., Tiwari, Y.K., and Patra, P.K. Trace gases and CO_2 isotope records from Cabo de Rama, India. *Current Science,* 97(9): 1336-1344, 2009.

[24] Amthor, J. S. Terrestrial higher-plant response to increasing atmospheric CO_2 in relation to the global carbon cycle. *Global Change Biology,* 1:243-274, 1995.

[25] Hanson, J. E., Sato, M., Lacias, A., Ruedy, R., Tegen, I., and Matthews, E. Climate forcings in the industrial era. *Proceeding of National Academy of Science, USA,* 95(12): 753-758, 1998.

[26] Norby, R.J., Wullschleger, S.D., Gunderson, C.A., Johnson, D.W., and Ceulemans, R. Tree responses to rising CO_2 in field experiments: Implication for the future forest. *Plant, Cell & Environment,* 22:683-714, 1999.

[27] Cha, S., Chae, H.M., Lee, S.H., and Shim, J.K. Effect of elevated atmospheric CO_2 concentration on growth and leaf litter decomposition of Quercus acutissima

and Fraxinus rhynchophylla. *PLoS ONE,* 12(2):e0171197, 2017.

[28] Alory, G. and Meyers, G. Warming of the upper equatorial Indian Ocean and changes in the heat budget (1960–99). *Journal of Climate,* 22:93-113, 2009.

[29] Tan, Z., Zhang, Y., Yu, G., Sha, L., Tang, J., Deng, X., and Song, Q. Carbon balance of a primary tropical seasonal rain forest. J*ournal of Geophysical Research,* 115:D00H26, 2010.

[30] Smith, P., Fang, C., Dawson, J.J.C., and Moncrieff, J.B. Impact of global warming on soil organic carbon. *Advances in Agronomy,* 97:1-43, 2008.

[31] Andres, R.J., Boden, T.A., Breon, F.M., Ciais, P., Davis, S., Erickson, D., Gregg, J.S., Jacobson, A., Marland, G., Miller, J., Oda, T., Olivier, J.G.J. Raupach, M.R., Rayner, P., and Treanton, K. A synthesis of carbon dioxide emissions from fossil-fuel combustion. *Biogeosciences*, 9:1845–1871, 2012.

[32] Raupach, M.R., Marland, G., Ciais, P., Le Quere, C., Canadell, J.G., Klepper, G., and Field. C.B. Global and regional drivers of accelerating CO_2 emissions. *PNAS*, 104(24):10288–10293, 2007.

[33] Jackson, R.B., Le Quere, C., Andrew, R.M., Canadell, J.G., Peters, G.P., Roy, J., and Wu, L. Warning signs for stabilizing global CO_2 emissions. *Environmental Research Letters*, 12:110202, 2017.

[34] Bakhtyar, B., Kacemi, T., and Nawaz, A. A Review on Carbon Emissions in Malaysian Cement Industry. *International Journal of Energy Economics and Policy*, 7(3):282-286, 2017.

[35] Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A. Global strategies and potentials to curb CO_2 emissions in cement industry. *Journal of Cleaner Production,* 51:142-161, 2013.

[36] Boden, T.A., Andres, R.J., and Marland, G. Global, Regional, and National Fossil-Fuel CO_2 Emissions, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., USA. Available at: http://cdiac.ess-dive.lbl.gov/trends/emis/meth_reg.html, last access: 28 June 2017.

[37] Ke, J., McNeil, M., Price, L., Khanna, N.Z., and Zhou, N. Estimation of CO_2 emissions from China’s cement production: Methodologies and uncertainties. *Energy Policy*, 57:172-181, 2013.

[38] Andrew, R.M. Global CO_2 emissions from cement production. *Earth System*

Science Data, 10:195-217, 2018.

[39] Canadell, J.G., Quere, C.L., Raupach, M.R., Field, C.B., Buitenhuis, E.T., Ciais, P., Conway, T.J., Gillett, N.P. Houghton, R.A., and Marland, G. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *PANS*, 104:18866-18870, 2007.

[40] Chanjuan, H., Guohua, L., Bojie, F., Liding, C., Yihe, L., and Lei, G. Soil Carbon Stock and Flux in Plantation Forest and Grassland Ecosystems in Loess Plateau, China. *Chinese Geographical Science*, 24(4): 423–435, 2014.

[41] Fan, L.C., Yang, M.Z., and Han, W.Y. Soil Respiration under Different Land Uses in Eastern China. *PLoS ONE*, 10(4): e0124198, 2015.

[42] Han, G.X., Xing, Q.H., Luo, Y.Q., Rafique, R., Yu, J.B., and Mikle, N. Vegetation types alter soil respiration and its temperature sensitivity at the field scale in an estuary wetland. *PLOS ONE*, 9:e91182, 2014.

[43] Houghton, R.A., House, J.I., Pongratz, J., van der Werf, G.R., DeFries, R.S., Hansen, M.C., Le Quere, C., and Ramankutty, N. Carbon emissions from land use and land-cover change. *Biogeosciences*, 9:5125–5142, 2012.

[44] IPCC, 2000: Land Use, Land Use Change and Forestry. Special Report, Inter-Governmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 127–180.

[45] Wang, W., Zeng, W.J., Chen, W.L., Zeng, H., and Fang, J.Y. Correction: Soil respiration and organic carbon dynamics with grassland conversions to woodlands in temperate China. *PLoS One*, 8:e71986, 2013

[46] Friedlingstein, P., Houghton, R.A., Marland, G., Hackler, J., Boden, T.A., Conway, T.J., Canadell, J.G., Raupach, M.R., Ciais, P., and Le Quere, C. Update on CO_2 emissions. *Nature Geoscience*, 3:811–812, 2010.

[47] Tollefson, J. Brazil set to cut forest protection. *Nature*, 485:19, 2012.

[48] Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., and Erasmi, S. Greenhouse gas emissions from soils-A review. *Chemie der Erde*, 76:327-352, 2016.

[49] Sofi, J.A., Lone, A.H., Ganie, M.A., Dar, N.A., Bhat, S.A., Mukhtar, M., Dar, M.A., and Ramzan, S. Soil Microbiological Activity and Carbon Dynamics in the Current Climate Change Scenarios: A Review. *Pedosphere*, 26(5): 577-591, 2016.

[50] Kuzyakov, Y. Sources of CO_2 efflux from soil and review of partitioning methods. *Soil Biology and Biochemistry,* 38(3):425-448. 2006.

[51] Rodeghiero, M. and Cescatti, A. Main determinants of forest soil respiration along an elevation/temperature gradient in the Italian Alps. *Global Change Biology,* 11(7):1024-1041, 2005.

[52] Grace, J. and Rayment, M. Respiration in the balance. *Nature*, 404:819-820, 2000.

[53] Le Quere, C., Moriarty, R., Andrew, R.M., Canadell, J.G., Sitch, S., Korsbakken, J.I., Friedlingstein, P., Peters, G.P., Andres, R.J., Boden, T.A., Houghton, R.A., House, J.I., Keeling, R.F., Tans, P., Arneth, A., Bakker, D.C.E., Barbero, L., Bopp, L., Chang, J., Chevallier, F., Chini, L.P., Ciais, P., Fader, M., Feely, R.A., Gkritzalis, T., Harris, I., Hauck, J., Ilyina, T., Jain, A.K., Kato, E., Kitidis, V., Klein Goldewijk, K., Koven, C., Landschützer, P., Lauvset, S.K., Lefèvre, N., Lenton, A., Lima, I.D., Metzl, N., Millero, F., Munro, D.R., Murata, A., Nabel, J.E.M.S., Nakaoka, S., Nojiri, Y., O'Brien, K., Olsen, A., Ono, T., Pérez, F.F., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Rodenbeck, C., Saito, S., Schuster, U., Schwinger, J., Séférian, R., Steinhoff, T., Stocker, B.D., Sutton, A.J., Takahashi, T., Tilbrook, B., van der Laan-Luijkx, I.T., van der Werf, G.R., van Heuven, S., Vandemark, D., Viovy, N., Wiltshire, A., Zaehle, S., and Zeng, N. Global Carbon Budget 2015. *Earth System Science Data,* 7:349-396, 2015.

[54] Grand, S., Rubin, A., Verrecchia, E.P., and Vittoz, P. Variation in Soil Respiration across Soil and Vegetation Types in an Alpine Valley. *PLOS ONE,* 11(9): e0163968, 2016.

[55] Srivastava, P., Raghubanshi, A.S., Singh, R., and Tripathi, S.N. Soil carbon efflux and sequestration as a function of relative availability of inorganic N pools in dry tropical agroecosystem. *Applied Soil Ecology,* 96:1–6, 2015.

[56] Cox, P.M., Betts, R.A., Jones, C.D., Spall, S.A., and Totterdell, I.J. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature,* 408:184-187, 2000.

[57] Siegenthaler, U. and Sarmiento, J.L. Atmospheric carbon dioxide and the ocean. *Nature,* 365:119-125, 1993.

[58] Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., Millero, F.J., Peng,

T., Kozyr, A., Ono, T., and Rios, A.F. The Oceanic Sink for Anthropogenic CO_2. *Science,* 305:367-371, 2004.

[59] Houghton, R.A. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000. *Tellus,* 55(2):378-390, 2003.

[60] Marland, G., Boden, T.A., and Andres, R.J. Global, regional and National fossil fuel CO_2 emissions, in Trends: A Compendium of Data on Global Change. Carbon Dioxide Inf. Anal. Cent. Oak Ridge Natl. Lab., U.S. Dept. of Energy, Oak Ridge, Tenn., *U.S.A,* 2006.

[61] Yang, H., Zhenghe, X., Fan, M., Gupta, R., Slimane, R.B., Bland, A.E., and Wright, I. Progress in carbon dioxide separation and capture: A review. *Journal of Environmental Sciences,* 20:14–27, 2008.

[62] Yamasaki, A. An overview of CO_2 mitigation options for global warming - Emphasizing CO_2 sequestration options. *Journal of Chemical Engineering of Japan,* 36(4):361–375, 2003.

[63] Lorenz, K. Ecosystem carbon sequestration; In: Lal R., Lorenz K., Huttl R. F., Schneider B.U. and Braun J. V. (Eds.), *Ecosystem services and carbon sequestration in the biosphere*. Springer, Netherlands, pp. 39–62, 2013.

[64] Janssens, I.A., Freibauer, A., Ciais, P., Smith, P., Nabuurs, G.J., Folberth, G., Schlamadinger, B., Hutjes, R.W.A., Ceulemans, R., Schulze, E.D., Valentini, R., and Dolman, A.J. Europe’s terrestrial biosphere absorbs 7 to 12% of European anthropogenic CO_2 emission. *Science,* 300:1538-1542, 2003.

[65] Gloor, M., Gatti, L., Brienen, R., Feldpausch, T.R., Phillips, O.L., Miller, J., Ometto, J.P., Rocha, H., Baker, T., De Jong, B., Houghton, R.A., Malhi, Y., Aragao, L.E.O.C., Guyot, J.L., Zhao, K., Jackson, R., Peylin, P., Sitch, S., Poulter, B., Lomas, M., Zaehle, S., Huntingford, C., Levy, P., and Lloyd, J. The carbon balance of South America: a review of the status, decadal trends and main determinants, *Biogeosciences,* 9:5407-5430, 2012.

[66] Grace, J., Mitchard, E., and Gloor, E. Perturbations in the carbon budget of the tropics. *Global Change Biology,* 20:3238-3255, 2014.

[67] Lal, R. Forest soils and carbon sequestration. *Forest Ecology and Management,* 220:242-258, 2005.

[68] Pimm, S.L., Jenkins, C.N., Abell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N.,

Raven, P.H., Roberts, C.M., and Sexton, J.O. The biodiversity of species and their rates of extinction, distribution, and protection. *Science,* 344(6187):1246752(1-10), 2014.

[69] Magnani, F., Mencuccini, M., Borghetti, M., Berbigier, P., Berninger, F., Delzon, S., Grelle, A., Hari, P., Jarvis, P.G., Kolari, P., Kowalski, A.S., Lankreijer, H., Law, B.E., Lindroth, A., Loustau, D., Manca, G., Moncrieff, J.B., Rayment, M., Tedeschi, V., Valentini, R., and Grace, J. The human footprint in the carbon cycle of temperate and boreal forests. *Nature,* 447:848-850, 2007.

[70] Carvalhais, N., Forkel, M., Khomik, M., Bellarby, J., Jung, M., Migliavacca, M., Mu, M., Saatchi, S., Santoro, M., Thurner, M., Weber, U., Ahrens, B., Beer, C., Cescatti, A., Randerson, J.T., and Reichstein, M. Global covariation of carbon turnover times with climate in terrestrial ecosystems. *Nature,* 514:213–217, 2014.

[71] Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J.H., Allard, G., Running, S.W., Semerci, A., and Cobb, N. A global overview of drought and heat induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management*, 259:660–684, 2010.

[72] Carey, E.V., Sala, A., Keane, R., and Callaway, R.M. Are old forests underestimated as global carbon sinks? *Global Change Biology,* 7:339-344, 2001.

[73] Pregitzer, K.S. and Euskirchen, E.S. Carbon cycling and storage in world forests: biome patterns related to forest age. *Global Change Biology,* 10:2052-2077, 2004.

[74] Luyssaert, S., Schulze, E.D., Aorner, A., Knohl, A., Hessenmoller, V., Law, B.E., Ciais, P., and Grace, J. Old growth forests as global carbon sinks. *Nature,* 455:213-215, 2008.

[75] Zuidema, P.A., Baker, P.J., Groenendijk, P., Schippers, P., van der Sleen, P., Vlam, M., and Sterck, F. Tropical forests and global change: filling knowledge gaps. *Trends in Plant Science,* 18:413-419, 2013.

[76] Fernandez-Martinez, M., Vicca, S., Janssens, I.A., Ciais, P., Obersteiner, M., Bartrons, M., Sardans, J., Verger, A., Canadell, J.G., Chevallier, F., Wang X.,

Bernhofer, C., Curtis, P.S., Gianelle, d., Grünwald, T., Heinesch, B., Ibrom, A., Knohl, A., Laurila, T., Law, B.E., Limousin, J.M., Longdoz, B., Loustau, D., Mammarella, I., Matteucci, G., Monson, R.K., Montagnani, L., Moors, E.J., Munger, J.W., Papale, D., Piao, S.L., and Penuelas, J. Atmospheric deposition, CO_2, and change in the land carbon sink. *Scientific Reports,* 7:9632, 2017.

[77] Lorenz, K. and Lal, R. The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. *Advances in Agronomy,* 88:35-66, 2005.

[78] Lal, R., Follett, R.F., and Kimble, J.M. Achieving soil carbon sequestration in the United States: A challenge to the policy makers. *Soil Science,* 168(12): 827-845, 2003.

[79] Lal, R. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science,* 304:1623-1627, 2004.

[80] Bolin, B., Sukumar, R., Ciais, P. et al. In: IPCC, Land Use, Land- Use Change, and Forestry. A Special Report of the IPCC (eds Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J., Dokken D.J.), 23–51. Cambridge University Press, Cambridge, UK, 2000.

[81] Heinemeyer, A., Hartley, I.P., Evans, S.P., Carreira De La Fuente, J.A., and Ineson, P. Forest soil CO_2 flux: uncovering the contribution and environmental responses of ectomycorrhizas. *Global Change Biology,* 13:1786-1797, 2007.

[82] Denmead, O.T. Comparative micrometeorology of a wheat field and a forest of Pinus radiata. *Agricultural and Forest Meteorology,* 6:357-371, 1969.

[83] Baumgartner, A. Meteorological approach to the exchange of CO_2 between atmosphere and vegetation, particularly forests stands. *Photosynthetica,* 3:127-149, 1969.

[84] Jarvis, P.G., James, G.B., and Landsberg, J.J. Coniferous forest. Vegetation and the Atmosphere, J.L. Monteith, Ed., Academic Press, 2:171:240, 1976.

[85] Houghton, R. A. and Woodwell, G. The flax pond ecosystem study: Exchanges of CO_2 between a salt marsh and the atmosphere. *Ecology,* 61:1434-1445, 1980.

[86] Baldocchi, D.D. Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystems: past, present and future. *Global Change Biology,* 9:479-492, 2003.

[87] Elbers, J.A., Jacobs, C.M.J., Kruijt, B., Jans, W.W.P., and Moors, E.J. Assessing

the uncertainty of estimated annual totals of net ecosystem productivity: a practical approach applied to a mid-latitude temperate pine forest. *Agricultural and Forest Meteorology,* 151(12):1823–1830, 2011.

[88] Baldocchi, D., Chu, H., and Reichstein, M. Inter-annual variability of net and gross ecosystem carbon fluxes: A review. *Agricultural and Forest Meteorology,* 249:520:533, 2018.

[89] Verma, S. B., Baldocchi, D.D., Anderson, D.E., Matt, D.R., and Clement, R.E. Eddy fluxes of CO_2 water vapor, and sensible heat over a deciduous forest. *Boundary-Layer Meteorology*, 36:71-91, 1986.

[90] Wofsy, S. C., Goulden, M.L., Munger, J.W., Fan, S.M., Bakwin, P.S., Daube, B.C., Bassow, S.L., and Bazzaz, F.A. Net exchange of CO_2 in a mid-latitude forest. *Science,* 260:1314-1317, 1993.

[91] Vermetten, A.W.M., Ganzeveld, L., Hofschreuder, A.J.P., and Mohren, G.M.J. CO_2 uptake by a stand of Douglasfir: Flux measurements compared with model calculations. *Agricultural and Forest Meteorology,* 72:57–80, 1994.

[92] Goulden, M.L., Munger, J.W., Fan, S.M., Daube, B.C., and Wofsy, S.C. Measurement of carbon storage by long-term eddy correlation: Methods and a critical assessment of accuracy. *Global Change Biology,* 2:169-182, 1996.

[93] Goulden, M.L., Munger, J.W., Fan, S.M., Daube, B.C., and Wofsy, S.C. Exchange of carbon dioxide by a deciduous forest: Response to interannual climate variability. *Science*, 271:1576-1578, 1996.

[94] Greco, S. and Baldocchi, D.D. Seasonal variations of CO_2 and water vapor exchange rates over a temperate deciduous forest. *Global Change Biology,* 2:183-198, 1996.

[95] Valentini, R., De Angelis, P., Matteucci, G., Monaco, R., Dore, S., and Scarascia-Mugnozza, G.E. Seasonal net carbon dioxide exchange of a beech forest with the atmosphere. *Global Change Biology,* 2:199-208, 1996.

[96] Yamamoto, S., Murayama, S., Saigusa, N. and Kondo, H. Seasonal and interannual variation of CO_2 flux between a temperate forest and the atmosphere in Japan. *Tellus,* 51B:402-413, 1999.

[97] Berbigier, P., Bonnefond, J.M., and Mellman, P. CO_2 and water vapour fluxes for 2 years above Euro-flux forest site. *Agricultural and Forest Meteorology,* 108:183-197, 2001.

[98] Granier, A., Ceschia, E., and Damesin, C. The carbon balance of a young beech forest. *Functional Ecology,* 14:312-325, 2000.

[99] Pilegaard, K., Hunnelshoj, P., Jensen, N.O., and Chen, Z. Two years of continuous CO_2 eddy-flux measurements over a Danish beech forest. *Agricultural and Forest Meteorology,* 107:29-41, 2001.

[100] Lee, X., Fuentes, J.D., Staebler, R.M., and Neumann, H.H. Long-term observation of the atmospheric exchange of CO_2 with a temperate deciduous forest in southern Ontario, Canada. *Journal of geophysical research,* 104(D13):15975-15984, 1999.

[101] Valentini, R, Matteucci, G., and Dolman, A. J. Respiration as the main determinant of carbon balance in European forests. *Nature,* 404:861-864, 2000.

[102] Malhi, Y., Nobre, A.D., Grace, J., Kruijt, B., Pereira, M., Culf, A., and Scott, S. Carbon dioxide transfer over a central Amazonian rain forest. *Journal of Geophysical Research,* 103:31593-31612, 1998.

[103] Lindroth, A., Grelle, A., and Moren, A.S. Long-term measurements of boreal forest carbon balance reveal large temperature sensitivity. *Global Change Biology,* 4:443-450, 1998.

[104] Markkanen, T., Rannik, U., Keronen, P., Suni, T., and Vesala, T. Eddy covariance fluxes over a boreal Scots pine forest. *Boreal Environment Research,* 6:65-78, 2001.

[105] Hollinger, D.Y., Goltz, S.M., Davidson, E.A., Lee, J.T., Tu, K., and Valentine, H.T. Seasonal patterns and environmental control of carbon dioxide and water vapor exchange in an ecotonal boreal forest. *Global Change Biology,* 5:891-902, 1999.

[106] Anthoni, P.M., Law, B.E., and Unsworth, M.H. Carbon and water vapor exchange of an open-canopied ponderosa pine ecosystem. *Agricultural and Forest Meteorology,* 95:115-168, 1999.

[107] Veenendaal, E., Kolle O., and Lloyd, J. Seasonal variation in energy fluxes and carbon dioxide exchange for a broad-leaved semi-arid savanna (Mopane woodland) in Southern Africa. *Global Change Biology,* 10:318-328, 2004.

[108] Desai, A.R., Bolstad, P.V., Cook, B.D., Davis, K.J., and Carey, E.V. Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature

forest in the upper Midwest, USA. *Agricultural and Forest Meteorology,* 128:33-55, 2005.

[109] Gielen, B., De Vos, B., Campioli, M., Neirynck, J., Papale, D., Verstraeten, A., Ceulemans, R., and Janssen. I.A. Biometric and eddy covariance-based assessment of decadal carbon sequestration of a temperate Scots pine forest. *Agricultural and Forest Meteorology,* 174-175:135-143, 2013.

[110] Barr, J.G., Engel, V., Fuentes, J.D., Zieman, J.C., O'Halloran, T.L., Smith, T.J., and Anderson, G.H. Controls on mangrove forest-atmosphere carbon dioxide exchanges in western Everglades National Park. *Journal of Geophysical Research,* 115:G02020, 2010.

[111] Dadhwal., V.K., Kushwaha, S.P.S., Singh, S., Patel, N.R., Nayak, R.K., Patil, P., Dutt, C.B.S., Murthy, M.S.R., Jha, C.S., Rajsekhar, G., Pujar, G.S., Trivedi, S., Sharma, N., and Ali, M.M. Recent results from eo studies on Indian carbon cycle assessment. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-8/W20, 2011 ISPRS Bhopal 2011 Workshop, 8 November 2011, Bhopal, India.

[112] Sundareshwar, P.V., Murtugudde, R., Srinivasan, G., Singh, S., Ramesh, K.J., Ramesh, R., Verma, S.B., Agarwal, D., Baldocchi, D., Baru, C.K., Baruah, K.K., Chowdhury, G.R., Dadhwal, V.K., Dutt, C.B.S., Fuentes, J., Gupta, P.K., Hargrove, W.W., Howard, M., Jha, C.S., Lal, S., Michener, W.K., Mitra, A.P., Morris, J.T., Myneni, R.R., Naja, M., Nemani, R., Purvaja, R., Raha, S., Santhana Vanan, S.K., Sharma, M., Subramaniam, A., Sukumar, R., Twilley, R.R., and Zimmerman., P.R. Environmental Monitoring Network for India. *Science,* 316: 204-205, 2007.

[113] Jha, C.S., Thumaty, K.C., Rodda, S.R., Sonakia, A., and Dadhwal, V.K. Analysis of carbon dioxide, water vapour and energy fluxes over an Indian teak mixed deciduous forest for winter and summer months using eddy covariance technique. *Journal of Earth System Science,* 122:1259-1268, 2013.

[114] Watham, T., Kushwaha, S., Patel, N., and Dadhwal, V. Monitoring of carbon dioxide and water vapour exchange over a young mixed forest plantation using eddy covariance technique. *Current Science,* 107:857-867, 2014.

[115] Rodda, S.R., Thumaty, K.C., Jha, C.S., and Dadhwal, V.K. Seasonal Variations of Carbon Dioxide, Water Vapor and Energy Fluxes in Tropical Indian

Mangroves. *Forests,* 7:35, 2016.

[116] Fu, Z., Stoy, P.C., Luo, Y., Chen, J., Sun, J., Montagnani, L., Wohlfahrt, G., Rahman, A.F., Rambal, S., Bernhofer, C., Wang, J., Shirkey, G., and Niu, S. Climate controls over the net carbon uptake period and amplitude of net ecosystem production in temperate and boreal ecosystems. *Agricultural and Forest Meteorology,* 243:9-18, 2017.

[117] Xia, J., Niu, S., Ciais, P., Janssens, I.A., Chen, J., Ammann, C., Arain, A., Blanken, P.D., Cescatti, A., Bonal, D., Buchmann, N., Curtis, P.S., Chen, S., Dong, J., Flanagan, L.B., Frankenberg, C., Georgiadis, T., Gough, C.M., Hui, D., Kiely, G., Li, J., Lund, M., Magliulo, V., Marcolla, B., Merbold, L., Montagnani, L., Moors, E.J., Olesen, J.E., Piao, S., Raschi, A., Roupsard, O., Suyker, A.E., Urbaniak, M., Vaccari, F.P., Varlagin, A, Vesala, T., Wilkinson, M., Weng, E., Wohlfahrt, G., Yan, L., and Luo, Y. Joint control of terrestrial gross primary productivity by plant phenology and physiology. *Proceedings of National Academy of Science (PNAS),* 112(9): 2788–2793, 2015.

[118] Zhou, S., Zhang, Y., Caylor, K.K., Luo, Y., Xiao, X., Ciais, P., Huang, Y., and Wang, G. Explaining inter-annual variability of gross primary productivity from plant phenology and physiology. *Agricultural and Forest Meteorology,* 226-227:246-256, 2016.

[119] Baldocchi, D.D., Hicks, B.B., and Meyers, T.P. Measuring biosphere-atmosphere exchanges of biologically related gases with micrometeorolgical methods. *Ecology*, 69:1331-1340, 1988.

[120] Mahrt, L. Flux sampling errors for aircraft and towers. *Journal of Atmospheric and Oceanic Technology,* 15:416-429, 1998.

[121] Aubinet, M., Grelle, A., Ibrom, A., Rannik, U., Moncrieff, J., Foken, T., Kowalski, A.S., Martin, P.H., Berbigier, P., Bernhofer, Ch., Clement, R., Elbers, J., Granier, A., Grünwald, T., Morgenstern, K., Pilegaard, K., Rebmann, C., Snijders, W., Valentini, R., and Vesala, T. Estimates of the annual net carbon and water exchange of European forests: the EUROFLUX methodology. *Advances in Ecological Research*, 30:114-175, 2000.

[122] Goldstein, A.H., Hultman, N.E., Fracheboud, J.M., Bauer, M.R., Panek, J.A., Xu, M., Qi, Y., Guenther, A.B., and Baugh, W. Effects of climate variability on the carbon dioxide, water, and sensible heat fluxes above a ponderosa pine plantation

in the Sierra Nevada (CA). *Agricultural and Forest Meteorology*, 101:113-129, 2000.

[123] Wilson, K.B. and Baldocchi, D.D. Seasonal and interannual variability of energy fluxes over a broadleaved temperate deciduous forest in North America. *Agricultural and Forest Meteorology,* 100:1-18, 2000.

[124] Schmid, H.P., Grimmond, C.S.B., Cropley, F., Offerle, B., and Su, H.B. Measurements of CO_2 and energy fluxes over a mixed hardwood forest in the mid-western United States. *Agricultural and Forest Meteorology,* 103:357–374, 2000.

[125] Wilson, K., Goldstein, A., Falge, E., Aubinet, M., Baldocchi, D., Berbigier, P., Bernhofer, C., Ceulemans, R., Dolman, H., Field, C., Grelle, A., Ibrom, A., Law, B.E., Kowalski, A., Meyers, T., Moncrieff, J., Monson, R., Oechel, W., Tenhunen, J., Valentini, R., and Verma, S. Energy balance closure at FLUXNET sites. *Agricultural and Forest Meteorology,* 113:223-243, 2002.

[126] Leuning, R., Gorsel, E., Massman, W.J., and Isaac, P.R. Reflections on the surface energy imbalance problem. *Agricultural and Forest Meteorology,* 156:65-74, 2012.

[127] Stannard, D.I., Blanford, J.H., Kustas, W.P., Nichols, W.D., Amer, S.A., Schmugge, T.J., and Weltz, M.A. Interpretation of surface flux measurements in heterogeneous terrain during the Monsoon'90 experiment. *Water Resources Research,* 30(5):1227-1239, 1994.

[128] Twine, T.E., Kustas, W.P., Norman, J.M., Cook, D.R., Houser, P.R., Meyers, T.P., Prueger, J.H., Starks, P.J., and Wesely, M.L. Correcting eddy-covariance flux underestimates over a grassland. *Agricultural and Forest Meteorology*, 103:279-300, 2000.

[129] Stoy, P.C., Mauder, M., Foken, T., Marcolla, B., Boegh, E., Ibrom, A., Arain, M.A., Arneth, A.L.U., Aurela, M., Bernhofer, C., Cescatti, A., Dellwik, E., Duce, P., Gianelle, D., van Gorsel, E., Kiely, G., Knohl, A., Margolis, H., McCaughey, H., Merbold, L., Montagnani, L., Papale, D., Reichstein, M., Saunders, M., Serrano-Ortiz, P., Sottocornola, M., Spano, D., Vaccari, F., and Varlagin, A. A data-driven analysis of energy balance closure across FLUXNET research sites: The role of landscape scale heterogeneity. *Agricultural and Forest Meteorology,* 171-172:137-152, 2013.

[130] Barr, A.G., Morgenstern, K., Black, T.A., McCaughey, J.H., and Nesic, Z. Surface energy balance closure by the eddy-covariance method above three boreal forest stands and implications for the measurement of the CO_2 flux. *Agricultural and Forest Meteorology,* 140:322-337, 2006.

[131] Saigusa, N., Yamamotoa, S., Murayamaa, S., Kondo, H., and Nishimura, N. Gross primary production and net ecosystem exchange of a cool-temperate deciduous forest estimated by the eddy covariance method. *Agricultural and Forest Meteorology*, 112:203–215, 2002.

[132] Eder, F., Schmidt, M., Damian, T., Traumner, K., and Mauder, M. Mesoscale Eddies Affect Near-Surface Turbulent Exchange: Evidence from Lidar and Tower Measurements. *Journal of Applied Meteorology and Climatology*. 54(1):189–206, 2014.

[133] Serrano-Ortiz, P., Sanchez-Canete, E.P. Olmo, F.J., Metzger, S. Perez-Priego, O., Carrara, A., Alados-Arboledas, L., and Kowalski, A.S. Surface-Parallel Sensor Orientation for Assessing Energy Balance Components on Mountain Slopes. *Boundary-Layer Meteorology,* 158(3):489-499, 2016.

[134] Wohlfahrt, G., Hammerle, A., Niedrist, G., Scholz, K., Tomelleri, E., and Zhao, P. On the energy balance closure and net radiation in complex terrain. *Agricultural and Forest Meteorology*, 226-227:37-49, 2016.

[135] Sanchez, J. M., Caselles, V., and Rubio, E. M. Analysis of the energy balance closure over a FLUXNET boreal forest in Finland. *Hydrology and Earth System Sciences*, 14:1487-1497, 2010.

[136] Meyers, T. and Hollinger, S. An assessment of storage terms in the surface energy balance of maize and soybean. *Agricultural and Forest Meteorology,* 125:105-115, 2004.

[137] Masseroni, D. Limitations and improvements of the energy balance closure with reference to experimental data measured over a maize field. *Atmosfera,* 27(4): 335-352, 2014.

[138] Oliphant, A.J., Grimmond, C.S.B., Zutter, H.N., Schmid, H.P., Su, H.B., Scott, S.L., Offerle, B., Randolph, J.C., and Ehman, J. Heat storage and energy balance fluxes for a temperate deciduous forest. *Agricultural and Forest Meteorology,* 126:185-201, 2004.

[139] Shuttleworth, W., Leuning, R., Black, T., Grace, J., Jarvis, P., Roberts, J., and Jones, H. Micrometeorology of Temperate and Tropical Forest and Discussion. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 324(1223):299-334, 1989.

[140] Kelliher, F.M., Leuning, R., and Schulze, E.D. Evaporation and canopy characteristics of coniferous forests and grasslands. *Oecologia*, 95:153-163, 1993.

[141] Baldocchi, D.D. and Vogel, C.A. Energy and CO_2 flux densities above and below a temperate broad-leaved forest and a boreal pine forest. *Tree Physiology*, 16:5-16, 1995.

[142] Aguilera, J., Karsten, U., Lippert, H., Vogele, B., Philipp, E., Hanelt, D., and Wiencke, C. Effects of solar radiation on growth, photosynthesis and respiration of marine macroalgar from the arctic. *Marine Ecology Progress Series*, 191:109-119, 1999.

[143] Pinker, R., Zhang, B., and Dutton, E.G. Do satellites detect trends in surface solar radiation? *Science,* 308(5723): 850-854, 2005.

[144] Xu, L.L., Zhang, X.Z., Shi, P.L., Yu, G.R., and Sun, X.M. Net ecosystem carbon dioxide exchange of alpine meadow in the Tibetan Plateau from August to October. *Acta Ecologica Sinica*, 25(8): 1948-1952, 2005.

[145] Shi, P., Sun, X., Xu, L., Zhang, X., He, Y., Zhang, D., and Yu, G. Net ecosystem CO_2 exchange and controlling factors in a steppe-Kobresia meadow on the Tibetan Plateau. Science in China Series D: Earth Sciences, 49(II):207-218, 2006.

[146] Zhao, L., Gu, S., Xu, S., Zhao, X., and Li, Y. Carbon Flux and Controlling Process of Alpine Meadow on Qinghai-Tibetan Plateau. *Acta Botanica Boreali-Occidentalia Sinica,* 25(5):1054-1060, 2007.

[147] Niu, S., Luo, Y., Fei, S., Montagnani, L., Bohrer, G., Janssens, I.A., Gielen, B., Rambal, S., Moors, E., and Matteucci, G. Seasonal hysteresis of net ecosystem exchange in response to temperature change: patterns and causes. *Global Change Biology,* 17(10):3102-3114, 2011.

[148] Zhang, Y., Xu, M., Chen, H., and Adams, J. Global pattern of NPP to GPP ratio derived from MODIS data: Effects of ecosystem type, geographical location and climate. *Global Ecology and Biogeography*, 18:280–290, 2009.

[149] Bernhofer, C., Aubinet, M., Clement, R., Grelle, A., Grunwald, T., Ibrom, A., Jarvis, P., Rebmann, C., Schulze, E.D., and Tenhunen, J.D. Spruce forests (Norway and Sitka spruce, including Douglas fir): Carbon and water fluxes, balances, ecological and ecophysiological determinants. *Ecological Studies*, 164:99–124, 2003.

[150] Ye, Z. and Zhao, Z. A modified rectangular hyperbola to describe the light-response curve of photosynthesis of Bidens pilosa L. grown under low and high light conditions. *Frontiers of Agriculture in China,* 4(1):50-55, 2010.

[151] Grace, J., Lloyd, J., Mcintyre, J., Miranda, A., Meir, P., Miranda, H., Moncrieff, J., Massheder, J., Wright, I., and Gash, J. Fluxes of carbon dioxide and water vapour over an undisturbed tropical forest in south-west Amazonia. *Global Change Biology,* 1:1-12, 1995.

[152] Falge, E., Baldocchi, D., Olson, R., Anthoni, P., Aubinet, M., Bernhofer, C., Burba, G., Ceulemans, R., Clement, R., Dolman, H., Granier, A., Gross, P., Grünwald, T., Hollinger, D., Jensen, N.O., Katul, G., Keronen, P., Kowalski, A., Lai, C.T., Law, B.E., Meyers, T., Moncrieff, J., Moors, E., Munger, J.W., Pilegaard, K., Rannik, U., Rebmann, C., Suyker, A., Tenhunen, J., Tu, K.,Verma, S., Vesala, T., Wilson, K., and Wofsy, S. Gap filling strategies for defensible annual sums of net ecosystem exchange. *Agricultural and Forest Meteorology,* 107(1): 43-69, 2001.

[153] Xu, L., Zhang, X., and Shi, P. The apparent quantum yield and maximum photosynthesis rate in alpine meadow on the Tibetan Plateau. Science in China (Series D), 34(Suppl. 2):125–130, 2004.

[154] Nakano, T., Nemoto, M. and Shinoda, M. Environmental controls on photosynthetic production and ecosystem respiration in semi-arid grasslands of Mongolia. *Agricultural and Forest Meteorology,* 148(10):1456-1466, 2008.

[155] Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M. and Baret, F. Methods for leaf area index determination. Part I. Theories, techniques and instruments. *Agricultural and Forest Meteorology,* 121:19-35, 2004.

[156] Gonsamo, A. and Pellikka, P. Methodology comparison for slope correction in canopy leaf area index estimation using hemispherical photography. *Forest Ecology and Management,* 256:749-759, 2008.

[157] Chen, J.M., Rich, P.M., Gower, S.T., Norman, J.M., and Plummer, S. Leaf area

index of boreal forests: Theory, techniques, and measurements. *Journal of Geophysical Research,* 102:429-443, 1997.

[158] Bonan, G.B. Importance of leaf area index and forest type when estimating photosynthesis in boreal forests. *Remote Sensing of Environment,* 43:303-314, 1993.

[159] Chen, J.M., Govind, A., Sonnentag, O., Zhang, Y., Barr, A., and Amiro, B. Leaf area index measurements at Fluxnet Canada forest sites. *Agricultural and Forest Meteorology,* 140:257–268, 2006.

[160] Dragoni, D., Schmid, H.P., Wayson, C.A., Potter, H., Grimmond, C.S.B., and Randolph, J.C. Evidence of increased net ecosystem productivity associated with a longer vegetated season in a deciduous forest in south-central Indiana, USA. *Global Change Biology,* 17:886-897, 2011.

[161] Smith, L.M. and Hall, S. Extended leaf phenology may drive 784 plant invasion through direct and apparent competition. *Oikos,* 125:839–848, 2016.

[162] Savoy, P. and Mackay, D.S. Modeling the seasonal dynamics of leaf area index based on environmental constraints to canopy development. *Agricultural and Forest Meteorology*, 200:46–56, 2015.

[163] Gonsamo, A. and Chen, J.M. Continuous observation of leaf area index at Fluxnet-Canada sites. *Agricultural and Forest Meteorology,* 189:168–174, 2014.

[164] Bao, Y., Gao, Y., Lu, S., Wang, Q., Zhang, S., Xu, J., Li, R., Li, S., Ma, D., Meng, X., Chen, H., and Chang, Y. Evaluation of CMIP5 earth system models in reproducing leaf area index and vegetation cover over the Tibetan Plateau. *Journal of Meteorological Research,* 28:1041-1060, 2014.

[165] Reichstein, M., Bahn, M., Mahecha, M.D., Kattge, J., and Baldocchi, D.D. Linking plant and ecosystem functional biogeography. *Proceedings of the National Academy of Sciences (PNAS),* 111(38):13697-13702, 2014.

[166] Richardson, A.D., Black, T.A., Ciais, P., Delbart, N., Friedl, M.A., Gobron, N., Hollinger, D.Y., Kutsch, W.L., Longdoz, B., Luyssaert. S., Migliavacca, M., Montagnani, L., Munger, J.W., Moors, E., Piao, S., Rebmann, C., Reichstein, M., Saigusa, N., Tomelleri, E., Vargas, R., and Varlagin, A. Influence of spring and autumn phenological transi-tions on forest ecosystem productivity. *Philosophical Transactions of the Royal Society B,* 365(1555):3227-3246, 2010.

[167] Carrara, A., Janssens, I.A., Yuste, J.C., and Ceulemans, R. Seasonal changes in

photosynthesis, respiration and NEE of a mixed temperate forest. *Agricultural and Forest Meteorology,* 126:15-31, 2004.

[168] White, M.A. and Nemani, R.R. Canopy duration has little influence on annual carbon storage in the deciduous broad leaf forest. *Global Change Biology,* 9:967–972, 2003.

[169] Muraoka, H., Noda, H.M., Nagai, S., Motohka, T., Saitoh, T.M., Nasahara, K.N., and Saigusa, N. Spectral vegetation indices as the indicator of canopy photosynthetic productivity in a deciduous broadleaf forest. *Journal of Plant Ecology,* 6:393–407, 2012.

[170] Boisvenue, C. and Running, S.W. Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century. *Global Change Biology,* 12:862-882, 2006.

[171] Niu, S., Luo, Y., Fei, S., Yuan, W., Schimel, D., Law, B., Ammann, C., Altaf Arain, M., Arneth, A., Aubinet, M., Barr, A., Beringer, J., Bernhofer, C., Andrew Black, T., Buchmann, N., Cescatti, A., Chen, J., Davis, K., Dellwik, E., Desai, A., Etzold, S., Francois, L., Gianelle, D., Gielen, B., Goldstein, A., Groenendijk, M., Gu, L., Hanan, N., Helfter, C., Hirano, T., Hollinger, D., Jones, M., Kiely, G., Kolb, T., Kutsch, W., Lafleur, P., Lawrence, D., Li, L., Lindroth, A., Litvak, M., Loustau, D., Lund, M., Marek, M., Martin, T., Matteucci, G., Migliavacca, M., Montagnani, L., Moors, E., William Munger, J., Noormets, A., Oechel, W., Olejnik, J., U, K., Pilegaard, K., Rambal, S., Raschi, A., Scott, R., Seufert, G., Spano, D., Stoy, P., Sutton, M., Varlagin, A., Vesala, T., Weng, E., Wohlfahrt, G., Yang, B., Zhang, Z., and Zhou, X. Thermal optimality of net ecosystem exchange of carbon dioxide and underlying mechanisms. *New Phytologist,* 194(3):775-783, 2012.

[172] Way, D. and Yamori, W. Thermal acclimation of photosynthesis: on the importance of adjusting our definitions and accounting for thermal acclimation of respiration. *Photosynthesis Research,* 119(1-2):89–100, 2014.

[173] Poulter, B., Frank, D., Ciais, P., Myneni, R.B., Andela, N., Bi, J., Broquet, G., Canadell, J.G., Chevallier, F., Liu, Y.Y., Running, S.W., Sitch, S., and van der Werf, G.R. Contribution of semi-arid ecosystems to inter annual variability of the global carbon cycle. *Nature,* 509:600-603, 2014.

[174] Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N.,

Rodenbeck, C., Arain, M.A., Baldocchi, D., Bonan, G.B., Bondeau, A., Cescatti, A., Lasslop, G., Lindroth, A., Lomas, M., Luyssaert, S., Margolis, H., Oleson, K.W., Roupsard, O., Veenendaal, E., Viovy, N., Williams, C., Woodward, F.I., and Papale, D. Terrestrial gross carbon dioxide uptake: Global distribution and covariation with climate. *Science,* 329:834-838, 2010.

[175] Paschalis, A., Fatichi, S., Katul, G.G., and Ivanov, V.Y. Cross-scale impact of climate temporal variability on ecosystem water and carbon fluxes. *Journal of Geophysical Research: Biogeosciences,* 120(9):1716-1740, 2015.

[176] Fei, X., Jin, Y., Zhang, Y., Sha, L., Liu, Y., Song, Q., Zhou, W., Liang, N., Yu, G., Zhang, L., Zhou, R., Li, J., Zhang, S., and Li, P. Eddy covariance and biometric measurements show that a savanna ecosystem in Southwest China is a carbon sink. *Scientific Reports,* 7:41025, 2017.

[177] Zeri, M., Sa, L.D.A., Manzi, A.O., Araujo, A.C., Aguiar, R.G., von Randow C, Sampaio, G. Cardoso, F.L., and Nobre C.A. Variability of Carbon and Water Fluxes Following Climate Extremes over a Tropical Forest in Southwestern Amazonia. *PLoS ONE,* 9(2): e88130, 2014.

[178] Wolf, S., Keenan, T., Fisher, J., Baldocchi, D., Desai, A., Richardson, A., Scott, R., Law, B., Litvak, M., Brunsell, N., Peters, W., and van der Laan-Luijkx, I. Warm spring reduced carbon cycle impact of the 2012 US summer drought. *Proceedings of the National Academy of Sciences,* 113(21):5880-5885, 2016.

[179] Fay, P.A., Carlisle, J.D., Knapp, A.K., Blair, J.M., and Collins, S.L. Altering rainfall timing and quantity in a mesic grassland ecosystem: Design and performance of rainfall manipulation shelters. *Ecosystems,* 3(3):308-319, 2000.

[180] Huxman, T.E., Snyder, K.A., Tissue, D., Leffler, A.J., Ogle, K., Pockman, W.T., Sandquist, D.R., Potts, D.L., and Schwinning, S. Precipitation pulses and carbon fluxes in semiarid and arid ecosystems. *Oecologia,* 141(2):254-268, 2004.

[181] Harper, C.W., Blair, J.M., Fay, P.A., Knapp, A.K., and Carlisle, J.D. Increased rainfall variability and reduced rainfall amount decreases soil CO_2 flux in a grassland ecosystem. *Global Change Biology,* 11:322–334, 2005.

[182] Sponseller, R.A. Precipitation pulses and soil CO_2 flux in a Sonoran desert ecosystem. *Global Change Biology,* 13:426-436, 2007.

[183] Thomas, C.K., Law, B.E., Irvine, J., Martin, J.G., Pettijohn, J.C., and Davis, K.J. Seasonal hydrology explains inter annual and seasonal variation in carbon

and water exchange in a semiarid mature ponderosa pine forest in central Oregon. *Journal of Geophysical Research*, 114:G04006, 2009.

[184] Mahrt, L. and Vickers, D. Relationship of area-averaged carbon dioxide and water vapour fluxes to atmospheric variables. *Agricultural and Forest Meteorology*, 112:195–202, 2002.

[185] Ishida, A., Toma, T., Matsumoto, Y., Yap, S.K., and Maruyama, Y. Diurnal changes in leaf gas exchange characteristics in the uppermost canopy of a rain forest tree, Dryobalanops aromatica Gaertn. f. *Tree Physiology*, 16:779-785, 1996.

[186] Muraoka, H., Tang, Y., Terashima, I., Koizumi, H., and Washitani, I. Contributions of diffusional limitation, photoinhibition and photorespiration to midday depression of photosynthesis in Arisaema heterophyllum in natural high light. *Plant, cell and environment*, 23:235-250, 2000.

[187] Richter, D.D., Markewitz, D., Wells, C.G., Allen, H.L., Dunscombe, J.K., Harrison, K., Heine, P.R., Stuanes, A., Urrego, B., and Bonani, G. Carbon cycling in a loblolly pine forest: implications for missing carbon sink and for the concept of soil. In: McFee, W., Kelly, J.M. (Eds.), Carbon Forms and Functions in Forest Soils. *Soil Science Society American, Madison, WI*, 233-251, 1995.

[188] Jabaggy, E.G. and Jackson, R.B. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10:423-436, 2000.

[189] Heimann, M. and Reichstein, M. Terrestrial ecosystem carbon dynamics and climate feedbacks. *Nature*, 451:289-292, 2008.

[190] Jiang, L., Shi, F., Li, B., Luo, Y., Chen, J., and Chen, J. Separating rhizosphere respiration from total soil respiration in two larch plantations in North-eastern China. *Tree Physiology*, 25:1187–1195, 2005.

[191] Schimel, D.S., Braswell, B.H., Holland, E.A., McKeown, R., Ojima, D.S., and Painter, T.H. Climatic, edaphic, and biotic controls over storage and turnover of carbon in soils. *Global Biogeochemical Cycles*, 8:279-293, 1994.

[192] Schlesinger, W.H. and Andrews, J.A. Soil respiration and the global carbon cycle. *Biogeochemistry*, 48:7-20, 2000.

[193] Kirschbaum, M.U.F. The temperature dependence of organic-matter

decomposition -still a topic of debate. *Soil Biology & Biochemistry,* 38:2510–2518, 2006.

[194] Qi, Y., Xu, M., and Wu, J. Temperature sensitivity of soil respiration and its effects on ecosystem carbon budget: nonlinearity begets surprises. *Ecological Modelling,* 153:131-142, 2002.

[195] Heinemeyer, A., Di Bene, C., Lloyd, A.R., Tortorella, D., Baxter, R., Huntley, B., Gelsomino, A., and Ineson, P. Soil respiration: implications of the plant-soil continuum and respiration chamber collar-insertion depth on measurement and modelling of soil CO_2 efflux rates in three ecosystems. *European Journal of Soil Science,* 62:82-94, 2011.

[196] Pandey, R.R., Sharma, G., Singh, T.B., and Tripathi, S.K. Factors influencing soil CO_2 efflux in a northeastern Indian oak forest and plantation. *African Journal of Plant Science,* 4(8): 280-289, 2010.

[197] Chen, M.M., Zhu, Y.G., Su, Y.H., Chen, B.D., Fu, B.J., and Marschner, P. Effects of soil moisture and plant interactions on the soil microbial community structure. *European Journal of Soil Biology,* 43:31-38, 2007.

[198] Williams, M.A. Response of microbial communities to water stress in irrigated and drought-prone tallgrass prairie soils. *Soil Biology and Biochemistry,* 39: 2750–2757, 2007.

[199] Bouma, I.J. and Bryla, D.R. On the assessment of root and soil respiration for soils of different textures: interactions with soil moisture contents and soil CO_2 concentrations. *Plant Soil,* 227: 215-221, 2000.

[200] Muhr, J., Goldberg, S.D., Borken, W., and Gebauer, G. Repeated drying rewetting cycles and their effects on the emission of CO_2, N_2O and CH_4 in a forest soil. *Journal of Plant Nutrition and Soil Science,* 171:719-728, 2008.

[201] Austin, A.T. and Vivanco, L. Plant litter decomposition in a semi-arid ecosystem controlled by photo degradation. *Nature,* 442(7102):555-558, 2006.

[202] Morner, N.A. and Etiope, G. Carbon degassing from the lithosphere. *Global Planet Change,* 33(1-2):185–203, 2002.

[203] Oechel, W.C., Vourlitis, G.L., Hastings, S.J., Zulueta, R.C., Hinzman, L., and Kane, D. Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming. *Nature,* 406:978-981, 2000.

[204] Jeong, S.H., Eom, J.Y., Park, J.Y., Lee, J.H., and Lee, J.S. Characteristics of accumulated soil carbon and soil respiration in temperate deciduous forest and alpine pastureland. *Journal of Ecology and Environment,* 42:3, 2018.

[205] Xu, Z., Tang, S., Xiong, L., Yang, W., Yin, H., Tu, L., Wua, F., Chen, L., and Tan, B. Temperature sensitivity of soil respiration in China's forest ecosystems: Patterns and controls. *Applied Soil Ecology,* 93:105-110, 2015.

[206] Guidolotti, G., Rey, A., D'Andrea, E., Matteucci, G., and De Angelis, P. Effect of environmental variables and stand structure on ecosystem respiration components in a Mediterranean beech forest. *Tree Physiology,* 33:960–972, 2013.

[207] Schulze, E.D., Ciais P., Luyssaert, S., Schrumpf, M., Janssens, I.A., Thiruchittampalam, B., Theloke, J., Saurat, M., Bringezu, S., Lelieveld, J., Lohila, A., Rebmann, C., Jung, M., Bastviken, D., Abril, G., Grassi, G., Leip, A., Freibauer, A., Kutsch, W., Don A., Nieschulze, J., Borner A., Gash, J.H., and Dolman, A.J. The European carbon balance. Part 4: integration of carbon and other trace gas fluxes. *Global Change Biology,* 16:1451–1469, 2010.

[208] Schmidt, M., Torn, M., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I., Kleber, M., Kogel-Knabner, I., Lehmann, J., Manning, D., Nannipieri, P., Rasse, D., Weiner, S., and Trumbore, S. Persistence of soil organic matter as an ecosystem property. *Nature,* 478(7367):49-56, 2011.

[209] Rumpel, C. and Kogel-Knabner, I. Deep soil organic matter-a key but poorly understood component of terrestrial C cycle. *Plant and Soil,* 338:143–158, 2011.

[210] Davidson, E.A. and Janssens. I.A. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, 440:165–73, 2006.

[211] Deluca, T.H. and Boisvenue, C. Boreal forest soil carbon: distribution, function and modelling. *Forestry,* 85(2):161-184, 2012.

[212] Kumar, P., Sharma, L.K., Pandey, P.C., Sinha, S., and Nathawat, M.S. Geospatial strategy for tropical forest-wildlife reserve biomass estimation. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 6:917-923, 2013.

[213] Ren, W., Tian, H., Tao, B., Huang, Y., and Pan, S. China's crop productivity and soil carbon storage as influenced by multifactor global change. *Global Change Biology.* 18(9):2945-2957, 2012.

[214] Schuur, E,A., McGuire, A.D., Schadel, C., Grosse, G., Harden, J.W., Hayes, D.J., Hugelius, G., Koven, C.D., Kuhry, P., Lawrence, D.M., Natali, S.M., Olefeldt, D., Romanovsky, V.E., Schaefer, K., Turetsky, M.R. Treat, C.C., and Vonk, J.E. Climate change and the permafrost carbon feedback. *Nature,* 520:171–179, 2015.

[215] De Deyn, G.B., Cornelissen, J.H.C., and Bardgett, R.D. Plant functional traits and soil carbon sequestration in contrasting biomes. *Ecology Letters,* 11:516–531, 2008.

[216] Santoyo, G., Hernandez-Pacheco, C., Hernandez-Salmeron, J., and Hernández-Leon, R. The role of abiotic factors modulating the plant-microbe-soil interactions: toward sustainable agriculture. A review. *Spanish Journal of Agricultural Research,* 15(1):e03R01, 2017.

[217] Guo, X., Meng, M., Zhang, J., and Chen, H.Y.H. Vegetation change impacts on soil organic carbon chemical composition in subtropical forests. *Scientific Reports,* 6:29607, 2016.

[218] Albaladejo, J., Ortiz, R., Garcia-Franco, N., Navarro, A., Almagro, M., Pintado, J., and Martinez-Mena, M. Land use and climate change impacts on soil organic carbon stocks in semi-arid Spain. *Journal of Soils and Sediments,* 13:265-277, 2012.

[219] Sevgi, O. and Tecimen, H.B. Changes in Austrian Pine forest floor properties in relation with altitude in mountainous areas. *Journal of Forest Science,* 54:306-313, 2008.

[220] Salim, M., Kumar, P., Gupta, M.K., and Kumar, S. Seasonal variation in some chemical characteristics of the soil under different land uses of Jhilmil Jheel wetland, Haridwar-Uttrakhand, India. *International Journal of Scientific and Research Publications,* 5:10, 2015.

[221] Dutta, J. and Gokhale, S. Field investigation of carbon dioxide (CO_2) fluxes and organic carbon from a conserved paddy field of North–East India. *International Soil and Water Conservation Research,* 5:325–334, 2017.

[222] Cai, H., Di, X., Chang, S.X., Wang, C., Shi, B., Geng, P., and Jin, G. Carbon storage, net primary production, and net ecosystem production in four major temperate forest types in northeastern China. *Canadian Journal of Forest Research,* 46:1–9, 2016.

[223] Six, J., Conant, R.T., Paul, E.A., and Paustian, K. Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. *Plant and Soil,* 241:155–176, 2002.

[224] Gruneberg, E., Ziche, D., and Wellbrock, N. Organic carbon stocks and sequestration rates of forest soils in Germany. *Global Change Biology,* 20:2644-2662, 2014.

[225] Poeplau, C., Vos, C., and Don, A. Soil organic carbon stocks are systematically overestimated by misuse of the parameters bulk density and rock fragment content. *Soil,* 3:61–66, 2017.

[226] Qiu, J., Khalloufi, S., Martynenko, A., Van Dalen, G., Schutyser, M., and Almeida-Rivera, C. Porosity, Bulk Density, and Volume Reduction during Drying: Review of Measurement Methods and Coefficient Determinations. *Drying Technology,* 33:1681-1699, 2015.

[227] Gupta, V.K. and Jangid, R.A. The Effect of Bulk Density on Emission Behavior of Soil at Microwave Frequencies. *International Journal of Microwave Science and Technology,* 2011:1-6, 2011.

[228] Wang, W.J., He, H.S., Zu, Y.G., Guan, Y., Liu, Z.G., Zhang, Z.H., Xu, H.N., and Yu, X.Y. Addition of HPMA affects seed germination, plant growth and properties of heavy saline-alkali soil in north eastern China: comparison with other agents and determination of the mechanism. *Plant Soil,* 339(1-2):177-191, 2011.

[229] Huntington, T.G., Johnson, C.E., Johnson, A.H., Siccama, T.G., and Ryan, D.F. Carbon, Organic matter and bulk density relationships in a forested spodosol. *Soil Science,* 148(5):380-386, 1989.

[230] Pereira, J.S., Mateus, J.A., Aires, L.M., Pita, G., Pio, C., David, J.S., Andrade, V., Banza, J., David, T.S., Paco, T.A., and Rodrigues, A. Net ecosystem carbon exchange in three contrasting Mediterranean ecosystems-the effect of drought. *Biogeosciences,* 4(5):791-802, 2007.

[231] Merbold, L., Eugster, W., Stieger, J., Zahniser, M., Nelson, D., and Buchmann, N. Greenhouse gas budget (CO_2, CH_4 and N_2O) of intensively managed grassland following restoration. *Global Change Biology,* 20(6):1913-1928, 2014.

[232] Shrestha, R.K., Strahm, B.D., and Sucre, E.B. Greenhouse gas emissions in

response to nitrogen fertilization in managed forest ecosystems. *New Forests,* 46(2):167-193, 2015.

[233] Schlesinger, W. and Bernhardt, E. The global cycles of nitrogen and phosphorous. Biogeochemistry: an analysis of global change. 92101. San Diego, CA: Academic Press, pp. 383–400, 1997.

[234] Tian H, Wang S, Liu J, Pan, S., Chen, H., Zhang, C., and Shi, X. Patterns of soil nitrogen storage in China. *Global Biogeochemical Cycles,* 20:1–9, 2006.

[235] Zhang, R. and Ding, G. Seasonal variation of soil carbon and nitrogen under five typical Pinus massoniana forests. *Chemistry and Ecology,* 33(6):543–559, 2017.

[236] Pan, P., Zhao, F., Ning, J., Zhang, L., Ouyang, X., and Zang. H. Impact of understory vegetation on soil carbon and nitrogen dynamic in aerially seeded Pinus massoniana plantations. *PLoS ONE*, 13(1):e0191952, 2018.

[237] Gurlevik, N., Kelting, D., and Allen H.L. Nitrogen mineralization following vegetation control and fertilization in a 14 year old loblolly pine plantation. *Soil Science Society of America Journal,* 68(1):272-281, 2004.

[238] Wu, J., Liu, Z., Wang, X., Sun, Y., Zhou, L., Lin, Y., and Fu, S. Effects of understory removal and tree girdling on soil microbial community composition and litter decomposition in two Eucalyptus plantations in South China. *Functional Ecology,* 25(4):921-931, 2011.

[239] Stokdyk, J.P. and Herrman, K.S. Effects of Frangula alnus on soil microbial communities and biogeochemical processes in Wisconsin forests. *Plant and Soil.* 409(1-2):65-75, 2016.

[240] Inoue, T., Fukuzawa, K., Watanabe, T., Yoshida, T., and Shibata, H. Spatial pattern of soil nitrogen availability and its relationship to stand structure in a coniferous-broadleaved mixed forest with a dense dwarf bamboo understory in northern Japan. *Ecological Research,* 32(2):227-241, 2017.

[241] Minick, K.J., Strahm, B.D., Fox, T.R., Sucre, E.B., Leggett, Z.H., and Zerpa, J.L. Switchgrass intercropping reduces soil inorganic nitrogen in a young loblolly pine plantation located in coastal North Carolina. *Forest Ecology and Management,* 319:161-168, 2014.

[242] Wu, J., Liu, Z., Huang, G., Chen, D., Zhang, W., Shao, Y., Wan, S., and Fu, S. Response of soil respiration and ecosystem carbon budget to vegetation removal

in Eucalyptus plantations with contrasting ages. *Scientific Reports,* 4(203):6262, 2014.

[243] Tang, X., Wang, Z., Xie, J., Liu, D., Desai, A.R., Jia, M., Dong, Z., Liu, X., and Liu, B. Monitoring the seasonal and interannual variation of the carbon sequestration in a temperate deciduous forest with MODIS time series data. *Forest Ecology and Management,* 306:150-160, 2013.

[244] Xie, J., Jia, X., He, G., Zhou, C., Yu, H., Wu, Y., Bourque, C.P.A., Liu, H., and Zha, T. Environmental control over seasonal variation in carbon fluxes of an urban temperate forest ecosystem. *Landscape and Urban Planning,* 142:63–70, 2015.

[245] Bao, X., Zhu, X., Chang, X., Wang, S., Xu, B., Luo, C., Zhang, Z., Wang, Q., Rui, Y., and Cui, X. Effects of Soil Temperature and Moisture on Soil Respiration on the Tibetan Plateau. *PLOS ONE,* 11(10):e0165212, 2016.

[246] Huang, Y.H., Hung, C.Y., Lin, I.R., Kume, T., Menyailo, O.V., and Cheng, C.H. Soil respiration patterns and rates at three Taiwanese forest plantations: dependence on elevation, temperature, precipitation, and litter fall. *Botanical Studies,* 58:49, 2017.

[247] Hursh, A., Ballantyne, A., Cooper, L., Maneta, M., Kimball, J., and Watts, J. The sensitivity of soil respiration to soil temperature, moisture, and carbon supply at the global scale. *Global Change Biology,* 23(555):2090–2103, 2017.

[248] Carey, J., Tang, J., Templer, P., Kroeger, K., Crowther, T., Burton, A., Dukes, J., Emmett, B., Frey, S., Heskel, M., Jiang, L., Machmuller, M., Mohan, J., Panetta, A., Reich, P., Reinsch, S., Wang, X., Allison, S., Bamminger, C., Bridgham, S., Collins, S., de Dato, G., Eddy, W., Enquist, B., Estiarte, M., Harte, J., Henderson, A., Johnson, B., Larsen, K., Luo, Y., Marhan, S., Melillo, J., Peñuelas, J., Pfeifer-Meister, L., Poll, C., Rastetter, E., Reinmann, A., Reynolds, L., Schmidt, I., Shaver, G., Strong, A., Suseela, V., and Tietema, A. Temperature response of soil respiration largely unaltered with experimental warming. *Proceedings of the National Academy of Sciences,* 113(48):13797-13802, 2016.

[249] Suseela, V., Conant, R.T., Wallenstein, M.D., and Dukes, J.S. Effects of soil moisture on the temperature sensitivity of heterotrophic respiration vary seasonally in an old-field climate change experiment. *Global Change Biology,* 18(1):336–348, 2012.

[250] Reynolds, L.L., Johnson, B.R., Pfeifer-Meister, L., and Bridgham, S.D. Soil respiration response to climate change in Pacific Northwest prairies is mediated by a regional Mediterranean climate gradient. *Global Change Biology,* 21(1):487-500, 2015.

[251] Bradford M.A., Davies, C.A., Frey, S.D., Maddox, T.R., Melillo, J.M., Mohan, J.E., Reynolds, J.F., Treseder, K.K., and Wallenstein, M.D. Thermal adaptation of soil microbial respiration to elevated temperature. *Ecology Letters,* 11(12):1316–1327, 2008.

[252] Crowther, T.W. and Bradford, M.A. Thermal acclimation in widespread heterotrophic soil microbes. *Ecology Letters,* 16(4):469–477, 2013.

[253] Hartley, I.P., Heinmeyer, A., and Ineson, P. Effects of three years of soil warming and shading on the rate of soil respiration: Substrate availability and not thermal acclimation mediates observed response. *Global Change Biology,* 13(8):1761–1770, 2007.

[254] Tjoelker, M.G., Oleksyn, J., and Reich, P.B. Modelling respiration of vegetation: Evidence for a general temperature-dependent Q10. *Global Change Biology,* 7(2):223–230, 2001.

[255] Exbrayat, J.F., Pitman, A.J., Zhang, Q., Abramowitz, G., and Wang, Y.P. Examining soil carbon uncertainty in a global model: Response of microbial decomposition to temperature, moisture and nutrient limitation. *Biogeosciences,* 10(11):7095–7108, 2013.

[256] Crowther, T.W., Thomas, S.M., Maynard, D.S., Baldrian, P., Covey, K., Frey, S.D., van Diepen, L.T.A., and Bradford, M.A. Biotic interactions mediate soil microbial feedbacks to climate change. *Proceeding of National Academy of Science, USA,* 112(22):7033–7038, 2015.

[257] Raj, R., Hamm, N.A.S., Van der Tol, C., and Stein, A. Uncertainty analysis of gross primary production partitioned from net ecosystem exchange measurements. *Biogeosciences,* 13:1409-1422, 2016.

[258] Lasslop, G., Reichstein, M., Papale, D., Richardson, A.D., Arneth, A., Barr, A., Stoy, P., and Wohlfahrt, G. Separation of net ecosystem exchange into assimilation and respiration using a light response curve approach: critical issues and global evaluation. *Global Change Biology,* 16 (1):187–208, 2010.

[259] Luyssaert, S., Ciais, P., Piao, S., Schulze, E., Jung, M., Zaehle, S., Schelhaas, M.,

Reichstein, M., Churkina, G., Papale, D., Abril, G., Beer, C., Grace, J., Loustau, D., Matteucci, G., Magnani, F., Nabuurs, G., Verbeeck, H., Sulkava, M., van der Werf, G., and Janssens, I. The European carbon balance. Part 3: forests. *Global Change Biology,* 16(5):1429-1450, 2010.

[260] Wohlfahrt, G. and Galvagno, M. Revisiting the choice of the driving temperature for eddy covariance CO_2 flux partitioning. *Agricultural and Forest Meteorology,* 237–238:135–142, 2017.

[261] Reichstein, M., Falge, E., Baldocchi, D., Papale, D., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Gilmanov, T., Granier, A., Grünwald, T., Havránková, K., Ilvesniemi, H., Janous, D., Knohl, A., Laurila, T., Lohila, A., Loustau, D., Matteucci, G., Meyers, T., Miglietta, F., Ourcival, J.M., Pumpanen, J., Rambal, S., Rotenberg, E., Sanz, M., Tenhunen, J., Seufert, G., Vaccari, F., Vesala, T., Yakir, D., and Valentini, R. On the separation of net ecosystem exchange into assimilation and ecosystem respiration: review and improved algorithm. *Global Change Biology*, 11(9):1424–1439, 2005.

[262] Kanniah, K.D., Beringer, J., Hutley, L.B., Tapper, N.J., and Zhu, X. Evaluation of Collections 4 and 5 of the MODIS Gross Primary Productivity product and algorithm improvement at a tropical savanna site in northern Australia, *Remote Sensing of Environment*, 113:1808-1822, 2009.

[263] Ma, J., Yan, X., Dong, W., and Chou, J. Gross primary production of global forest ecosystems has been overestimated. *Scientific Reports*, 5:10820, 2015.

[264] Gray, A.N. and Whittier, T.R. Carbon stocks and changes on Pacific Northwest national forests and the role of disturbance, management, and growth. *Forest Ecology and Management*, 328:167–178, 2014.

[265] Yu, G., Chen, Z., Piao, S., Peng, C., Ciais, P., Wang, Q., Li, X., and Zhu, X. High carbon dioxide uptake by subtropical forest ecosystems in the East Asia monsoon region. *Proceedings of the National Academy of Sciences, USA,* 111:4910–4915, 2014.

[266] Raupach, M.R., Canadell, J.G., and Le Quere, C. Anthropogenic and biophysical contributions to increasing atmospheric CO_2 growth rate and airborne fraction. *Biogeosciences*, 5:1601-1613, 2008.

[267] Zhao, M. and Running, S.W. Drought-induced reduction in global terrestrial net primary production from 2000 through 2009. *Science,* 329:940-943, 2010.

[268] Pita, G., Gielen, B., Zona, D., Rodrigues, A., Rambal, S., Janssens, I.A., and Ceulemans, R. Carbon and water vapor fluxes over four forests in two contrasting climatic zones. *Agricultural and Forest Meteorology,* 180:211-224, 2013.

[269] Rodig, E., Huth, A., Bohn, F., Rebmann, C., and Cuntz, M. Estimating the carbon fluxes of forests with an individual-based forest model. *Forest Ecosystems,* 4(1):4, 2017.

[270] Ciais, P., Reichstein, M., Viovy, N., Granier, A., Ogee, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A.D., Friedlingstein, P., Grunwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J.M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Soussana, J.F., Sanz, M.J., Schulze, E.D., Vesala, T., and Valentini, R. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature*, 437:529–533, 2005.

[271] Hirata, R., Saigusa, N., Yamamoto, S., Ohtani, Y., Ide, R., Asanuma, J., Gamo, M., Hirano, T., Kondo, H., Kosugi, Y., Li, S.G., Nakai, Y., Takagi, K., Tani, M., and Wang, H. Spatial distribution of carbon balance in forest ecosystems across East Asia. *Agricultural and Forest Meteorology,* 148:761:775, 2008.

[272] Solberg, S., Dobbertin, M., Lange, H., Andreassen, K., Fernandez, P.G., Hildingsson, A., and De Vries, W. Analyses of the impact of changes in atmospheric deposition and climate on forest growth in European monitoring plots: a stand growth approach. *Forest Ecology and Management,* 258:1735-1750, 2009.

[273] Janssens, I.A., Lankreijer, H., Matteucci, G., Kowalski, A.S., Buchmann, N., Epron, D., Pilegaard, K., Kutsch, W., Longdoz, B., Grunwald, T., Dore, S., Montagnani, L., Rebmann, C., Moors, E.J., Grelle, A., Rannik, U., Morgenstern, K., Oltchev, S., Clement, R., Gudmundsson, J., Minerbi, S., Berbigier, P., Ibrom, A., Moncrieff, J., Aubinet, M., Bernhofer, C., Jensen, N.O., Vesala, T., Granier, A., Schulze, E.D., Lindroth, A., Dolman, A.J., Jarvis, P.G., Ceulemans, R., and Valentini, R. Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. *Global Change Biology,* 7:269-278, 2001.

[274] Luyssaert, S., Reichstein, M., Schulze, E., Janssens, I., Law, B., Papale, D., Dragoni, D., Goulden, M., Granier, A., Kutsch, W., Linder, S., Matteucci, G., Moors, E., Munger, J., Pilegaard, K., Saunders, M., and Falge, E. Toward a consistency cross-check of eddy covariance flux-based and biometric estimates of ecosystem carbon balance. *Global Biogeochemical Cycles,* 23(3):1–13, 2009.

[275] Schimel, D., Pavlick, R., Fisher, J., Asner, G., Saatchi, S., Townsend, P., Miller, C., Frankenberg, C., Hibbard, K., and Cox, P. Observing terrestrial ecosystems and the carbon cycle from space. *Global Change Biology,* 21(5):1762-1776, 2015.

[276] Matteucci, M., Gruening, C., Ballarin, I.G., Seufert, G., and Cescatti, A. Components, drivers and temporal dynamics of ecosystem respiration in a Mediterranean pine forest. *Soil Biology & Biochemistry,* 88:224-235, 2015.

[277] Lambers, H., Robinson, S.A., Ribas Carbo, M. Regulation of respiration in vivo. In: Lambers, H., Ribas- Carbo, M. (Eds.). Plant respiration: from cell to ecosystem. Springer, Dordrecht, pp 43-61, 2005.

[278] Reichstein, M., Tenhunen, J.D., Roupsard, O., Ourcival, J.M., Rambal, S., Miglietta, F., Peressotti, A., Pecchiari, M., Tirone, G., and Valentini, R. Severe drought effects on ecosystem CO_2 and H_2O fluxes at three Mediterranean evergreen sites: revision of current hypotheses? *Global Change Biology,* 8:999-1017, 2002.

[279] Lloyd, J. and Taylor, J.A. On the temperature dependence of soil respiration. *Functional Ecology,* 8:315-323, 1994.

[280] Davidson, E.A., Belk, E., and Boone, R.D. Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. *Global Change Biology,* 4:217-227, 1998.

[281] Raich, J.W. and Tufekciogul, A. Vegetation and soil respiration: correlations and controls. *Biogeochemistry,* 48:71-90, 2000.

[282] Hogberg, P., Nordgren, A., Buchmann, N., Taylor, A., Ekblad, A., Högberg, M., Nyberg, G., Ottosson-Löfvenius, M., and Read, D. Large-scale forest girdling shows that current photosynthesis drives soil respiration. *Nature,* 411(6839):789-792, 2001.

[283] Schulze, E.D., Wirth, C., and Heimann, M. ‘‘Kyoto forests’’ and a broader perspective on management-response. *Science,* 290:1896-1896, 2000.

[284] Zhao, J., Yan, X., Guo, J., and Jia, G. Evaluating spatial-temporal dynamics of net primary productivity of different forest types in northeastern China based on improved FORCCHN. *PLoS One,* 7:e4813, 2012.

[285] Baldocchi, D. Turner review no. 15. Breathing of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems. *Australian Journal of Botany,* 56(1):1-26, 2008.

[286] Froelich, N., Croft, H., Chen, J.M., Gonsamo, A., and Staebler, R.M. Trends of carbon fluxes and climate over a mixed temperate-boreal transition forest in southern Ontario, Canada. *Agricultural and Forest Meteorology,* 211:72–84, 2015.

[287] Yamamoto, S., Saigusa, N., Gamo, M., Fujinuma, Y., Inoue, G., and Hirano, T. Findings through the AsiaFlux network and a view toward the future. *Journal of Geographical Sciences,* 15(2):142-148, 2005.

[288] Thomas, M.V., Malhi, Y., Fenn, K.M., Fisher, J.B., Morecroft, M.D., Lloyd, C.R., Taylor, M.E., and McNeil, D.D. Carbon dioxide fluxes over an ancient broadleaved deciduous woodland in southern England. *Biogeosciences,* 8:1595–1613, 2011.

[289] Ross, I., Misson, L., Rambal, S., Arneth, A., Scott, R.L., Carrara, A., Cescatti, A., and Genesio, L. How do variations in the temporal distribution of rainfall events affect ecosystem fluxes in seasonally water-limited Northern Hemisphere shrub lands and forests? *Biogeosciences,* 9:1007-1024, 2012.

[290] Coursolle, C., Margolis, H.A., Giasson, M.A., Bernier, P.Y., Amiro, B.D., Arain, M.A., Barr, A.G., Black, T.A., Goulden, M.L., McCaughey, J.H., Chen, J.M., Dunnj, A.L., Grant, R.F., and Lafleur, P.M. Influence of stand age on the magnitude and seasonality of carbon fluxes in Canadian forests. *Agricultural and Forest Meteorology,* 165:136-148, 2012.

[291] Allard, V., Ourcival, J.M., Rambal, S., Joffre, R., and Rocheteau, A. Seasonal and annual variation of carbon exchange in an evergreen Mediterranean forest in southern France. *Global Change Biology,* 14(4):714-725, 2008.

[292] Richardson, A.D., Hollinger, D.Y., Dail, D.B., Lee, J.T., Munger, J.W., and O'keefe, J. Influence of spring phenology on seasonal and annual carbon balance in two contrasting new England forests. *Tree Physiology,* 29(3):321-331, 2009.

[293] Barr, A.G., Black, T.A., Hogg, E.H., Griffis, T.J., Morgenstern, K., Kljun, N., Theede, A., and Nesic, Z. Climatic controls on the carbon and water balances of a boreal aspen forest, 1994–2003. *Global Change Biology*, 13(3):561–576, 2007.

[294] Granier, A., Reichstein, M., Bréda, N., Janssens, I., Falge, E., Ciais, P., Grünwald, T., Aubinet, M., Berbigier, P., Bernhofer, C., Buchmann, N., Facini, O., Grassi, G., Heinesch, B., Ilvesniemi, H., Keronen, P., Knohl, A., Köstner, B., Lagergren, F., Lindroth, A., Longdoz, B., Loustau, D., Mateus, J., Montagnani, L., Nys, C., Moors, E., Papale, D., Peiffer, M., Pilegaard, K., Pita, G., Pumpanen, J., Rambal, S., Rebmann, C., Rodrigues, A., Seufert, G., Tenhunen, J., Vesala, T., and Wang, Q. Evidence for soil water control on carbon and water dynamics in European forests during the extremely dry year: 2003. *Agricultural and Forest Meteorology,* 143(1-2):123-145, 2007.

[295] Wu, C., Chen, J., Black, T., Price, D., Kurz, W., Desai, A., Gonsamo, A., Jassal, R., Gough, C., Bohrer, G., Dragoni, D., Herbst, M., Gielen, B., Berninger, F., Vesala, T., Mammarella, I., Pilegaard, K., and Blanken, P. Interannual variability of net ecosystem productivity in forests is explained by carbon flux phenology in autumn. *Global Ecology and Biogeography,* 22(8):994-1006, 2013.

[296] Zha, T., Barr, A., Bernier, P., Lavigne, M., Trofymow, J., Amiro, B., Arain, M., Bhatti, J., Black, T., Margolis, H., McCaughey, J., Xing, Z., Van Rees, K., and Coursolle, C. Gross and aboveground net primary production at Canadian forest carbon flux sites. *Agricultural and Forest Meteorology,* 174-175:54-64, 2013.