Referee # 1

General formal points are:

- Latin plant names should consistently be printed in italic font. REVISED

1. - Definitions of abbreviations appear repeatedly throughout the text, they should only be introduced on their first occurrence. REMOVED all repetitive abbreviations

2. - The verbs "to experience" and "to respond" are used excessively and sometimes not in the appropriate context. It is clearly a matter of taste but I would advise to revise some sentences. Fluency could partly be improved by language simplification. Removed/modified a number of recurring instances, may need to further edit

3. - Tenses are not always used consistently, please revise (see line comments). REVISED

Scientific issues:

4. - "Carbon" is partly used interchangeably with "carbon dioxide". There are more components to the carbon cycle in forests than vertical CO_2 exchange. Therefore, sometimes statements are not entirely correct, please review. REVIEWED

5. - Measurement and model uncertainty are not addressed. The authors should add some information on this topic. The ranges of the annual flux sums given in the abstract likely describe inter-annual variability (not measurement/model uncertainty), I assume using mean and standard deviation of the six annual flux sums per forest. An explanation should be added. Added a section in the methods detailing the model uncertainty and confidence intervals for the measurements presented. However, I still kept the standard deviations with the mean values to highlight interannual variability as mentioned.

6. - The description of the used partitioning models (equations 1 and 2) is very concise, at least units should be added. For equation 1 a citation is provided, the short description is defendable. Equation 2, however, is not clearly referenced and therefore definitely needs more explanation. The optimization process of the temperature, VPD and soil moisture functions behind the scaling terms need to be described better, to only mention the sigmoidal shape is not enough in my opinion. Added the necessary citation (Richardson et al., 2007), completely rearranged the entire section, and added an additional equation to better explain the sigmoidal functions used within the partitioning models.

7. - Some of the conclusions about the effects of drought rely on the analysis of the especially warm and dry year 2012. The fact that there was a disturbance (thin cutting) in one of the forests in this year is not discussed comprehensively enough. The authors should for example include the effect of a diminished leaf area on CO_2 exchange fluxes in their interpretation of this (and the

next?) year's budget and explore if for the interpretation of the data set from 2012 to 2017 post disturbance effects should be considered. Included additional information in the site information and methods which highlighted the past findings at the site in regards to the thinning/disturbance

Line comments:

8. Page 1, Line 3 (Title) "similar-age" should not be hyphenated. REVISED

9. Page 1, Line 19 I would suggest replacing the somewhat complicated sentence ", ... the evergreen forest saw greater annual reduction" with e.g. "..., net CO_2 uptake was reduced more at the evergreen forest than at the deciduous forest." However, during warm and dry years, the evergreen forest had largely reduced annual NEP values compared to the deciduous forest.

10. Page 1, Line 22 "Annual ET was driven by changes in air temperature" Are you sure? Is T change really the driver? It sounds like the slope of a T change determines ET. If so, which timescale do you refer to? Maybe average temperature actually is the driver? Variability in annual ET at both forests was related most to the variability in annual air temperature (Ta), with the largest annual ET observed in the warmest years in the deciduous forest.

11. Page 1, Line 23 "During drought years, …" It is a bit hard to follow the logic. The preceding sentence says that dry periods greatly reduced ET at the deciduous forest. Now it is stated that the sensitivity of ET to temperature changes (?) at the deciduous forest is comparably low. Maybe say: ET is sensitive to dry periods/increased T at both sites. ET reduction at TP39 is comparably larger. Additionally, ET was sensitive to prolonged dry periods that reduced ET at both stands, although the reduction at the conifer forest was relatively larger than that of the deciduous forest.

12. Page 1, Line 25 "If longer periods..." Longer than what? Can you give us an idea about time scales? If prolonged periods (weeks to months) of increased Ta and reduced precipitation are to be expected under future climates during summer months…

13. Page 1, Line 26 "...the carbon sink capacity [...] will continue." is a bit complicated. Maybe "...will continue to act as a sink..." "...while that of..." is not very elegant, consider reformulating. … the deciduous broadleaf forest will likely remain an annual carbon sink, while the carbon sink-source status of the coniferous forest remains uncertain.

14. Page 1, Line 29 Remove comma before "through". "Absorption of CO2 emissions" can be replaced by "CO2 uptake". REVISED

15. Page 1, Line 30 remove "processes". REVISED

16. Page 2, Line 38 I would add "events" after "extreme weather". Remove "stress". Stress is the consequence of extreme weather not an example for an extreme event. REVISED

17. Page 2, Line 39 "Adversely impacting [...] forest–atmosphere interactions" What does that mean? Sounds like there is no interaction anymore due to extreme weather, you clearly do not mean that. Also: replace hyphen with en-dash in expression "forest–atmosphere". REVISED … forests to sequester carbon, and thus regional forest–atmosphere interactions

18. Page 2, Line 40 The authors state that there are positive and negative feedbacks but give only an example for a process leading to a positive feedback. Example for opposite case? Had thought to mention enhanced CO_2 leading to partial stomatal closures and reduced water loss leading to possible cooling, but REMOVED feedback sentence instead

19. Page 2, Line 46 I do not get the reasoning. "The result of a shifting climate..." [which result?] impacts both forest types differently because broad-leaved species are replaced by needle-leaved species? I do not understand the cause-effect concept behind the statement, consider revising. REVISED beginning of the paragraph. However, climate change will impact deciduous and coniferous forest ecosystems differently due to their physiological differences.

20. Page 2, Line 50 I assume you refer to a disturbance of regional cycles and not within forest cycling, can be formulated more clearly. REMOVED sentence

21. Page 2, Line 51 "Conversely," I do not see an opposition to the previous statement, which is about photosynthetic rate. This sentence talks about season length. REVISED sentence but ultimately removed conversely

22. Page 2, Line 58 "...have the ability to conduct research..." is needlessly convoluted. Consider replacing with e. g. "Few studies have reported multi-annual time series." Also: omit "sufficiently long". Otherwise you need to explain which timescale would be sufficient. Even fewer studies have reported multi-annual time series

23. Page 2, Line 59 In my opinion, there is no need to construct ("Such a study would...") the need for the current study. I would omit lines 59 to 63 and go straight to Page 3, Line 73 ("This study..."). REMOVED suggested section

24. Page 2, Line 61 The "benefit" of forests to "terrestrial–atmosphere gas exchange" seems vague. Gas exchange takes place anyway, there only is a benefit if you prescribe a service of forests (e. g. carbon sink function), which is not mentioned here. As stated before, I would omit the whole section. REMOVED suggested section

25. Page 3, Lines 64-69 Should be moved to section 2.1 (Study sites) REMOVED

26. Page 3, Lines 70 to 73 As no results of the previous studies are mentioned here, listing them is not very informative. I would move this section to the results or discussion section and mention the results of previous studies there in comparison/relation to the current study. REMOVED

27. Page 3, Line 80 "will be used". The choice of tense in confusing to me. Starting in line 73, present tense is used, future here. Sentence was REMOVED

28. Page 3, Line 83 What is "natural terrain"? REMOVED the word natural

29. Page 3, Line 83 "The forest is classified". By whom? Is there a citation or a classification system this assumption refers to? REMOVED. The forest is unevenly aged

30. Page 3, Line 91 "Conifer species including make-up..." Sentence incomplete.
REVISED Conifer species only account for a minor component…

31. Page 4 Line 106 Personally, I do not like the frequent use of the verb "experience". For this sentence a simpler way could be: "While edaphic and climatic conditions are similar between both sites, they differ in vegetation cover and canopy structure." REVISED
While edaphic and climatic conditions are similar between both sites, they differ in vegetation cover and canopy structure and physiology.

32. Page 4 Line 107 What do you mean by "historically defined"? That past events (ice age) shaped the landscape or that authors in the past defined the landscape like this? These sandy soils are part of the Southern Norfolk Sand Plains, an area shaped by past ice age glacial melt processes.

33. Page 4 Line 109 It would be easier for international soil scientists to understand if the name according to the FAO World Reference Base would be given additionally to the name according to the national Canadian system. … Canadian Soil Classification Scheme and FAO World Reference Base as Brunisolic grey-brown luvisol and Albic Luvisol/Haplic Luvisol, respectively

34. Page 4, Line 113 "Help" is not ideal. How does the lake control cold temperatures?
REMOVED sentence – moderating effect of water body

35. Page 4, Line 114 "...were 8 ◦C and..." past tense? The mean is still the mean. Next sentence present tense again. REVISED is 8.0 ± 1.6°C and 997 mm

36. Page 4, Line 116 The citation is incomplete. Based on the information provided, the given data cannot be verified. Updated the citation and included a link to the website

37. Page 4, Line 116 Last sentence of paragraph can be omitted, it is poorly formulated. Information also given in "Data availability" section. REMOVED

38. Page 4, Line 121 Omit ", though". Start new sentence with "Measurements". REVISED Measurements at both sites are still ongoing

39. Page 4, Line 124 Supplementary material would be a separate pdf-file, I think. Table A1 seems to be in the appendix. REVISED …are outlined in the appendix (Table A1).

40. Page 4, Line 124 "...are calibrated". Present tense? Paragraph starts in present perfect (..."have been measured"). At both sites, IRGAs are calibrated monthly using high purity N_2 gas for the zero offset. Measurements at both sites are still ongoing/being calibrated.

41. Page 4, Line 125 The expression "Environment Canada Greenhouse gas specified CO2" is not understandable. Which concentration did the span gas have? At both sites, IRGAs were calibrated monthly using high purity N2 gas for the zero offset and CO_2 gas (360 μmol mol^{-1} CO_2; following WMO standards) for the CO_2 check.

42. Page 5, Line 127 It comes as a surprise that there is more than one IRGA per EC setup. In line 123 singular was used ("...an IRGA"). I would stress this type of setup more as it is typical and necessary for forest EC. Half-hourly net ecosystem exchange (NEE, μmol m^{-2} s^{-1}) is calculated as the sum of the vertical CO_2 flux (F_c), and the rate of CO_2 storage (S_{CO2}) change in the air column below the IRGA ($NEE = F_c + S_{CO2}$).

43. Page 5, first two paragraphs A mixture of tenses is used. "is completed", "were assumed", "have been conducted", "are measured", "will focus". Check for consistency. REVISED

44. Page 5, Line 139 Unclear what "Environment Canada Delhi CDA" is. Why mention if precipitation data is not used after all (as stated in line 141)? REMOVED … P data from an accumulation rain gauge (T-200B, GEONOR) installed 1 km south of TP39

45. Page 5, Line 145 What is the difference between quality control, filtering and cleaning? If you do not want to go into detail just mention the citation and say e. g. "processed as described by Brodeur (2014)". REVISED entire section. All meteorological and flux data were processed on lab-developed software following the FluxNet Canada Research Network (FCRN) guidelines as described by Brodeur (2014).

46. Page 5, Line 147 How was the frequent cross-checking with AmeriFlux done? Statement seems vague. Sentence REMOVED – not very frequently

47. Page 5, Line 148 How were outliers identified? A two-step cleaning process was used to remove outliers in half-hourly meteorological data: coarse upper and lower thresholds were applied to half-hourly values to remove obvious outliers, and additional erroneous half-hourly data were removed from time series when instruments were known to be malfunctioning or visual

inspection by multiple reviewers resulted in certain agreement that an outlier was present. Added citation of Papale et al. (2006).

48. Page 5, Line 150 There are other EC towers at Turkey Point Observatory? Where are they? Can you expect them to be representative for your site? Only then using them to gap-fill your data would make sense. More information needed. Missing meteorological data of all lengths were gapfilled using extant data for the same half hours from either (in order of preference) a second sensor at the site, or an equivalent sensor from a nearby (1-3 km away) station in the network (sites described in Peichl et al., 2010).

49. Page 5, Line 150 What is "mean flux recovery"? Percentage of half-hourly measurements left after filtering? Including or excluding times of instrument maintenance/malfunction? Yes, the mean flux recovery was the data remaining after all the filtering processes, including data lost from the start (i.e. maintenance and malfunctions). The resulting final mean flux data recovery following both threshold filtering methods

50. Page 5, Line 159 Omit "where daytime and nighttime"; it means all fluxes, correct? No need to specify then. REMOVED

51. Page 6, Line 160 It is stated that filtered NEE was gap-filled using soil temperature. Why is "flux recovery" after gap-filling only 49 %. Check if this gap-filling step was actually applied. It seems unlikely. Later more complicated methods for flux partitioning and gap-filling are described. The simple NEE-Ts model seems redundant. REMOVED the sentence. Flux recovery would be before any gap-filling just filtering.

52. Page 6, Line 164 Symbol for soil moisture appears here first. Explanation too late in line 163. Introduced the soil water content in Line 119 when discussing met measurements.

53. Page 6, Line 164 Partitioning of NEE into GEP and RE has not been introduced. The reader does not know the RE time series at this point. If you talk about gaps in it you have to introduce it first. NEE gap-filling and its partitioning into components of ecosystem respiration (RE) and gross ecosystem productivity (GEP) were achieved using the methods described in Peichl et al. (2010a), which are summarized below.

54. Page 6, Line 166 What is the definition of nighttime? A radiation threshold? Yes, radiation threshold… nighttime (PAR < 100 μmol m^{-2} s^{-1}) fluxes

55. Page 6, Line 166 It is stated that nighttime NEE was modeled as a function of soil temperature and moisture in order to (!) describe the relationship of RE and Ts which represents diurnal air temperature variability. Check meaning of the sentence. It seems incoherent to use nighttime measurements to describe diurnal variability of something. Sentence was removed and preceding paragraph modified (edit shown above)

56. Page 6, Line 173 What are the units of the model parameters, especially of a1 and a2? a1 and a2 are not a function of soil moisture (as stated) when looking at equation 1. I assume all four parameters were fit during the same optimization process. Added an additional equation to better explain everything (Equation 2). where a_1 and a_2 are fitted parameters that describe a sigmoidal curve that ranges from 0 to 1 (Richardson et al., 2007). In this approach, the Ts_{5cm} component of the function defines a theoretical maximum half-hourly respiration rate based on soil temperature (i.e. driving variable), while the $\theta_{0\text{-}30cm}$ component modulates the resultant predicted value as a function of the volumetric water content (i.e. scaling variable).

57. Page 6, Line 173 "...acting to scale the RE relationship" to what? REMOVED (above)

58. Page 6, Line 180 Explanation of equation 2 needs more detail. How are these sigmoidal functions set up? Do they have parameters? Parameters optimized at the same time? The remaining terms use the functional form introduced in Equation 2 to described the responses of GEP to Ts, vapor pressure deficit (VPD), and $\theta_{0\text{-}30cm}$, respectively.

59. Page 6, Line 187 Seems inconclusive. Don't you need the modeled GEP time series in order to calculate phenologically-derived summer months? For the GEP model you in turn need the derived summer months. Please explain. No change made. Phenologically-derived summer months and all phenologically-modelled periods were found using 'non-gapfilled GEP' (only periods where non-gapfilled NEE matched gap-filled NEE).

60. Page 6, Line 189 Sentence starting with "Furthermore..." ending in line 191 with "both sites" can be omitted, unnecessary/circular information. Yes, in the growing season plants grow, therefore it is a key season of CO2 uptake. REMOVED

61. Page 7, Line 201 Omit first sentence of paragraph, contains no new information. REMOVED sentence

62. Page 7, Line 208 "water or heat stressed periods", check meaning, the periods are not under stress. … during low water or high heat periods

63. Page 7, Line 210 Contents of last paragraph can be moved to results, stays a bit vague here anyway. Section mostly REMOVED. Added an ANOVA/t-test sentence in results

64. Page 8, Line 237 GEP might not be gap-filled, still it is not direct measurement data but modeled as the difference of RE (modeled) and NEE (=EC Fc, measured). Could be stressed here, it took me a while to get my head around this fact. From half-hourly non-gapfilled data (calculated as the difference between modeled RE and measured non-gapfilled NEE), the maximum daily photosynthetic uptake (GEPMax) was calculated.

65. Page 8, Line 240 The approach does not calculate, the computer calculates according to the approach. This approach identified photosynthetic transition dates

66. Page 8, Line 241 "logistic curve" instead of "logistics curve" REVISED

67. Page 8, Line 241 "The second derivative estimated the end of greenup..." How? Time when derivative turns zero or similar? The local minima of the second derivatives estimated the end of greenup (EOG), the length of canopy closure (LOCC), and the start of browndown (SOB), while the local maxima of the third derivatives estimated the start of the growing season (SOS), and the end of the growing season (EOS).

68. Page 8, Line 242 "while the third derivatives calculated..." see two comments above. REVISED

69. Page 8, Line 251 accumulation REVISED

70. Page 8, Line 257 Ta responds to what? behaved similarly

71. Page 8, Line 258 "Record warm Ta conditions". Expression unclear to me. Annual mean above 30-year average? Most days/half hours above 30-year average of corresponding DOY/half hour? Added (exceeding 30-year mean daily maximum values)

72. Page 8, Line 260 What does extreme mean? What does "magnitude of extreme cold days" mean exactly? Added (exceeding 30-year mean daily minimum values)

73. Page 9, Line 261 "record Ta outside the normal peak summer period" Unclear, what does record and normal mean? Temperature is outside the period? Check meaning of sentence. with record Ta outside of the typical summer (June – August) period

74. Page 9, Line 262 The sites are not growing, the vegetation is. REVISED

75. Page 9, Line 263 "Meteorological conditions between the sites were [...] examined". Check meaning. Consider replacing with "Differences in meteorological conditions between the sites were examined" or "Meteorological conditions at both sites were examined" REVISED

76. Page 9, Line 263 "..., beginning with..." Sequence of analysis steps not relevant. REMOVED

77. Page 9, Line 264 Sentence "However, the shapes..." is circular and can be omitted. It says: The seasonal course of APAR depicts the course of absorbed PAR, meaning APAR is APAR. REMOVED

78. Page 9, Line 267 "APAR was similar throughout the year". Not true, see figure 2. Relative quantity FPAR might be about constant during annual course, APAR is not. Updated the methods/figure to describe why the sites show similar APAR measurements

79. Page 9, Line 270 Cloudy conditions along with a reduction in incoming radiation are not a coincidence. Daily reductions in PARdn and APAR often resulted from cloudy conditions and precipitation (P) events (Fig. 2a).

80. Page 9, Line 278 Could replace "followed closely to Ta" with "follow Ta closely" REVISED

81. Page 9, Line 281 replace "of TPD" with "at TPD". REVISED

82. Page 9, Line 282 replace "similar patterns between sites" with "similar patterns at both sites" REPLACED

83. Page 9, Line 283 Soil moisture deficit compared to what? At which value does it start to be deficient? …with prolonged summer θ declines in 2012, 2016, and 2017 (Fig. 2f). Changed to declines instead of deficits so there's no specific threshold

84. Page 9, Line 283 "In summer" comma missing REVISED

85. Page 9, Line 285 "while all other times of the year TP39 was higher". Soil moisture was higher not TP39. Yes. during all other times of the year θ at TP39 was higher (Fig. 2g).

86. Page 9, Line 292 Consider replacing unit "day" with unambiguous "day of year (DOY)" throughout manuscript, first occurrence here. Replaced all cases of 'day' with DOY

87. Page 10, Line 295 Check meaning. "The response [...] to changes in GDD was considered as a trigger for SOS." The response is the trigger? I think GDD change is the trigger and the response of the forest to this trigger manifested in SOS. The response of the forest to increasing GDD was shown to be a trigger for the SOS.

88. Page 10, Line 296 "cumulative GDD" GDD is cumulative by definition, is it not? Total

89. Page 10, Line 297 Cumulative heat is not expressed directly in GDD, GDD is a proxy for absorbed heat as correctly stated above. I would omit the half-sentence "However, [...], which we calculated as" REMOVED

90. Page 10, Line 299 "represented" not anymore? check tense. Represents - REVISED

91. Page 10, Line 303 replace "start" with "are reached" REVISED

92. Page 10, Line 314 Omit first sentence of paragraph, it is a bit vague. "influenced by a certain degree of cooling"? REMOVED

93. Page 10, Line 316 replace "were found to be highly correlated" with "were highly correlated" REVISED

94. Page 10, Line 325 "At first glance..." Sentence seems vague. What do you mean by similar? Which properties of the forests responded similar to which forcings? What does "seasonal irregularities" mean? Difference between same season of different years or within one year between seasons? How do these irregularities govern annual fluxes (cumulative fluxes?). Highest contribution to sum during periods when forcings deviate from average behavior? Consider restructuring or omitting sentence. REMOVED The water (evapotranspiration) and carbon (photosynthesis and respiration) fluxes were analysed in both forests from 2012 to 2017, with the seasonal patterns of these fluxes illustrated in Fig. 3 and cumulative fluxes in Table 3.

95. Page 11, Line 327 replace "within" with "at" REVISED

96. Page 11, Line 337 "...did not greatly benefit the forest..." seems unassertive. What do you mean? No increase in CO2 uptake? If the latter is meant, I would question the statement. Sure, when you look at average daily GEP, a longer spring increases n for the conifer forest and adds mostly low values (from earlier in the year) lowering the average. Looking at spring GEP/NEP sums might lead to a different interpretation. In all 6-years, spring was the only season when daily GEP was similar between the forests, as the advancement of SOS at TP39 did not statistically benefit carbon uptake due to seasonal meteorological conditions (i.e. low PAR, Ta, etc.) acting to limit photosynthesis.

97. Page 11, Line 339 Details about statistical tests could be inserted here. I am not sure what the p-value refers to, a t-test? Added a sentence describing tests. Using the analysis of variance (ANOVA) technique, t-tests were completed to evaluate statistical differences between the two groups (i.e. deciduous broadleaf vs. evergreen needleleaf) of data.

98. Page 11, Line 341 I would replace "minimums/maximums" with "minima/maxima", might be a matter of taste. Sentence removed at advice of reviewer/comment below

99. Page 11, Line 341 How is a maximum significant? Consider removing. REMOVED

100. Page 11, Line 342 RE was modeled not measured. greatest annual RE was found…

101. Page 11, Line 344 replace "let the year to have" with "led to" REVISED

102. Page 11, Line 346 see previous comment REVISED

103. Page 11, Line 349 response to what? Updated to behaved similarly

104. Page 11, Line 351 check meaning. Ta always high between rain events? In both cases, maximum rates of RE and ET occurred following precipitation events, as the soil was sufficiently wet, helping to promote ET and enhance RE through respiration pulses (Misson et al., 2006).

105. Page 12, Line 363 Should it be "sink" instead of "source"? REVISED

106. Page 12, Line 369 Check meaning. "NEP [...] exceeded TP39" Following SOS, daily NEP at TPD exceeded that at TP39 in all years except 2015 ($p < 0.01$).

107. Page 12, Line 385 "to" missing, should be "let to rates" REVISED

108. Page 12, Line 387 Consider replacing "deviations" with "variability expressed as standard deviation" and omitting the plus-minus sign in brackets. REVISED

109. Page 12, Line 391 "WUE varied [...] due to different [...] overall GEP and ET". Check statement, seems circular to me. Does it say: "The ratio of GEP and ET varies because GEP and ET vary"? REMOVED sentence

110. Page 13, Line 394 "..., the SOS began..." Reformulate, now it says "the start began" In 2016, an early SOS (March 15; DOY 74) promoted prompt increases in spring GEP, when Ta and ET remained low.

111. Page 13, Line 396 remove "forest" REMOVED

112. Page 13, Line 400 Same number for TPD and TP39. REVISED

113. Page 13, Line 405 monthly GEP and APAR sums or averages? Mean monthly

114. Page 13, Line 409 Sentence incomplete. "To better understand and the water...." Meteorological variables (i.e. Ta, PAR, θ, etc.) were analysed during the study period to better understand their impact on water and carbon fluxes within each forest.

115. Page 13, Line 410 remove "first". Sequence of analysis steps irrelevant. REMOVED

116. Page 13, Line 412 "the impact of winter soil water storage..." on what? A smaller secondary effect on ET ($R^2 = 0.83$; Table 4) was found for winter and early spring (January 1st to SOS) $\theta_{0\text{-}30cm}$, which helped to explain the impact of winter soil water storage and seasonal water availability on ET at the start of each year.

117. Page 13, Line 419 Consider reformulating "responses between". I would expect "the response of something to something else" REVISED to The response of monthly ET to monthly VPD was similar between sites

118. Page 13, Line 425 Maybe there is no linear relationship between GEP and meteorological variables. There should, however, definitely be relations with PAR. As far as I understand GEP was modeled using PAR, you should see the saturation curve you prescribed in the model (eqn. 2) in a PAR-GEP plot. You are correct. I believe here it's only considering the annual values, so no annual relationship between PAR and GEP.

119. Page 13, Line 426 There is an extra space after the closing bracket and "resulted" REVISED

120. Page 14, Line 429 Why "most importantly"? Mean or cumulative summer NEP? REMOVED most importantly …cumulative summer NEP ($R^2 = 0.99$).

121. Page 14, Line 431 "was seen" is not very elegant. Consider simplifying the sentence, e.g. "...spring was shorter due to..." For the evergreen conifer site, spring was shorter in years with the highest annual NEP due to rapid photosynthetic development.

122. Page 14, Line 431 "Higher summer Ta". Season average or half-hourly or daily? Higher mean summer Ta decreased annual NEP, highlighting the influence of limitations due to heat stress

123. Page 14, Line 434 "relationship between RE and spring Ta". timescales? annual RE, spring RE, sums or averages? At the deciduous forest, the relationship between annual RE and spring Ta ($R^2 = 0.77$) suggested that warmer springs generally acted to decrease annual RE.

124. Page 14, Line 437 "Lastly,...", "Ultimately,..." can be omitted. Sequence of analysis irrelevant. REMOVED

125. Page 14, Line 438 They sites do not emphasize, you do. REVISED – Highlighted

126. Page 14, paragraph starting in line 439 This paragraph requires more explanation. How were the model parameters examined? The methods section is not detailed enough about this type of analysis, Table 5 is also ambiguous ("GPP:Ta" sounds like correlation analysis. Should it be f(Ta) as in eqn. 1 to denote that the scaling factor is meant?). The scaling method is very interesting, it deserves a proper explanation for others to be able to reproduce it. Added a section in the methods: 2.4 Estimating effects of meteorological variables on carbon component fluxes. This helps to better explain the modeling and parameterization of the data outlined in the paragraph and Table 5.

127. Page 14, Line 445 "Outside of Ts". Sounds strange to me. Do you mean "apart from"? Yes. \Aside from Ts_{5cm}, $\theta_{0\text{-}30cm}$ impacted summer RE at both sites.

128. Page 14, Line 447 Similar response of what to what? REVISED – similar trends

129. Page 14, Line 448 What do you mean with "predicted daily rate"? The observed fluxes were the result of a prediction? I do not understand, consider clarifying. Overall, the annual fluxes were a product of the season length and the estimated daily rates of the CO_2 fluxes that were in turn influenced by seasonal variability in meteorological variables.

130. Page 14, Line 451 replace "experienced by" with "at" REVISED

131. Page 14, Line 451 Typical meteorological conditions? Introduction says air temperature was consistently above the 30-year average. The meteorological conditions at both sites during the study period were characteristic of temperate North American forest ecosystems, characterized by four distinct seasons, with cold winters and warm summers.

132. Page 14, Line 455 "certain differences were primarily influenced" is a bit vague, which difference, why primarily. What about relief position, water content or soil type? Even with similar climatic forcings (i.e. Ta) seasonal deviations in Ts_{5cm} were found, likely influenced by the opposing forest canopy characteristics

133. Page 14, Line 456 "In this case" Soil temperature is always linked to incoming radiation. REMOVED ‘in this case’

134. Page 14, Line 457 Mean Ts or each half-hourly value? In all years, mean daily Ts_{5cm} at the conifer forest was higher during each summer

135. Page 15, Line 459 What does "highly clumped" mean? High compared to what? In the conifer forest, branches and needles were closely clumped... highlighting that conifer canopies show less ability to fill canopy gaps, instead driven by shape.

136. Page 15, Line 459 Minor variations in APAR? Maybe true for fPAR, looking at Figure 2 APAR seems highly variable throughout an annual course. REVISED to fPAR

137. Page 15, Line 461 "Incoming radiation was directly absorbed by the soil" All of it? What about LE etc.? Not all energy goes into ground heat flux. In the deciduous forest, Ts_{5cm} was higher when leaves were absent and a higher fraction of incoming radiation was directly absorbed by the soil.

138. Page 15, Line 464 Incomplete sentence. "...similar trends VPD..." similar VPD trends

139. Page 15, Line 469 "species specific responses shaped the timing of phenological events" Responses to what? Isn’t it obvious that species type determines phenology? REMOVED

140. Page 15, Line 480 There is only one SOS per year. How can SOS have high variability in a warm year when there is only one value per year? …variability (between years)

141. Page 15, Line 486 Seems contradictory. Either timing of senescence and soil moisture are not related ("insignificant") or the forests experienced "later senescence dates with decreased soil moisture". If the finding opposes previous studies it would be interesting to read about possible reasons (water stress?). Both forests experienced later senescence dates with decreased θ (although likely due to increased Ta). For the conifer forest, the two years (i.e. 2012 & 2016) with continued heat and drought stress saw the latest dates of senescence, while at the deciduous forest, greater mean summer θ led to earlier senescence in all years but decreased θ extended senescence.

142. Page 16, Line 496 replace "in the deciduous site occurred a month (31 days) before that of the evergreen..." with "at the deciduous site occurred one month (31 days) earlier compared to the evergreen..." REVISED

143. Page 16, Line 497 omit "experienced" REVISED

144. Page 16, Line 500 "only limited by their specific leaf strategy". **This seems to be a major argument (Title!)**. Can you expand more, why "only" limited by this strategy? … season length from prolonged autumns, limited by their specific leaf-strategy. But ultimately decided to change the title to not include 'leaf strategy'

145. Page 16, Line 503 "Ta anomalies [...] strongly determine the carbon sequestered". Check meaning. Ta determines the carbon? Maybe the amount of carbon? Are you sure the anomalies determine C uptake as opposed to the average temperature? REVISED Anomalous Ta (extreme heat or cold) and seasonal fluctuations in water availability (θ) over a predictable course of the year were shown to strongly impact the carbon sequestered in many forests.

146. Page 16, Line 505 ",... higher Ta..." Anomalies, average, min/max? higher mean Ta

147. Page 16, Line 506 "drawback" only if maximum sink strength is the goal. why judge? Conceptually, higher mean Ta will promote longer growing seasons and greater GEP, though increased RE may also be expected

148. Page 16, Line 507 typo: "differing forest[s] responses" REVISED

149. Page 16, Line 508 "season length in 2012 was the second shortest despite..." Maybe there is another factor co-controlling season length then? It's definitely possible. The determination of the phenological dates and the growing season length were modeled from GEP data, which was reduced in 2012 at both sites as a result of drought.

150. Page 16, Line 509 Maybe not "despite" but "because" high air temperatures. There could be a temperature optimum (parabolic function) for GEP. What does "record Ta" mean? Daily/Half-hourly maximum, mean, average above long-term average? At both sites, the overall growing season length in 2012 was the second shortest (behind 2014), as a result of the anomalously warm Ta experienced throughout much of the year.

151. Page 16, Line 510 Why "also"? Section already talks about outlier year 2012. REMOVED

152. Page 16, Line 512 "due to thinning performed..." Definitely! This fact is introduced too late. Such a disturbance could single-handedly be responsible for budget deviations in 2012 and override all possible reasons stated before. The disturbance must be stressed and discussed more and earlier. Introduced the thinning and management in the methods

153. Page 16, Line 513 "higher Ta and low theta" Annual/seasonal mean or each/most half hours/days? Replace "acted to enhance" with "enhanced" Additionally, higher daily mean Ta and low θ enhanced RE in the conifer forest, but significantly reduced RE in the deciduous forest.

154. Page 16, Line 525 replace "due to comparable decreases" with "due to comparably large decreases" REVISED

155. Page 17, Line 535 "very similar NEP" at both sites vs. Page 17, Line 538 "led the conifer forest [...] to have a greater magnitude of annual NEP". Is NEP similar or different? In all years the magnitude of GEP and RE were greater in the conifer forest, however, analogous reductions at the deciduous forest led the two forests to have very similar mean annual NEP (despite large annual differences).

156. Page 17, Line 543 "...some of the highest rates..." Highest single half-hourly fluxes? REVISED – highest daily rates

157. Page 17, Line 543 "especially the deciduous forest)." remove extra full stop. REMOVED

158. Page 17, Line 543 What is the definition of a "normal" year? Is this really the conclusion of Griffis et al and Gonsamo et al.? Do they use the term "normal"? Are you surprised that the forests adapted to average site conditions? Before, I read the conclusion that the deciduous forest NEP could profit from comparably dry conditions. Yes, they use the term normal, which was edited here to better explain the thought process. This suggests that both forests favor meteorologically “normal” years (comparable to the 30-year mean meteorological conditions), equivalent to the conclusion of Griffis et al. (2003) and Gonsamo et al. (2015). Therefore, under future climates, which are predicted to be warmer compared to the current 30-year norm for the

area, the carbon sequestration capacity of both forests may be reduced, although to a lesser effect at TPD.

159. Page 17, Line 548 Statement in first sentence of paragraph is trivial, omit sentence. REVISED

160. Page 17, Line 549 "With insufficient water availability annual tree growth and productivity may be limited". Seems circular to me: When you say insufficient, I suspect you implicitly have in mind that water availability is not sufficient for optima productivity? To me the sentence says then: When productivity is limited it is limited. REMOVED

161. Page 17, Line 555 "ET responds year-round" What do you mean? There is no particularly rainy season? Much like RE, ET responds year-round (with summer maxima), so warmer spring or autumn periods often lead to annual increases in ET

162. Page 17, Line 555 "...so warmer spring or autumn periods often lead to annual increases in ET" Warm summer did not impact ET? Yes it did, outside of the summer maxima

163. Page 18, Line 559 "An opposing ET response..." To what? "...was measured in the coniferous forest" Any idea why? A contrasting ET response was measured in the coniferous forest. The deciduous forest measured increased ET during the hot/dry year of 2016, but it was too dry at the conifer forest, leading to an opposite response

164. Page 18, Line 564 "...little summer and annual P removed most of the water from the system, significantly reducing ET" There is no negative precipitation, removal is the wrong term here. The process that (vertically) removes water from the soil is ET, why is ET reduced then? Please clarify. In our case, high summer Ta, the lowest $\theta_{0\text{-}30cm}$, and very little summer and annual P (input) into the system, significantly reduced ET, while RE continued to rise.

165. Page 18, Line 565 "timing of summer P" I do not understand, what is meant by timing? Is there only one rain event during summer? Do you mean a peak precipitation event? At the conifer forest, the timing of summer P events appeared to influence ET (i.e. 2013)

166. Page 18, Line 565 "...the availability of rainfall [...] led to the greatest demand for water" Sorry, I do not get it, consider revising. REMOVED

167. Page 18, Line 566 "...differing response" to what? opposing responses of ET to θ

168. Page 18, Line 574 "...to respond similarly" to what? We found the course of annual WUE of both forests to respond similarly across all years

169. Page 18, Line 577 Is there a reason you picked the forest in Ohio for comparison? The Ohio forest was used as WUE was researched in a regionally local oak-dominated forest

170. Page 18, Line 578 "..., this implies..." What does "this" refer to. I cannot follow. Assuming similar daily rates of carbon assimilation (GEP), higher WUE implies a higher evapotranspiration flux at the conifer forest (Augusto et al., 2015), which we saw.

171. Page 19, Line 610 "significant abnormalities were measured between sites" Strange wording, do you mean "differences between sites"? Yes, REVISED

172. Page 19, Line 610 "...meteorology was shown to greatly impact fluxes at both sites, though to varying degrees" Either the impact is great or it is sometimes great and sometimes minor (= varying degrees). REMOVED greatly. Summer meteorology was shown to impact fluxes at both sites

173. Page 19, Line 614 Why "Conversely"? No contradiction to sentence before (which talks about drought years), this sentence about all years. Secondly, NEP is also the result of respiration and photosynthesis at the broad-leaved forest. The annual NEP at the conifer forest was ultimately shaped by total summer NEP.

174. Page 19, Line 618 "Both sites saw average ET, but increased NEP during 'normal' years..." What is the definition of a normal year, 30-year average? What is your baseline for a "normal" NEP? Should be average NEP during average years, shouldn't it? How can NEP deviate (be increased) from the average during an average year then? Clarify.
Both sites saw average ET, but increased NEP (against the 6-year study mean) during climatologically (30-year mean) 'normal' years, but only the conifer forest saw annual reductions in carbon sequestration during drought years.

175. Page 19, Line 621 "...while the response of the conifer forest remains uncertain." Sure, there is uncertainty, which is true for the projections about the deciduous forest's sink strength as well. Why not report some of the ideas about conifer forest in a future climate developed before in the discussion? We also found that drought-induced RE increases or GEP decreases may impact the overall net carbon uptake in the coniferous stand. Our study suggests that the deciduous forest will continue to be a net carbon sink under increased temperatures and larger variability in precipitation under future climate changes, while the response of the coniferous forest will continue to remain uncertain.

Referee # 2

Specific comments:

1. -Title. The leaf-retention and shape strategies are only implied not studied in the manuscript. I suggest changing to a more relevant and accurate title. Title changed to: Response of carbon and water fluxes to meteorological and phenological variability in two Eastern North American forests of similar age but contrasting species composition – a multiyear comparison

1. -Line 16-24. The influences of drought and temperature on NEP and ET are entangled together here, which is a bit unclear. Also, some sentences seem to be repetitive. I suggest rewriting this part of the abstract to make it clearer. REVISED
Summer meteorology greatly impacted the carbon and water fluxes in both stands, however the degree of response varied among the two stands. In general, warm temperatures caused higher ecosystem respiration (RE), resulting in reduced annual NEP values – an impact that was more pronounced at the deciduous broadleaf forest compared to the evergreen needleleaf forest. However, during warm and dry years, the evergreen forest had largely reduced annual NEP values compared to the deciduous forest.

3. - Abstract. Clarify and quantify (if possible) "greatly controlled", "greatly reduced", and "greatly impact". Updated the abstract so most uses of greatly were removed

4. -Line 55-57. Can you add a sentence or two summarizing the previous studies contrasting fluxes coniferous and deciduous forests? Ultimately reduced the focus on the previous studies in the revised introduction. Mentioned a few differences in past sentences.

5. -Methods. I noticed the distances of EC relative to the canopy top are different for the two sites. Would the heights of the EC affect the fluxes due to flux divergence or convergence? Following the assumptions that we are above the canopy roughness layer in each forest, and we're footprint-filtering appropriately, we don't think there is an effect.

6. -Line 157. Is friction velocity a good metric for filtering intermittent turbulence? Previous studies show intermittent turbulence is frequently observed during evening hours at forested sites. No, it's not. It should be paired with stationarity tests, to make it more appropriate. We also calculate the storage change as a means of capturing significant changes in carbon storage in the volume.

7. -Section 2.3. Have the data been filtered for stationarity? Yes. Stationarity test is done.

8. -Section 2.3. The threshold u* seem to be large (0.2 or 0.3 m/s are pretty standard)? Any explanations associated with the sites? I don't think our sites have particularly denser canopies than other sites. May hint at advection processes playing a role?

9. -Section 2.3. Add one or two sentences explaining how you processed/averaged the meteorological data. Meteorological variables were sampled at 5 second intervals and averaged at a half-hourly scale. A two-step cleaning process was used to remove outliers in half-hourly meteorological data: coarse upper and lower thresholds were applied to half-hourly values to remove obvious outliers, and additional erroneous half-hourly data were removed from time series when instruments were known to be malfunctioning or visual inspection by multiple reviewers resulted in certain agreement that an outlier was present. Missing meteorological data of all lengths were gapfilled using extant data for the same half hours from either (in order of preference) a second sensor at the site, or an equivalent sensor from a nearby (1-3 km away) station in the network (sites described in Peichl et al., 2010).

10. -Section 2.4. Can you describe the uncertainties associated with the approach estimating phenological seasons? Uncertainties would be similar to gap-filling processes. While the estimation of the phenological seasons used 'non-gapfilled' GEP, this still includes the modeled RE and non-gapfilled NEE. A closing comment in Gonsamo et al. (2013) was that studies should also look into detailed uncertainty analysis with representative study sites from global distributions of plant functional types, as it was not previously done.

11. -Line 257 and Line 349. Clarify "responded similarly". REVISED – behaved similarly

12. -Line 255-262. Can you show the standard deviations of the annual mean Ta in Fig.1? Not entirely sure what was being asked, if it is a standard deviation of daily/annual temperature data or a comparison with the climate normals (deviations from mean). Added 30-year mean standard deviation in methods (8.0 ± 1.6°C).

13. -Line 265. Better explanation for the discrepancies is needed here. The discrepancies areover 300 umol m-2 day-1 in spring. Is it in the range of the measurement uncertainty? I'd suggest check the downward PAR to tease out the influences from the canopies and to evaluate the meteorological differences. This section was heavily edited. A paragraph was added in the methods section to highlight the reason for the discrepancies and how they were fixed. Once fixed, this sentence was edited accordingly.

14. -Line 267. Clarify "APAR was similar throughout the year". What are the values (mean and standard deviations) of the FPAR mentioned? At TP39, APAR exhibited a similar parabolic curve each year due to the seasonal amplitude in PARdn and the continuous presence of an apparently dense coniferous canopy promoting a nearly constant fraction (fPAR) of PARdn being absorbed (Fig 2a). Mean fPAR at TP39 was 0.9375 ± 0.05.

15. -Line 281. "Ts(5cm) at TP39 exceeded that of TPD" seems to suggest that thePARgroud at TPD is less, which implies that the APAR at TPD should be higher in summer and autumn. Please explain. However, during the summer and autumn of each year, Ts_{5cm} at TP39 exceeded that of at

TPD due to differences in canopy cover. Also, a higher seasonal fPAR at TPD due to the presence of a dense deciduous canopy.

16. -Line 296. Can you explain why 6-year mean day of season growth was used instead of the days of individual years? The 6-year mean was used as it produced a better fit, but also helped explain a more long-term trend of growing season start dates.

17. -Line 327. Could you also add a sentence or two at the beginning of this paragraph to explain the physical meaning of the cumulative (seasonal and annual) fluxes, especially its differences from daily fluxes? Seasonal and total fluxes provide insight on each stands ability to sequester carbon and release water over interannually comparable timescales.

18. -Line 336. "spring was the only season when daily GEP was similar between the forests". As shown in Table 3, the seasonal GEP in spring show larger differences between sites, which I think to some extent contradicts with your statement in Line 336. Please reconcile. Also, when you compare the daily GEP for phenological seasons, how did you address the different lengths of the seasons (i.e. different number of data points)? The second part of this question answers the first part. They were similar in terms of daily rates of GEP not the total seasonal sum, which was impacted by the total length.

19. -There are a few places where I have similar comments as the previous one. I suggest adding some explanations for the statistical techniques (ANOVA and MANOVA) you used, which would shed some light on the discrepancies. -Line 338. The cumulative GEP in autumn (and 2012, 2014, 2015 summer) is higher at TP39 (except for 2012). Does it contradict the argument in Line 338? -Line 352. "RE was higher at TPD". But the cumulative RE were lower at TPD in spring and autumn. -Line 384. Seasonal ET is more different in spring not autumn. Also, "daily ET" or "seasonal ET"? The other reviewer suggested to remove the statistical techniques from the previous section. A sentence was added at Line 325 to briefly highlight the t-tests used. I revised the majority (if not all) the instances where I mentioned comparisons. I added time scales and key words to highlight the comparison of rates or averages in different periods.

20. -Line 339. "the 2016 summer was the only period . . .". Clarify "sufficiently". Also, it seems a false statement to me because summer GEP in 2013 and 2017 are also greater at TPD. REMOVED

21. -Line 353. Any figure or data to support this statement? Daily rates but REMOVED

22. -Line 399. How the low WUE in winter is reflected in Figure 6c? Did you only use data from spring to autumn? If so, clarify in the manuscript. All months were plotted

23. -Line 405. Can you clarify "similar results"? The LUE at TPD is 30% higher than that at TP39. Fixed the figure to implement corrected APAR data

24. -Line 406. Is the annual and seasonal LUE shown in the manuscript? If not, clarify it in the manuscript by adding "(data not shown)". Also, as shown in Table 3, TPD has lower annual GEP, which contradicts with the "greater GEP" referred here. Reconcile. Similarly, TPD had higher annual (data not shown) and summer LUE ($p < 0.01$), although spring and autumn LUE was similar at both sites.

25. -Line 435. Do you mean "deciduous forest" instead of "conifer"? If not, add the correlation of annual NEP and summer RE for the conifer forest to Table 4. If the answer is yes, I'd suggest delete this sentence because it conveys the same meaning as the following two sentences. Meant conifer, but only included the key linear relationships

26. -Line 434-435. Can you add a brief explanation for the relationship of RE and spring Ta. Could be because of the fact that there's only 6 data points, but the warmest spring/year (2012) had the lowest annual RE, which the highest annual RE (2017) saw the coldest spring. Similarly, the coolest year in our record (2014) had a very warm spring.

27. -Line 439-448. The annual GEP has no significant relationships with meteorological variables as stated in Line 425. But this paragraph talks about GEP and meteo controls. Is it only summer GEP discussed in this paragraph? Yes, only looking at summer fluxes

28. -Line 439. What does "flux parameterizations" mean here? Is it explained in the methodology section? If not, I suggest adding it to the methods section. Yes. Added a new section to the methods: 2.4 Estimating effects of meteorological variables on carbon component fluxes

29. -Line 578. Is the assumption of similar carbon assimilation valid here given the different NEP? Changed to: Assuming similar daily rates of carbon assimilation (GEP)

30. -Table 3. Why the GEP sum for Jan 1 to SOS is missing? They seem to be available in Fig. 3. The assumption is that leaves aren't present so GEP remains zero until the SOS

31.-Table 4. Can you change this table to a figure similar to Fig. 4? The reasons are (i) you'd be able to show the standard deviations; (ii) the positive/negative correlation would be easier to tell. Ultimately chose not to, but it could be added to an appendix if needed

32.-Table 5. What model did you use for this calculation? Highlighted in methods (2.4)

33.-I notice the uncertainty analysis for measurements and calculations is missing. Can you add a brief subsection to Methods section (or wherever you find appropriate) dedicated to uncertainties? Added a paragraph on the uncertainty analysis in Section 2.3

Minor comments:

34. -I suggest changing all “warm temperatures/Ta” to “high temperatures/Ta” in the manuscript. REVISED

35. -Line 78. Clarify “controls”. Environmental/meteorological controls? REVISED determine the impact of meteorological controls on overall forest productivities

36. -Line 88-91. Are percentages available for the tree species? Not that we know of for the specific study area. Could probably be done by students in the future.

37. -Line 119. Did you use the momentum and heat fluxes in this study? If not, there’s no need to mention them. We do not. REMOVED

38. -Line 258. What is the value of “record Ta”? Also, “record high Ta”. Record high Ta conditions (exceeding 30-year mean daily maximum values)

39. -Line 315. Are the “days 230 to 290” 6-year mean? Explain. At both sites, the cumulative CDD from DOY 230 to 290 (mid-August to mid-October; loosely based on the range of dates in Oishi et al. [2018]). They used DOY 210 to 290.

40. -Line 325-326. This statement is not clear. Clarify or delete. DELETED

41. -Line 347. Define “outlier”. RE within the deciduous forest was greatly reduced, leading to an apparent outlier (exceeding mean and standard deviation) in annual RE

42. -Line 398. Clarify “the ratio of monthly ET”. Then modify the figure caption accordingly. … linear relationships of the monthly total ET and GEP (calculating WUE)

43. -Line 354-355. Confusing sentence. How do “comparable” results shape the “differences”? Rephrase. REMOVED

44. -Line 363. “for either site”? It’s hard to tell that the monthly NEP is negative at TPD in Figure 5b. Rephrase. Figure inset highlights the negative TP39 NEP during the summer

45. -Line 416. P value for being “significant”? “linear relationships of monthly Ta and monthly VPD”? Linear relationships of the 6-year monthly mean Ta and VPD ($p<0.01$).

46. -Be concise. See examples below. -Line 325. “at first glance” is not necessary. -Line 341-342. “significant daily minimums and maximums” seems to be repetitive as “highly variable”. -Line 417. Delete “,”. -Line 409-410. Delete “and”. Also, make the sentence clearer. -Line 372. “the highest” ——-> “highest”. REVISED ALL

47. -Given the different time scales used here, I suggest be more mindful about the uses of “daily, season, annual” when talking about fluxes. -Line 261. In “Ta at both sites”, do you mean “daily mean Ta”? daily mean Ta -Line 360. Change “The NEP in the conifer...” to “The annual NEP” or “The cumulative NEP”. annual NEP -Line 352. “spring and autumn RE was higher . . .”. Do you mean “daily RE in spring and summer”? Sentence removed -Line 410. Delete “When first considering . . .”. DELETED Change “ET”—-> “Annual ET”. -Line 325. Should “daily patterns” be “seasonal patterns”? Seasonal Also, substitute “expanded upon in Table3” with “the cumulative fluxes in Table 3”, just to be clear and accurate. REVISED

48. -I noticed quite a few miscitation or misspelling or inaccurate statements. See some examples below. -Line 270. “daily reductions in PAR (shouldn’t it be APAR?)”. -Line 401. 4.7 —–> 3.82 gC kg-1 H2O. -Line 406. R2 = 0.96 —–> R2 = 0.86. -Line 535. “increases” ——-> “decreases”? -Line 538. “most years” ——-> “half of the years”? - Line 553. “during drought years” is not accurate. It’s really just 2016. REVISED ALL

49. -I have a few minor comments regarding the tables and figures. See below. -Table 3. Can you highlight the highest and lowest annual fluxes with colored boxes? -Be more clear with figure captions, especially for words like “daily, monthly, seasonal, and annual”. For example, “A daily time series” in Fig. 2 is a bit confusing. -Figure 3. Green-red combination is not color-blind friendly. Also, can you annotate SOS, EOG, SOB, and EDS on the top panels? -Figure 4 caption. Two “and”. REVISED

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Response of carbon and water fluxes to meteorological and phenological variability in two Eastern North American forests of similar age but contrasting species composition – a multiyear comparison

Deleted: environmental…eteorological and phenological variability in two Eastern North American forests of similar-age but contrasting leaf-retention and shape strategies ... [1]

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Abstract. The annual carbon and water dynamics of two Eastern North American temperate forests were compared over a six-year period from 2012 to 2017. The geographic location, forest age, soil, and climate were similar between the two stands, however, stand composition varied in terms of tree leaf-retention and shape strategy: one stand was a deciduous broadleaf forest, while the other was an evergreen needleleaf forest. The 6-year mean annual net ecosystem productivity (NEP) of the coniferous forest was slightly higher and more variable (218 ± 109 g C m^{-2} yr^{-1}) compared to that of the deciduous forest NEP (200 ± 83 g C m^{-2} yr^{-1}). Similarly, the 6-year mean annual evapotranspiration (ET) of the coniferous forest was higher (442 ± 33 mm yr^{-1}) than that of the deciduous forest (388 ± 34 mm yr^{-1}), but with similar interannual variability. Summer meteorology greatly impacted the carbon and water fluxes in both stands, however the degree of response varied among the two stands. In general, warm temperatures caused higher ecosystem respiration (RE), resulting in reduced annual NEP values – an impact that was more pronounced at the deciduous broadleaf forest compared to the evergreen needleleaf forest. However, during warm and dry years, the evergreen forest had largely reduced annual NEP values compared to the deciduous forest. Variability in annual ET at both forests was related most to the variability in annual air temperature (Ta), with the largest annual ET observed in the warmest years in the deciduous forest. Additionally, ET was sensitive to prolonged dry periods that reduced ET at both stands, although the reduction at the coniferous forest was relatively larger than that of the deciduous forest. If prolonged periods (weeks to months) of increased Ta and reduced precipitation are to be expected under future climates during summer months in the study region, our findings suggest that the deciduous broadleaf forest will likely remain an annual carbon sink, while the carbon sink-source status of the coniferous forest remains uncertain.

Deleted: …year period from 2012 to 2017. The geographic location, forest age, soil, and climate were similar between the sites…wo stands, however, the species…tand composition varied in terms of tree leaf-retention and shape strategy: one stand was a deciduous broadleaf forest, while the other was an evergreen needleleaf forest. During the…he 6-year study period, the…mean annual net ecosystem productivity (NEP) of the coniferous forest was slightly higher and more variable (218 ± 109 g C m^{-2} yr^{-1}) compared to that of the deciduous broadleaf …orest NEP of …200 ± 83 g C m^{-2} yr^{-1}….. Similarly, the 6-year mean annual evapotranspiration (ET) of the conifer…oniferous forest over the 6-year study period …as higher (442 ± 33 mm yr^{-1}) compared to…han that of the broadleaf…eciduous forest (388 ± 34 mm yr^{-1}), but with similar interannual variability. Significant abnormalities in fluxes were measured between sites during drought years. …ummer meteorology greatly impacted the carbon and water fluxes at…n both sites, but to varying degrees and with varying
however the degree of response varied among the two stands. In general, warm temperatures caused higher ecosystem respiration (RE), resulting in reduced mean…annual NEP values – an impact that was more pronounced at the deciduous broadleaf forest compared to the evergreen needle-leaf…eedleleaf forest. However, during drought…arm and dry years, the evergreen forest saw greater…ad largely reduced annual reduction in carbon sequestration…EP values compared to the deciduous forest. In the evergreen conifer forest, variability of summer meteorology greatly controlled the forest's annual carbon sink-source strength. Annual Variability in annual ET at both forests was driven by changes related most to the variability in annual air temperature (Ta), with the largest annual ET measured…bserved in the warmest years in the deciduous forest. Additionally, ET was sensitive to prolonged dry periods with increased Ta, greatly…hat reduced ET. During drought years,…at both stands, although the reduction at the carbon and water fluxes…oniferous forest was relatively larger than that of the deciduous forest were less sensitive to changes in temperature or water availability compared to the evergreen forest.… If longer…rolonged periods (weeks to months) of increased temperatures…a and larger…educed precipitation variability during summer months …re to be expected under future climates during summer months in the study region, our findings suggest the carbon sink capacity of…hat the deciduous broadleaf forest will continue…ikely remain an annual carbon sink, while that …he carbon sink-source status of the conifer…oniferous forest remains uncertain in the study region. ... [2]

1 Introduction

Temperate forests play a significant role in the global carbon and water cycles through their photosynthetic CO_2 uptake and through their evapotranspiration (ET) (Huntington, 2006; Houghton et al., 2007). In Eastern North America, temperate forests are a significant sink of carbon and are an important element of future climate mitigation strategies; however, these forests have been going through transformations due to both natural and anthropogenic impacts for quite some time (Bonan, 2008; Cubasch et al., 2013; Weed et al., 2013). At the start of the 20th century, many of these forests were cleared for agricultural

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purposes, effectively releasing carbon to the atmosphere (Bonan, 2008; Richart and Hewitt, 2008). With the rise of industrial development and movement of agricultural practices to other regions, many of these agricultural lands were abandoned and subsequently reforested through natural regrowth and afforestation practices (Canadell and Raupach, 2008). Currently, much of the forested area within the mixed-wood plains ecozone in the Great Lakes region of Canada and the USA is comprised of reforested or plantation stands which are in different stages of growth (Wiken et al., 2011).

Climate change and the associated changes in extreme weather events and the hydrologic cycle such as warmer spring temperatures, intense heat and drought events in the summer, early snowmelt, reduced snowfall, or increased freeze and thaw cycles in winter, may impact the ability of these local forests to sequester carbon, and thus impact regional forest-atmosphere interactions (Bonan, 2008; Allen et al., 2010; Teskey et al., 2015). However, climate change will impact deciduous and coniferous forest ecosystems differently due to their physiological differences. Even in deciduous and coniferous forests of similar age, geographic location, climatic conditions, and soil properties, differences in the timing and rate of photosynthesis, ecosystem respiration, and evapotranspiration may lead to asymmetries in the overall forest productivity, water use, and hence longevity and survival. Consequently, regions once dominated by coniferous forests may yield way to more deciduous species (Givnish, 2002; Bonan, 2008). Such a shift could disturb regional carbon and water budgets, as deciduous forests typically have shorter growing seasons, and higher photosynthetic rates and water use efficiencies when compared to coniferous forests (Givnish, 2002; Ciais et al., 2005). While many studies have examined the annual carbon and water fluxes within specific land use and forest types, to date, only a handful of studies have compared these fluxes among similar-age deciduous and coniferous forests growing in close proximity, in similar climatic and edaphic conditions (Gaumont-Guay et al., 2009; Baldocchi et al., 2010; Novick et al., 2015; Wagle et al., 2016). Even fewer studies have reported multi-annual time series.

This study examined the carbon and water fluxes in two Eastern North American forest ecosystems of different tree species but similar age, climate, and edaphic conditions during a 6-year period from 2012 to 2017. One stand was an 80-year old (as of 2019) evergreen needleleaf forest, while the other was a roughly 90-year old broadleaf deciduous forest. The specific objectives of the study were: (1) examine seasonal and interannual dynamics of carbon and water exchanges in the two forests, (2) determine the impact of meteorological controls on overall forest productivities, and (3) analyse and contrast the varying responses of the two different species forests to extreme meteorological events such as heat and drought.

2 Methods

2.1 Study Sites

The two forests are located within 20 km of each other, situated on the north side of Lake Erie in Norfolk County, Ontario, Canada (Table 1). These forests are a part of the Turkey Point Observatory in association with the global FluxNet program. The landscape in the region is dominated by agricultural lands, while plantation and regenerated forests cover a small fraction (~25%) of the land cover; accounting for the highest forest cover in southeastern Ontario. The broadleaf deciduous forest (from here on abbreviated and referred to as, Turkey Point Deciduous, TPD) was naturally regenerated in the early 1900s from

Deleted: at the start of the 20th century …ffectively releasing carbon to the atmosphere (Bonan, 2008; Richart and Hewitt, 2008). With the rise of industrial development and movement of agriculture into western states, many of these …gricultural areas…ractices to other regions, many of these agricultural lands were abandoned and subsequently reforested through natural regrowth and afforestation practices (Canadell and Raupach, 2008). Within…urrently, much of the forested area within the mixed …wood plains ecozone in the Great Lakes region of Canada and the USA, much of the current forested area …is comprised of reforested or plantation or managed forests ... [4]

Deleted: Recent increases…limate change and the associated changes in extreme weather,…events and the hydrologic cycle such as warmer spring temperatures, intense heat and drought and heat stress…vents in the summer, early snowmelt, reduced snowfall, or the absence of …ncreased freeze and thaw cycles in winter snow or freezing events… may directly …mpact the abilities…bility of these local forests to sequester carbon, adversely impacting…nd thus impact regional forest-atmosphere interactions (Bonan, 2008; Allen et al., 2010; Teskey et al., 2015). Furthermore, forests have the ability to dampen or deepen the effects of warming, acting as…owever, climate feedback systems (Bonan, 2008). With continued extreme weather and insufficient water will impact deciduous and coniferous forest ecosystems differently due to more frequent intermittent drought events, carbon assimilation and ET in …heir physiological differences. Even in deciduous and coniferous forests could be hindered, leading to positive feedbacks of continued warming and decreased water availability (Bréda et al., 2006; Choat et al., 2012; Wu et al., 2013). Given the uncertainty of the duration and …f similar age, location, climatic conditions, and soil properties, differences in the timing of future extreme weather events, it is necessary to further improve our understanding of the controls and limitations of carbon and water cycles in forests under changing climates. ¶
The result of a shifting climate…nd rate of photosynthesis, ecosystem respiration, and evapotranspiration may lead to different impacts on deciduous broadleaf and evergreen needleleaf ... [5]

Deleted: The Turkey Point Observatory in southern Ontario, Canada is located near Lake Erie Lowlands at…his study examined the northernmost extent of temperate deciduous forests in …arbon and water fluxes in two Eastern North America, just south of the Great Lakes – St. Lawrence forest ecotone (Liu, 1990). Forests in the area contain numerous North …merican temperate species (e.g. white oak [Quercus Alba], red maple [Acer Rubrum], eastern white pine [Pinus Strobus L.], and red pine [Pinus Resinosa]), many at the northern extent of their natural climatic ranges (Richart and Hewitt, 2008; Froelich et al., 2015). Four sites make up the Observatory, three white pine plantation forests of various ages and a mixed-wood deciduous broadleaf forest. ¶
Previous carbon and water studies conducted within the conifer forests of the Turkey Point Observatory have been reported in literature (i.e. Arain and Restrepo-Coupe, 2005; Peichl and Arain... [6]

Deleted: northern edge…orth side of Lake Erie, near St. Williams…in Norfolk County, Ontario, Canada (Table 1). Monoculture pine plantations…hese forests are a part of the Turkey Point Observatory in association with the global FluxNet program. The landscape in the region is dominated by agricultural lands, while plantation and mixed-wood deciduous…egenerated forests cover only … small fraction of the agriculturally dominated landscape (~25%) of southern…he land cover; accounting for the highest forest cover in southeastern Ontario. The deciduous ... [7]

abandoned agricultural land-use on sandy terrain. The forest is unevenly aged (70 – 110 years-old) with a mean age of roughly 90-years. The stand is dominated by white oak (*Quercus Alba*), with secondary hardwood species including: red maple (*Acer Rubrum*), sugar maple (*Acer Saccharum*), black oak (*Quercus Velutina*), red oak (*Quercus Rubra*), white ash (*Fraxinus Americana*), yellow birch (*Betula alleghaniensis*), and American beech (*Fagus Grandifolia*). Conifer species only account for a minor component (~5%) of the total tree population (Kula, 2014). The understory is made up of young deciduous trees as well as Canadian mayflower (*Maianthemum canadense*), putty root (*Aplectrum hymale*), yellow mandarin (*Disporum lanuginosum*), red trillium (*Trillium erectum*), and horsetail (*Equistum*). The stand has been managed in the past with the last commercial harvesting occurring in 1984 and 1986 where 440 and 39.97 m^3 (wood volume) of wood were removed, respectively. The specific harvesting of white pine (*Pinus Strobus L*; 106 m^3), red pine (*Pinus Resinosa*; 71.42 m^3), poplar (*Populus*; 48.22 m^3), and dead oak (61.35 m^3) also occurred from 1989 to 1994 (Long Point Region Conservation Authority records). Since 1994, no management activity has occurred in this stand.

The evergreen needleleaf conifer forest, referred to as Turkey Point 39 (TP39 from here on), was planted in 1939 on cleared oak-savanna lands. The dominant tree species in this approximately 80-year old stand are eastern white pine and balsam fir (*Abies balsamifera L. Mill*), making up 82% and 11% of the total tree population, respectively. The remaining 7% of trees are typical native eastern North American forest species, which includes: white oak, black oak, red maple, wild black cherry (*Prunus serotina Ehrh.)* and white birch (*Betula papyrifera*). The understory consists of young white pines, oak, balsam fir, and black cherry trees, as well as other ground vegetation, including: bracken fern (*Pteridium aquilinum*), blackberry (*Rubus spp.*), poison ivy (*Rhus radicans*), moss (*Polytrichum spp.*), and Canada Mayflower. The conifer forest has also been managed on two occasions. A thinning was performed in 1983 in which 4,044 m^3 was removed from 38.6 ha land area (Ontario Ministry of Natural Resources and Forestry records). In the early winter of 2012, the stand was again thinned by harvesting one third of the trees (2,308 m^3), leading to a reduction in stand density (Table 1). A subsequent study conducted by our group found that while the 2012 thinning of the coniferous stand significantly reduced the annual net ecosystem productivity (NEP) when compared to the 9-year pre-thinning (2003 – 2011) mean annual NEP values, the post-thinning NEP was still within the range of interannual variability (Trant, 2014). Additionally, Skubel et al. (2017) reported that stand-level evapotranspiration (ET) was not impacted by the 2012 thinning, as increased soil evaporation and understory transpiration resulted due to a more open forest canopy. Ultimately, the objectives of this study did not focus on examining the impacts of this disturbance.

While edaphic and climatic conditions are similar between both sites, they differ in vegetation cover and canopy structure and physiology. The soils in each stand are predominantly sandy (greater than 90% sand), classified by the Canadian Soil Classification Scheme and FAO World Reference Base as Brunisolic Grey-Brown Luvisol and Albic Luvisol/Haplic Luvisol, respectively (Present and Acton, 1984; Lavkulich and Arocena, 2011). These sandy soils are part of the Southern Norfolk Sand Plains, an area shaped by past ice age glacial melt processes (Richart and Hewitt, 2008). Soils at both sites are well-drained with a low-to-moderate water holding capacity (McLaren et al., 2008). Further soil and site details can be found in Arain and Restrepo-Coupe (2005), Peichl et al. (2010a), and Beamesderfer et al. (2020a). The climate of the region is humid continental with warm, humid summers and cool winters. The 30-year (from 1981 to 2010) mean annual air temperature and total

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The white pine plantation in this study

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precipitation measured at the Environment Canada Delhi CDA weather station (25 km north of sites) is 8.0 ± 1.6°C and 997 mm, respectively. Total precipitation is normally evenly distributed throughout the year, with 13% of that falling as snow (Environment and Climate Change Canada, 2019).

2.2 Eddy Covariance and Meteorological Measurements

Half-hourly fluxes of water vapor and CO_2 (Fc) have been measured continuously at TP39 and TPD using closed-path eddy covariance (EC) systems since 2003 and 2012, respectively. This study examines the first 6 years (2012 to 2017) of data at the deciduous forest, and the corresponding period for the conifer forest. Measurements at both sites are still ongoing. The closed-path EC systems at each site consist of a 3D sonic anemometer (CSAT3, Campbell Scientific Inc.) and an infrared gas analyzer (IRGA); an LI-7000 (LI-COR Inc.) at TP39 and an LI-7200 (LI-COR Inc.) at TPD. The specific details of the EC systems are outlined in the appendix (Table A1). At both sites, IRGAs are calibrated monthly using high purity N_2 gas for the zero offset and CO_2 gas (360 μmol mol^{-1} CO_2; following WMO standards) for the CO_2 check.

The CO_2 storage (S_{CO2}) in the air column below the EC system is calculated by vertically integrating the half-hourly difference in CO_2 concentrations. This calculation is completed for both the canopy and mid-canopy gas analyzers (Table A1). Half-hourly net ecosystem exchange (NEE, μmol m^{-2} s^{-1}) is calculated as the sum of the vertical CO_2 flux (F_c), and the rate of CO_2 storage (S_{CO2}) change in the air column below the IRGA (NEE = F_c + S_{CO2}). Horizontal and vertical advections are assumed to average to zero over long periods and were not considered. Half-hourly net ecosystem productivity (NEP) is calculated as the opposite of NEE (NEP = -NEE), where positive NEP (-NEE) indicates net carbon uptake by the forest (sink), and negative NEP (+NEE) is carbon loss from the forest to the atmosphere (source).

Meteorological measurements have been conducted alongside EC measurements during the entire measurement period at both sites. Air temperature (Ta), relative humidity (RH), wind speed and direction, downward and upward photosynthetically active radiation (PAR), and the four-components of radiation (Rn) are measured at the specified EC sampling heights for both sites (Table A1). Soil temperature (Ts) and soil water content (θ) are measured at 2, 5, 10, 20, 50, and 100 cm depths in two soil pit locations at both sites. At TPD, precipitation (P) is measured in a small forest opening, 350 m southwest of the tower. However, this analysis used P data from an accumulation rain gauge (T-200B, GEONOR) installed 1 km south of TP39. All meteorological, soil, and P data were recorded using data loggers with automated data downloads occurring every half hour on desktop computers located at the base of the scaffold walk-up towers located at each site.

Following an AmeriFlux visit to TP39 for an instrument and data comparison (in 2019; post-processing), the downward PAR sensor at that site was found to be identical to the AmeriFlux measurements. Consequently, downward PAR at TPD was thus underestimating (likely due to sensor differences [i.e. PAR-Lite vs PQSI] and their coefficients) actual PAR values. A correction factor of 1.22 (slope between the two sites) was applied to daily mean PAR data at TPD for each year.

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2.3 Meteorological and Eddy Covariance Data Processing

All meteorological and flux data were processed on lab-developed software following the FluxNet Canada Research Network (FCRN) guidelines as described by Brodeur (2014). Meteorological variables were sampled at 5 second intervals and averaged at a half-hourly scale. A two-step cleaning process was used to remove outliers in half-hourly meteorological data; coarse upper and lower thresholds were applied to half-hourly values to remove obvious outliers, and additional erroneous half-hourly data were removed from time series when instruments were known to be malfunctioning or visual inspection by multiple reviewers resulted in certain agreement that an outlier was present. Missing meteorological data of all lengths were gapfilled using extant data for the same half hours from either (in order of preference) a second sensor at the site, or an equivalent sensor from a nearby (1-3 km away) station in the network (sites described in Peichl et al., 2010a). This approach was supported by a very high correlation between variables ($R^2 > 0.96$). Linear regressions between variables from different sources were used to correct for any offset and gain discrepancies.

The same two-step cleaning process was also used to remove outliers from the flux data. For eddy-covariance derived fluxes, the spike detection method described in Papale et al. (2006) was subsequently applied. After these quality control measures were applied, the mean flux data coverage was 91% (from 83% to 94%) at TPD and 88% (from 79% to 94%) at TP39 over the 6-years of data collection. Each timeseries was then subjected to a footprint filtering process, where a footprint model (Kljun et al., 2004) was applied to exclude fluxes when greater than 10% of the flux footprint extended outside of the defined forest boundary (Brodeur, 2014). This process removed approximately 32% of half-hourly fluxed from TPD and 16% from TP39. Finally, nighttime (PAR < 100 µmol m^{-2} s^{-1}) fluxes were subjected to friction velocity (u*) filtering to remove half-hours where low turbulence may lead to underestimations by EC systems. The Moving Point Test determination method (Reichstein et al., 2005; Papale et al., 2006; Barr et al., 2013) was used to estimate annual u* threshold (u^{*Th}) values at each site, and the nighttime half-hourly flux data were removed when the measured friction velocity (u*) was below the calculated threshold (u^{*Th}). The mean site-specific u^{*Th} values were 0.40 m s^{-1} at TPD and 0.49 m s^{-1} at TP39. The resulting final mean flux data recovery following both threshold filtering methods was 49% (from 46% to 53%) at TPD and 53% (from 48% to 57%) at TP39 for the 6-years of measurements. Confidence intervals (95%) incorporating the effect of random instrument error, and systematic and random errors associated with the gap-filling process used for annual NEE estimates were calculated using a functional relationship with annual gap percentage, developed for these sites by Brodeur (2014). The NEE model uncertainty ranged from ± 33 – 37 g C m^2 yr^{-1} at TPD and ± 31– 36 g C m^2 yr^{-1} at TP39. Furthermore, uncertainties in annual evapotranspiration (ET) values totaling the sum of both measurement uncertainties and data gap-filling (as described by Arain et al. 2003), were estimated to be ± 35 – 43 mm yr^{-1} at TPD and ± 41 – 50 mm yr^{-1} at TP39.

NEE gap-filling and its partitioning into components of ecosystem respiration (RE) and gross ecosystem productivity (GEP) were achieved using the methods described in Peichl et al. (2010a), which are summarized below. RE was assumed to be equivalent to NEE during nighttime periods (PAR < 100 µmol m^{-2} s^{-1}) that passed both footprint and friction velocity filters.

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Deleted: Following the footprint passing method, the remaining flux data recovery was 59% (from 54% to 64%) at TPD and 72% (from 67% to 77%) at TP39. Moreover, during periods of low turbulence, EC systems often underestimate fluxes. As a result, inaccurate measurements captured during periods of low turbulence were removed when measured u* was below thresholds estimated using a u^{*Th}

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These values were used to model a continuous RE timeseries based on a non-linear regression with Ts_{5cm} and $\theta_{0\text{-}30cm}$ (depth-weighted average from measurements made at 5, 10, 20, and 50 cm depths) using the functional form:

$$\mathrm{RE} = \mathrm{R}_{10} \times \mathrm{Q}_{10}^{\frac{(\mathrm{Ts}_{5\,cm} - 10)}{10}} \times \frac{1}{[1 + \exp(a_1 - a_2\,\theta_{0-30\,cm})]}\,, \qquad (1)$$

where parameters R_{10} and Q_{10} define controls of Ts_{5cm} on RE. The $\theta_{0\text{-}30cm}$ related controls are defined as follows:

$$f(\theta_{0-30cm}) = \frac{1}{[1 + \exp(a_1 - a_2\,\theta_{0-30\,cm})]}, \qquad (2)$$

where a_1 and a_2 are fitted parameters that describe a sigmoidal curve that ranges from 0 to 1 (Richardson et al., 2007). In this approach, the Ts_{5cm} component of the function defines a theoretical maximum half-hourly respiration rate based on soil temperature (i.e. driving variable), while the $\theta_{0\text{-}30cm}$ component modulates the resultant predicted value as a function of the volumetric water content (i.e. scaling variable). Parameter values for Equation 1 were derived for each site and year; values were estimated simultaneously using the Nelder-Mead simplex optimization approach via the MATLAB *fminsearch* function (The MathWorks, Inc). The estimated parameters were then used to model RE for all half-hour periods using the measured values of Ts_{5cm} and $\theta_{0\text{-}30cm}$.

Half-hourly GEP was derived as the difference between modeled daytime RE and footprint-filtered NEE. Gaps in the GEP time series were filled using predicted values derived from the following relationship:

$$\mathrm{GEP} = \frac{\alpha \mathrm{PAR}\, \mathrm{A}_{max}}{\alpha \mathrm{PAn} + \mathrm{A}_{max}} \times f(\mathrm{Ts}_{5cm}) \times f(\mathrm{VPD}) \times f(\theta_{0\text{-}30cm})\,, \qquad (3)$$

where the first term is a rectangular hyperbolic functional relationship between PAR and GEP, defined by the values of the photosynthetic flux per quanta (α, quantum yield) and the light-saturated rate of CO_2 fixation (A_{max}). The remaining terms use the functional form introduced in Equation 2 to described the responses of GEP to Ts, vapor pressure deficit (VPD), and $\theta_{0\text{-}30cm}$, respectively. Parameters were optimized using the same approach described above. Finally, gaps in the NEP timeseries were filled using the differences between the filled GEP and modeled RE timeseries.

Following the aforementioned threshold and point cleaning, gaps in the latent heat flux (LE), and therefore the mass equivalent evapotranspiration, were filled using an artificial neural network which utilized Rn, wind speed, Ts_{5cm}, VPD, and $\theta_{0\text{-}30cm}$ (Brodeur, 2014). Following the approach outlined by Amiro et al. (2006), any remaining gaps in LE data were filled using a moving window linear regression method. Past studies examining the relationships between ET and meteorological variables for the forests of the Turkey Point Observatory have found Ta to largely drive ET, with smaller secondary effects driven by VPD and $\theta_{0\text{-}30cm}$ during low water or high heat periods (McLaren et al., 2008; MacKay et al., 2012; Skubel et al., 2015; Burns, 2017). All data processing and analyses were completed using MatLab R2014b software (The MathWorks, Inc.).

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2.4 Estimating effects of meteorological variables on carbon component fluxes

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2.4

The partitioning models described above were further used to explore interannual differences in controlling meteorological variables and their impacts on annual RE and GEP values at each site. In this analysis, the RE and GEP models (see Equations 1 and 3 above, respectively) were parameterized for the phenologically-derived summer months (end of greenup to the start of browndown, defined in the next section) for all years (2012 to 2017). To overcome issues of equifinality that arose when fitting parameters of Equations 1 and 3 to each year of data, parameterization was performed as a two-step process, where parameters describing 'scaling' variable relationships (i.e. $\theta_{0\text{-}30cm}$ for RE; Ta, $\theta_{0\text{-}30cm}$, VPD for GEP) were fixed to all-years of data, while relationships with 'driving' variables (i.e. Ts_{5cm} for RE; PAR for GEP) were parameterized to each year of data with other parameters fixed. Furthermore, the mean annual value for each scaling variable function was used to compare the quality of meteorological conditions between years. Given that these variables scale between 0 and 1, higher annual values (i.e. closer to 1) indicated that the variable was relatively more favourable for RE or GEP production in that given year. To present in true relative terms, the annual values for a given functional relationship were normalized by the highest annual value. Thus, reported annual values represent a proportion of the most favourable year. A similar metric was derived for the driving variables by modelling RE and GEP using the driving relationships only (i.e. no scaling variables). Modelled annual values were normalized by the highest one, thus creating a relative annual score like that for scaling variables. Finally, all metrics derived for scaling and driving variables in a given year were multiplied together to provide a measure of the cumulative effect of all meteorological variables to a given component flux in a given year.

2.5 Definitions of key climatic and plant-physiological variables

In this study, we define the term drought similar to Wolf et al. (2013), where drought periods are related to deficits in precipitation, which impose either plant physiological stress due to decreased soil moisture (θ) or impose stress due to stomatal closures in response to high VPD.

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Two resource efficiencies were calculated at both forests to compare the links between productivity and resource supply in order to reveal differences in their responses to changing climatic conditions. The amount of carbon fixed through photosynthesis per unit absorbed solar radiation, described as the photosynthetic light use efficiency (LUE) was calculated as:

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$$\mathrm{LUE} = \frac{\mathrm{GEP}}{\mathrm{APAR}} \qquad (4)$$

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where GEP is equivalent to the carbon fixed through photosynthesis, and APAR is the portion of PAR that is absorbed (Jenkins et al., 2007; Liu et al., 2019). The forest canopy radiation budget used in the calculation of APAR is described as:

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$$\mathrm{APAR} = \mathrm{PARdn} - \mathrm{PARup} - \mathrm{PARground} \qquad (5)$$

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where PARdn is the incident PAR measured by PAR sensors mounted at the top of each tower facing skyward, PARup is measured as reflected PAR by instruments mounted at the same height as the PARdn sensor, but facing downward towards the forest canopy. PARground is the PAR transmitted through the canopy to a ground sensor located at 2 m height.

Furthermore, the forest-level water-use efficiency (WUE), describing the carbon fixed through photosynthesis per water lost, was calculated as the ratio of GEP to ET (Keenan et al., 2013).

Using the methods of Gonsamo et al. (2013), we calculated phenologically-derived seasons for each year for each site. From half-hourly non-gapfilled data (calculated as the difference between modeled RE and measured non-gapfilled NEE), the maximum daily photosynthetic uptake (GEP_{Max}) was calculated and fit using a double logistic function described by Gonsamo et al. (2013). From the initial fit, a Grubb's test was conducted to statistically ($p < 0.01$) remove outliers in GEP_{Max} data using the approach outlined by Gu et al. (2009). With outliers removed, the function was fit once more. This approach identified photosynthetic transition dates, hereafter described as phenological dates, using first, second, and third derivatives of the logistic curves. The local minima of the second derivatives estimated the end of greenup (EOG), the length of canopy closure (LOCC), and the start of browndown (SOB), while the local maxima of the third derivatives estimated the start of the growing season (SOS), and the end of the growing season (EOS). The start of the growing season (SOS) marked the end of winter dormancy and the beginning of the spring season, leaf emergence/greenup. The phenologically defined spring season is defined as the period from SOS to EOG. The phenologically defined summer or peak carbon uptake period is defined as the entire LOCC period from the final day of greenup (EOG) to the initiation of leaf senescence (SOB), bound by spring and autumn shoulder seasons. Finally, the resulting phenologically defined autumn season is from SOB date to EOS date, with EOS marking leaf abscission and the end of photosynthetic activity in autumn. The length of the overall growing season (LOS) was calculated as the number of days between SOS and EOS.

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Lastly, the impact of climate on phenology was examined by the use of growing degree days (GDD) and cooling degree days (CDD), in order to understand the thermal response of each forest. GDD accumulation was defined to occur when the mean daily Ta was greater than 0°C, while CDD were calculated using the daily mean Ta below a base Ta of 20°C (Richardson et al., 2006). Cumulative GDD and CDD were briefly considered in this analysis.

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3 Results

3.1 Meteorological Variability

Air temperature measurements conducted above the canopies at both sites showed that the daily mean values of Ta at TP39 (Fig. 1a) and TPD (Fig. 1b) behaved similarly (Fig. 1c) over the study period. All years experienced annual mean Ta greater than the 30-year mean (8.0°C). Record high Ta conditions (exceeding 30-year mean daily maximum values) were measured throughout the majority of the year in 2012 and during the summer of 2016. Cooler conditions dominated 2013 and 2014, while these years had a higher magnitude of extreme cold days in winter (exceeding 30-year mean daily minimum values), acting to decrease mean annual Ta. In 2015, 2016, and 2017, autumn warming was observed, with record Ta outside of the typical summer (June – August) period. Overall, daily mean Ta at both sites was almost identical (Fig. 1c), highlighting the similar climate both forests were growing in during the study period.

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Meteorological conditions at both sites were examined over the study period. At TP39, APAR exhibited a similar parabolic curve each year due to the seasonal amplitude in PARdn and the continuous presence of an apparently dense coniferous canopy, promoting a nearly constant fraction (fPAR) of PARdn being absorbed (Fig 2a). At TPD, APAR exhibited lower values in the winter seasons when the forest remained leafless. The timing of the peak APAR at TPD was similar to TP39, though it varied each year based on the annual timing of leaf-out and spring canopy development. Daily reductions in PARdn and APAR often resulted from cloudy conditions and precipitation (P) events (Fig. 2a).

Fewer P events were measured during the first half of 2012, and most of 2015, 2016, and the late-summer of 2017, as the latter three years had annual P less than the 30-year mean (997 mm). Autumn P in 2012 helped the forests to recover from the record heat and water deficits, while 2013 and 2014 experienced consistent rain throughout much of the year. Heightened daily VPD (Fig. 2b) was experienced throughout 2012 by both sites, with seasonal maximum values measured during warm and dry conditions. In all years, except for 2012 and the autumn of 2016, daily VPD at TP39 was higher than at TPD Fig. 2c). Annually, mean VPD was on average about 0.04 kPa higher at TP39 than TPD, with 2012 being the obvious exception (Fig. 2c).

Ts at 5 cm soil depths follow Ta closely (Fig. 1) with dampening effects evident at deeper (100 cm) soil layers (Fig. 2d). The differences in Ts_{5cm} were explained by the species compositions of the two forests (Fig. 2e). At TPD, when the deciduous forest was leafless in winter and spring, Ts_{5cm} was higher than at TP39 as the soil received more direct radiation. However, during the summer and autumn of each year, Ts_{5cm} at TP39 exceeded that of at TPD due to differences in canopy cover. Lastly, θ from 0-30 cm ($\theta_{0\text{-}30cm}$) followed similar patterns at both sites, with prolonged summer θ declines in 2012, 2016, and 2017 (Fig. 2f). The magnitudes again were different, but each forest experienced similar declining θ and the subsequent recharging θ analogous to local P events. In the summer, θ was typically lower at TPD than TP39, while during all other times of the year θ at TP39 was higher (Fig. 2g).

3.2 Phenological Variability

The meteorological conditions had a significant impact on the timing and duration of key phenological events, although ultimately the response was governed by different leaf-strategies of the various dominant tree species in each forest. The phenological transition dates and seasons calculated from EC-flux data are shown in Table 2 and Fig. 3. The SOS varied considerably between the two forests, with the SOS at the evergreen forest, TP39, beginning on average 38 ± 14 days earlier than at the deciduous forest, TPD. TP39 experienced a larger variation in SOS dates, spanning a period of 26 days between the earliest (10 March 2012; day of year [DOY] 70) and latest (6 April 2014; DOY 96) years, while TPD varied by 11 days between years.

Growing degree days (GDD) are a proxy used to assess the amount of heat the ecosystem has absorbed, as a result of increasing air temperatures. The response of the forest to increasing GDD was shown to be a trigger for the SOS. The total GDD from the start of the year (January 1st, DOY 1) to 6-year mean day of season growth (25 March; DOY 84), was found to be highly correlated to SOS at TP39 ($R^2 = 0.81$), but not at TPD (Fig. 4a & 4b). GDD for DOY 117-127 (27 April to 7 May; which represents the range of 6-year mean SOS data ± one standard deviation) was found to significantly influence the SOS

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at TPD ($R^2 = 0.95$), with a weaker influence at TP39 (DOY 73-95; $R^2 = 0.76$). This difference likely reflects the different leaf-strategies, in that evergreen trees are ready to start photosynthesizing as soon as conditions are favorable, while the deciduous trees still need to grow their leaves once conditions are favorable, before comparable rates of photosynthesis are reached. Spring, defined as the period from SOS to EOG, was more than double the length (69 ± 14 days) at TP39 when compared to TPD (31 ± 5 days). However, even with largely different SOS and spring lengths, the peak summer period, defined as the period between EOG in spring and SOB in autumn, was essentially identical between the forests (Fig. 3). This period, spanning June, July, and August, was found to be a key contributor to the net annual productivity of each forest (discussed below).

With similar peak summer lengths, the forests began senescence at similar times, though the length of autumn, the period from the SOB to the EOS, varied considerably between the forests, due to differences in the timing of the EOS (Fig. 3). Drought conditions in the summer of 2012 led both sites to have the shortest autumns and earliest EOS (Fig. 2f & 3). Conversely, late season warming in the autumns of 2016 and 2017 helped to prolong the growing season at both sites, but the impacts of late season warming in 2015 were not as evident in shaping the timing of EOS (Fig. 1 & 3; Table 2).

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At both sites, the cumulative CDD from DOY 230 to 290 (mid-August to mid-October; loosely based on the range of dates in Oishi et al. [2018]), were highly correlated to the EOS at TP39 ($R^2 = 0.84$) and TPD ($R^2 = 0.95$) (Fig. 4e & 4f). Temperature responses in both the spring (i.e. GDD) and autumn (i.e. CDD) were much higher for TPD than TP39 (Fig. 4). These results suggest that warmer winter and early spring (i.e. January to April) conditions will lead to an advancement of the SOS in the conifer forest, but the same cannot be said for the deciduous forest, whose SOS dates were heavily dependent on late-April, early-May growing conditions. To a certain degree, both forests responded similarly in autumn, however physiological constraints of the different tree leaf-strategies defined the overall differences in growing season lengths.

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3.3 Carbon and Water Fluxes

The water (evapotranspiration) and carbon (photosynthesis and respiration) fluxes were analysed in both forests from 2012 to 2017, with the seasonal patterns of these fluxes illustrated in Fig. 3 and cumulative fluxes in Table 3. Seasonal and total fluxes provide insight on each stands ability to sequester carbon and release water over interannually comparable timescales. Annual photosynthesis (GEP) at the conifer forest (TP39) was the highest in 2017 (1709 g C m^2 yr^{-1}) and 2015 (1701 g C m^2 yr^{-1}), while the lowest annual GEP was measured in 2012 (1452 g C m^2 yr^{-1}) and 2013 (1501 g C m^2 yr^{-1}). GEP reductions during these years were due to opposing influences, with 2012 experiencing heat and drought conditions for most of the year, and 2013 experiencing cooler Ta and the highest annual P (1266 mm), reducing PAR and therefore GEP (Fig. 3a). At the deciduous forest (TPD), similar GEP reductions were captured in 2012 (1198 g C m^2 yr^{-1}), but not in 2013 (1369 g C m^2 yr^{-1}) due to high photosynthetic gains, outside of the 2013 peak growing season (i.e. in the early spring and autumn periods). The highest annual GEP at TPD was found in 2016 (1420 g C m^2 yr^{-1}) and 2017 (1447 g C m^2 yr^{-1}) due to warm summer conditions (Fig. 3b). Although 2014 had one of the shortest summers and the shortest overall growing season length of all years, high daily GEP rates were sustained through the summer, resulting in the year having above average annual GEP (1382 g C m^2 yr^{-1}). In all 6-years, spring was the only season when daily rates of GEP were similar between the forests, as the advancement of SOS at

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TP39 did not statistically benefit carbon uptake due to seasonal meteorological conditions (i.e. low PAR, Ta, etc.) acting to limit photosynthesis. Using the analysis of variance (ANOVA) technique, t-tests were completed to evaluate statistical differences between the two groups (i.e. deciduous broadleaf vs. evergreen needleleaf) of data. Summer and autumn daily GEP were higher at TPD when compared to TP39 across the 6-years ($p < 0.01$). In all years, TP39 annual GEP was greater than TPD due to the longer growing seasons.

TP39 RE was highly variable in all years (Fig. 3a), with the greatest annual total RE found in 2016 (1492 g C m^{2} yr^{-1}) and 2017 (1525 g C m^{2} yr^{-1}). The annual RE during these years was about 100 to 200 g C m^{2} yr^{-1} greater than during the other years. Cooler spring Ta and reductions in RE during the summer of 2013, led to the lowest annual RE (1282 g C m^{2} yr^{-1}) of the 6-years. While 2012 encountered reduced ET and GEP during the summer, RE was largely unaffected, leading to the third highest annual RE (1386 g C m^{2} yr^{-1}). Conversely, the 2012 RE within the deciduous forest was greatly reduced, leading to an apparent outlier (exceeding mean and standard deviation) in annual RE at that site (954 g C m^{2} yr^{-1}). Similar to TP39, but to a lesser degree, the annual RE at TPD during 2017 was the greatest of the 6-years (1317 g C m^{2} yr^{-1}). Annually, the RE at both forests behaved similarly, with 2012 being the exception (Fig. 3b). The highest daily rates of RE at both sites were measured during the summer of 2013, coinciding with similar maximums in ET. In both cases, maximum rates of RE and ET occurred following P events, as the soil was sufficiently wet, helping to promote ET and enhance RE through respiration pulses (suggested in Misson et al., 2006). Daily summer RE was higher at TP39 in all years with 2013 and 2015 being the exceptions.

The resulting balance between GEP and RE, net ecosystem productivity (NEP), was found to be largely irregular between sites during individual years due to site-specific differences in the timing, magnitude, and duration of daily fluctuations in GEP and RE. The trajectory of growing season NEP was strikingly different between sites (Fig. 3a & 3b). TPD (deciduous) captured consistently positive daily NEP (sink), while TP39 (conifer) was highly variable, with negative daily NEP (source) often occurring throughout the growing season. The annual NEP in the conifer forest was the lowest in 2012 (76 g C m^{2} yr^{-1}) and 2016 (139 g C m^{2} yr^{-1}), coinciding with heat and drought stress in both years (Fig. 5a). At TP39, July 2012 was the only month during the 6-years of measurements where the peak summer growing season monthly NEP for either site was negative (Fig 5a inset). The most productive years (largest annual sink) at the conifer site were 2015 (395 g C m^{2} yr^{-1}) and 2014 (263 g C m^{2} yr^{-1}). While 2014 (305 g C m^{2} yr^{-1}) was simultaneously the most productive year at the deciduous forest, 2015 (90 g C m^{2} yr^{-1}) was the lowest annual sink, highlighting the differences between sites (Fig. 5b). Similarly, the least productive year at TP39 (2012) was the second most productive year at TPD (292 g C m^{2} yr^{-1}). The cumulative site differences in NEP were analyzed to focus on seasonal differences (Fig. 5c). With earlier SOS at TP39, the conifer site quickly became a sink in spring, while the growing season had not yet begun at TPD. Following SOS, daily NEP at TPD exceeded that at TP39 in all years except 2015 ($p < 0.01$). In the autumn, there was no statistical difference between sites, although as GEP ceased at TPD with leaf abscission, the cumulative difference in NEP between sites benefited the extended photosynthesis measured at TP39 (Fig. 5c).

Within the evergreen conifer forest (TP39), annual ET was highest in 2012 (495 mm yr^{-1}) and 2013 (468 mm yr^{-1}). High Ta throughout much of the year and high summer VPD caused 2012 to have the highest annual ET, while continuous spring and summer P (Fig. 2a) allowed 2013 to sustain higher daily rates of ET (Fig. 3a). Cooler Ta during all of 2014 (421 mm yr^{-1})

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and cooler Ta in the phenological spring of 2016 (409 mm yr^{-1}), combined with the lowest annual P (in 2016), caused these years to have the lowest ET for the conifer forest (Table 3). Within the deciduous forest (TPD), 2012 (428 mm yr^{-1}), 2016 (417 mm yr^{-1}), and 2017 (403 mm yr^{-1}), had the greatest annual ET, coinciding with the years with the highest annual Ta (Fig. 1b). In 2014, the coolest year during the 6-years of measurements, annual ET (350 mm yr^{-1}) was greatly reduced at TPD. While the ET of each forest ultimately responded differently to the local meteorological forcings, on a few occasions, similar daily ET rates were measured, coinciding with significant P events. In the summer of 2013 (May 30 to July 19 or DOY 150 to 200), high daily ET was measured at both sites, immediately following multiple daily P events exceeding 40 mm of rain (Fig. 2a, 4a & 4b). Additionally, in 2015 (June 20 to July 10 or DOY 180 to 200), increased ET was measured at both sites following steady P events. Considering the 6-years as a whole, phenological autumn was the only season where ET significantly differed between the sites. While the mean autumn ET was greater at TP39, the shorter duration of autumn (Table 2) led to rates of daily ET to be higher at TPD as compared to TP39 ($p < 0.01$). In this case, the phenological autumn at TPD occurred when Ta remained high, while at TP39 autumn stretched later into the year when Ta and daily ET were reduced. Both forests experienced similar variability expressed as standard deviation in ET (33 & 34 mm), and in all years except for 2016, the ET of the conifer forest exceeded that of the deciduous forest.

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3.4 Forest Light and Water Use Efficiencies

The forest light and water use efficiencies (i.e. WUE & LUE) were examined to understand the relationships between forest carbon uptake and site resources (i.e. water & light), illustrated in Fig. 6. At TP39, WUE was the highest in the spring of 2016, the summers of 2014 and 2017, autumns of 2015, 2016, and 2017 (Fig. 6a). In 2016, an early SOS (March 15; DOY 74) promoted prompt increases in spring GEP, when Ta and ET remained low. In autumn, the years with extended growing seasons, saw GEP increase later in the year as ET decreased, leading to higher WUE. At TPD, WUE was lowest in the warm years (i.e. 2012, 2016, & 2017) due to increased annual ET, while the cool and highly productive year of 2014 experienced the highest summer and autumn WUE (Fig. 6b). In the 6-years of measurements, highly significant ($p < 0.01$) linear relationships of the monthly total ET and GEP (calculating WUE) were measured at both sites, with monthly WUE remaining relatively constant (Fig. 6c; $R^2 = 0.92$). While monthly WUE was similar between forests (Fig. 6c), WUE was higher at TPD (4.70 g C kg^{-1} H_2O) when compared to that of TP39 (3.82 g C kg^{-1} H_2O).

The general LUE trends and deviations were statistically comparable between the two forests. At both sites, 2014 and 2017 had the highest summer LUE, while reduced GEP at both sites during the summers of 2012 and 2016 yielded the lowest summer LUE (Fig. 6d & 6e). Across all years, mean monthly linear relationships between GEP and APAR yielded similar results, with larger variation ($R^2 = 0.70$) and lower LUE at TP39 when compared to TPD (Fig. 6f; $R^2 = 0.82$). Similarly, TPD had higher annual (data not shown) and summer LUE ($p < 0.01$), although spring and autumn LUE was similar at both sites.

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3.5 Meteorological Controls on Fluxes

Meteorological variables (i.e. Ta, PAR, θ, etc.) were analyzed during the study period to better understand their impact on water and carbon fluxes within each forest. Considering annual values, ET at the deciduous (TPD) forest was found to be highly correlated ($R^2 = 0.84$) to annual mean Ta. A smaller secondary effect on ET ($R^2 = 0.83$; Table 4) was found for winter and early spring (January 1st to SOS) $\theta_{0\text{-}30cm}$, which helped to explain the impact of winter soil water storage and seasonal water availability on ET at the start of each year. At TPD, higher winter $\theta_{0\text{-}30cm}$ was measured in the years with the greatest annual ET. At the conifer (TP39) forest, no strong relationships were found between annual ET values and seasonal or annual meteorological variables. However, monthly linear relationships of Ta and VPD to ET were significant ($p < 0.01$) at both sites (Fig. 7). The evergreen conifer and deciduous broadleaf forests experienced similar increases in monthly ET with increasing monthly mean Ta (Fig. 7a). While the evergreen forest saw higher rates of ET compared to the deciduous forest, the correlation of ET to Ta was greater for the deciduous forest ($R^2 = 0.95$ vs $R^2 = 0.89$; for TPD and TP39, respectively). The response of monthly ET to monthly VPD was similar between sites, as a mean monthly VPD of 1kPa corresponded to a monthly total ET of 104 mm and 97 mm at TP39 and TPD, respectively (Fig. 7b). Overall, the correlation of ET to increasing VPD was greater for the evergreen forest ($R^2 = 0.82$ vs $R^2 = 0.74$; for TPD and TP39, respectively).

Following similar annual time scales used in the ET comparison, GEP, RE, and NEP were compared to meteorological measurements for each site and season (Table 4). In both forests, no significant relationships were found between meteorological variables and annual GEP. In terms of RE at TP39, the years with the highest annual RE (i.e. 2016 & 2017) resulted from summer drought conditions, as evident through prolonged reductions in mean summer $\theta_{0\text{-}30cm}$ ($R^2 = 0.89$). The years with the lowest annual RE (i.e. 2013 & 2015) were ultimately the most productive (largest annual carbon sink) and both measured the highest mean summer $\theta_{0\text{-}30cm}$. The annual NEP was correlated to the length of spring ($R^2 = 0.75$), mean summer Ta ($R^2 = 0.73$), cumulative summer NEP ($R^2 = 0.99$). For the evergreen conifer site, spring was shorter in years with the highest annual NEP due to rapid photosynthetic development. Higher mean summer Ta decreased annual NEP, highlighting the influence of limitations due to heat stress. Lastly, summer NEP at TP39 was nearly identical to the annual NEP, stressing the importance of this period (roughly June, July & August) in shaping the annual carbon sink status of the forest.

At the deciduous forest, the relationship between annual RE and spring Ta ($R^2 = 0.77$) suggested that warmer springs generally acted to decrease annual RE. Annual NEP at the conifer forest was shown to be correlated to summer RE ($R^2 = 0.80$; Table 4). Within the deciduous forest, the years with lower summer RE (i.e. 2012, 2014) were the largest annual carbon sinks. The smallest annual NEP (2015) was observed when summer RE was highest (714 g C m^{-2}). On annual time scales, both sites highlighted the importance of summer meteorological conditions on annual productivity.

Based on the importance of summer outlined above, the flux parameterizations were further examined to understand the dominant meteorological factors during each summer. At the deciduous broadleaf forest, $\theta_{0\text{-}30cm}$ was shown to have no impact on GEP, while Ta, VPD, and PAR contributed to the summer photosynthesis each year (Table 5). Based on meteorological conditions experienced in each year, 2016 and 2014 were the most favorable for summer GEP, while 2012 was the least

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favorable. Similar results were found for the evergreen conifer forest, though at that site, low θ_{0-30cm} was shown to influence GEP. Therefore, years with lower θ_{0-30cm} or higher VPD did not experience the same beneficial meteorological inputs necessary for optimal summer GEP. Aside from Ts_{5cm}, θ_{0-30cm} impacted summer RE at both sites. At TPD, the years with the highest summer θ_{0-30cm} (i.e. 2013 & 2015) experienced optimal conditions for enhanced RE, while 2012 and 2016 saw less favorable RE. Similar trends were also found at TP39. Overall, the annual fluxes were a product of the season length and the estimated daily rates of the CO_2 fluxes that were in turn influenced by seasonal variability in meteorological variables.

4 Discussion

4.1 Meteorological and Phenological Variability

The meteorological conditions at both sites during the study period were characteristic of temperate North American forest ecosystems, characterized by four distinct seasons, with cold winters and warm summers. The close proximity between the two forests (~20 km apart at the same latitude) led them to experience similar synoptic scale weather conditions during each year, and therefore nearly identical Ta. Even with similar climatic forcings (i.e. Ta) seasonal deviations in Ts_{5cm} were found, likely influenced by the opposing forest canopy characteristics (Palmroth et al., 2005; Stoy et al., 2006). Ts was linked to the proportion of incoming radiation penetrating the forest canopy, reaching the forest floor. In all years, mean daily Ts_{5cm} at the conifer forest was higher during each summer, but lower than that of the deciduous forest during the rest of the year. In the conifer forest, branches and needles were closely clumped while the canopy remained comparatively open, leading to minor annual variations in fPAR by the forest canopy and soil, in line with Brummer et al. (2012). In the deciduous forest, Ts_{5cm} was higher when leaves were absent and a higher fraction of incoming radiation was directly absorbed by the soil. Following the development and closure of the forest canopy in spring, deciduous Ts_{5cm} was lower than the conifer forest in our study, which was in line with other similar studies (i.e. Lee et al., 2010; Augusto et al., 2015).

In general, both forests had similar VPD trends in all years while TP39 had somewhat higher VPD compared to TPD, except in the record warm year of 2012. The higher VPD at the deciduous forest in 2012 could be due to the relative unresponsiveness of stomata to higher VPD typical of broadleaved species, or the suggested larger leaf boundary layers in deciduous trees, where VPD measured above a canopy can be greater than what leaves experience (Baldocchi and Vogel, 1996; Baldocchi et al., 2002; Stokes et al., 2006).

The response of leaf phenology in temperate forests to changes in temperature has been shown throughout much of the Northern Hemisphere (Jeong et al., 2011; Settele et al., 2014). In future climates, rising Ta is predicted to lead to an earlier start, later end, and prolonged duration of the growing season, though ecosystem-level responses are expected to vary as there is a strong genetic control among plant species on the timing of phenological events (Vitasse et al., 2011; Sanz-Perez et al., 2009; Polgar and Primack, 2011; Oishi et al., 2018). In locations such as ours where different tree species face similar climates, the relative advantage of conifer species is seen as the SOS may often precede spring frost events (Givnish, 2002; Augusto et al., 2015). On the other hand, deciduous species (such as *Quercus*) often delay leaf-out to decrease the probability of frost

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In the autumn, the onset of senescence and EOS has been reported to be advanced by high θ deficits, and delayed with increased warming (Kramer, 2010, Warren et al., 2011; Liu et al., 2016). Both forests experienced later senescence dates with decreased θ (although likely due to increased Ta). For the conifer forest, the two years (i.e. 2012 & 2016) with continued heat and drought stress saw the latest dates of senescence, while at the deciduous forest, greater mean summer θ led to earlier senescence in all years but decreased θ extended senescence. Furthermore, we found that the late-summer (August to October) degree of cooling had a significant impact on the EOS as well as overall growing season length. This response has been confirmed by long term observational data, which has shown strong positive correlations between Ta and EOS, helping to postpone EOS for many forest ecosystems (Dragoni and Rahman, 2012; Gallinat et al., 2015; Liu et al., 2016). More cold days promoted earlier EOS and shorter seasons, while less cooling (greater warming) extended the season and phenologic autumn period at both sites. However, the degree of extension was much different between sites, similar to the response in spring. The mean EOS (10 November; DOY 314 ± 8 days) at the deciduous site occurred one month (31 days) earlier compared to the evergreen coniferous site (11 December; DOY 345 ± 17 days). There was greater variability in EOS at the conifer forest compared to the deciduous broadleaf forest. Based on these findings, in future climates, evergreen conifer forests in the region may expect earlier springs, later autumns, and longer growing seasons, while the deciduous broadleaf forests will likely see greater gains in growing season length from prolonged autumns, limited by their specific leaf-strategy.

4.2 Meteorological Impacts on Carbon Fluxes

Changes in local meteorology (and climate) have been recognized as a primary factor driving the interannual variability of carbon fluxes within forests (Bonan, 2008; Desai, 2010; Coursolle et al., 2012). Anomalous Ta (extreme heat or cold) and seasonal fluctuations in water availability (θ) over a predictable course of the year were shown to strongly impact the carbon sequestered in many forests (Ciais et al., 2005; Sun et al., 2011; Xie et al., 2014). Conceptually, higher mean Ta will promote longer growing seasons and greater GEP, though increased RE may also be expected (White and Nemani, 2003; Noormets et al., 2015). In this study, the differing forest responses to meteorological conditions led to significant divergences in annual GEP, RE, and NEP. At both sites, the overall growing season length in 2012 was the second shortest (behind 2014), as a result of the anomalously warm Ta experienced throughout much of the year. If this year is excluded, both the conifer and deciduous forests experienced longer growing season lengths with increased annual Ta. Annual GEP reductions were experienced in each forest during the heat and drought year of 2012. GEP reductions at our conifer site may also be associated with the reduction in canopy size, due to thinning performed at the site in the early winter of 2012 (see more discussion in the following section).

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Additionally, higher daily mean Ta and low θ enhanced RE in the conifer forest, but significantly reduced RE in the deciduous forest. The suppression of RE has been previously reported for other deciduous forests during warm and dry periods (Davidson et al., 1998; Palmroth et al., 2005; Novick et al., 2015; Darenova and Cater, 2018). Overall, these reductions in both the growing season length and the magnitude of carbon fluxes highlighted the forests sensitivities to heat and drought events, though it ultimately varied between sites. Contrasting studies have shown varying results on the overall drought tolerance of conifer forests. Some studies suggest that conifer species, especially those in resource-poor locations, may be less responsive to seasonal climate anomalies (Aerts et al., 1995; Way and Oren, 2010; Wolf et al., 2013). Others have found that conifer (i.e. *Pinus*) forests are highly coupled to atmospheric demand and drought sensitivities (Griffis et al., 2003; Stoy et al., 2006). The two years (i.e. 2012 & 2016) with the lowest annual carbon sequestration (NEP) in our conifer forest were found during hot and dry years with high atmospheric demand (i.e. high VPD). These years measured the lowest summer LUE (due to decreased GEP) and the lowest summer NEP, consistent with past studies (Griffis et al., 2003; Vargas et al., 2013). Similar LUE reductions were measured at the deciduous forest during the summers of 2012 and 2016, though annual NEP was drastically different due to comparably large decreases in summer and annual RE, not experienced in the conifer forest. Instead, the two drought years were some of the largest annual carbon sinks (greater positive NEP) during the six years of measurements at the deciduous forest. Similar to this study, other research has shown deciduous oak (*Quercus*) forests to be more resilient to drought than their conifer counterparts (Elliot et al., 2015; Wang et al., 2016). Studies have suggested that warm (drought) conditions may lead to reduced carbon uptake or even carbon release (White and Nemani, 2003; Grant et al., 2009; Vargas et al., 2013). Based on our findings, reductions in NEP during expected future intermittent drought conditions in the area could be projected in the evergreen conifer forest, but not in the deciduous broadleaf forest.

Over the measurement period, both forests experienced similar interannual variability in all carbon fluxes (~100 g C m^{-2} yr^{-1}) to that expected in midlatitude forests (Yuan et al., 2009; Desai 2010). In all years the magnitude of GEP and RE were greater in the conifer forest, however, analogous reductions at the deciduous forest led the two forests to have very similar mean annual NEP (despite large annual differences). While evergreen conifer forests have been shown to have lower photosynthetic capacities than deciduous broadleaf forests (Reich et al., 1995; Baldocchi et al., 2010), the longer growing seasons led the conifer forest in this study to have a greater magnitude of annual NEP in half of the years, with drought years being the exceptions. Even in drought years, both the conifer forest and the deciduous forest in our study experienced annual NEP similar to past studies conducted in the temperate region of North America (Barford et al., 2001; Arain and Restrepo-Coupe, 2005; Gough et al., 2013; Xie et al., 2014; Dymond et al., 2016; Oishi et al., 2018). In the coolest year of this study (i.e. 2014), which was closest to the 30-year norm for the area in terms of its mean annual Ta, the two forests experienced similar seasonal and annual carbon uptake and some of the highest daily rates over the 6-year study. This suggests that both forests favor meteorologically "normal" years (comparable to the 30-year mean meteorological conditions), equivalent to the conclusion of Griffis et al. (2003) and Gonsamo et al. (2015). Therefore, under future climates, which are predicted to be warmer compared to the current 30-year norm for the area, the carbon sequestration capacity of both forests may be reduced, although to a lesser effect at TPD.

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4.3 Meteorological Impacts on Water Fluxes

An understanding of WUE is necessary to understand the corresponding release of water vapor (ET) to the atmosphere on seasonal and annual time scales. On average, our conifer forest had greater annual ET and less variability than the deciduous forest. However, we found conflicting results between sites in regards to annual ET during drought years (mainly 2016). At both sites, ET was shown to be strongly driven by Ta. ET in 2012 was the highest of all years following amplified Ta for most of the year. Much like RE, ET responds year-round (with summer maxima), so warmer spring or autumn periods often lead to annual increases in ET (Schwartz et al., 2006; Taylor et al., 2008). Similarly, in the deciduous forest, annual ET was heightened during the hot and dry year of 2016. The characteristic amplification of both Ta and VPD during warm drought years led the years with the lowest mean summer $\theta_{0\text{-}30cm}$ and highest summer Ta (or VPD) to experience increased annual ET at the deciduous forest. A contrasting ET response was measured in the coniferous forest, as 2016 had the lowest annual ET, the only year where the annual conifer ET was lower than that of the deciduous forest ET.

Typically, transpiration is beneficial to plants, helping to cool leaves and thereby reducing respiration (Rambal et al., 2003; Baldocchi et al., 2010; Brummer et al., 2012). In our case, high summer Ta, the lowest $\theta_{0\text{-}30cm}$, and very little summer and annual P (input) into the system, significantly reduced ET, while RE continued to rise. At the conifer forest, the timing of summer P events appeared to influence ET (i.e. 2013). However, it is likely that the opposing responses of ET to soil water availability between sites was due to the ability of each forest to access deep soil water storages. Studies have shown oak (*Quercus*) forests to be less sensitive and more resilient to drought, due to more efficient access to deeper soil water, than conifer forests (Bréda et al., 2006; Bonan et al., 2008; Wang et al., 2016; Matheny et al., 2017). Evergreen conifer forests may have roots extending just as deep as deciduous broadleaf forests, but they are not as effective at obtaining water as broadleaf trees (Oren and Pataki, 2001). With higher atmospheric demand during dry periods often leading to greater ET across many forest types (Meinzer et al., 2013; Wu et al., 2013; Tang et al., 2014), the access and availability of water in deep soil layers allowed the deciduous forest to sustain high ET, even in drought years.

We found the course of annual WUE of both forests to respond similarly across all years, though variations in GEP and ET between the forests led to seasonal WUE differences due to the aforementioned responses of both fluxes. The WUE at the conifer forest was consistent with previously reported values for that location (Brummer et al., 2012; Skubel et al., 2015), while the deciduous forest WUE was found to be higher than a regionally similar oak-dominated forest in Ohio (Xie et al., 2016). Assuming similar daily rates of carbon assimilation (GEP), higher WUE implies a higher evapotranspiration flux at the conifer forest (Augusto et al., 2015), which we saw.

4.4 Forest Management and Future Climate Impacts

Forest age, management practices, and historical land-use have been shown to impact annual carbon fluxes within forests (Wofsy et al., 1993; Song and Woodcock, 2003). While our forests are of relatively similar age (~80-90 years), they have experienced different management practices over their lifetime so far, with the coniferous forest being a planted forest that

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underwent low density partial thinning in 1983 and 2012, while the deciduous broadleaf forest was naturally regenerated with periodic selective harvesting in the past. The difference in carbon uptake over the forest's life will be influenced by management treatments (Herbst et al., 2015). Some studies (Zha et al., 2009; Dore et al., 2012; Skubel et al., 2017) have suggested that overall forest carbon and water fluxes recover rapidly post-disturbance. Furthermore, some studies have found a positive correlation between species number and productivity in temperate forests (Morin et al., 2011). Similarly, mixed forests are generally assumed to be more resilient to extreme weather events and disturbance events than mono-specific forest stands (Pretzsch, 2014; Herbst et al., 2015). With a greater number of species in our deciduous broadleaf forest (500+ tree & plant species, as per Elliot et al., 1999), and the resistance to heat and drought induced carbon losses shown in this study, it is likely that the deciduous broadleaf forest will remain a carbon sink well into the future. Even following increased RE losses expected with warmer late-summer and autumn conditions (Dunn et al., 2007; Piao et al., 2008), such as those experienced in 2016 and 2017 at our site, the conclusions remain the same.

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For similar forest types, the annual responses of GEP and RE to local meteorology will affect natural and managed forests similarly, however it has been proposed that many managed forests may already be maximized for a given Ta regime, leaving less room for adaptability or acclimation in the future (Litton and Giardina, 2008; Chen et al., 2014; Noormets et al., 2015). With RE shown to be higher in managed forests compared to natural forests (Arain and Restrepo-Coupe, 2005), it is possible that our conifer forest may see limitations in the annual carbon sequestration capability in the future. With considerable daily RE losses experienced following summer P events (i.e. 2013 & 2014), enough hot periods with intermittent heavy rains in the future could cause forest RE to exceed in the conifer forest. As the climate continues to change, the management practices and responses to meteorological conditions will determine the relative carbon sink or source strength in many temperate forests.

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5 Conclusions

The annual carbon and water dynamics were compared between two forests of different leaf-strategy in the Great Lakes region of southern Ontario, Canada, over a 6-year (2012 to 2017) period. The geographic location, forest age, soil characteristics, and climate were similar in both stands, where one was an evergreen needleleaf conifer plantation while the other was a naturally regenerated deciduous broadleaf forest. Management treatments were applied in both forests. On average, the evergreen conifer forest was a greater carbon sink (218 ± 109 g C m^{-2} yr^{-1}) with higher annual ET (442 ± 33 mm yr^{-1}) than the deciduous broadleaf forest (200 ± 83 g C m^{-2} yr^{-1} & 388 ± 34 mm yr^{-1}, respectively). While mean annual fluxes were similar in magnitude and variation, differences were measured between sites, especially during drought years. Summer meteorology was shown to impact fluxes at both sites, though to varying degrees with varying responses. Annual NEP was reduced at the deciduous forest during years with increased summer RE. Similarly, annual ET at the deciduous forest was driven by changes in Ta, with the largest annual ET measured in the warmest years. During droughts, the carbon and water fluxes of the deciduous forest were less sensitive to changes in temperature or water availability. The annual NEP at the conifer forest was ultimately shaped by total summer NEP. The significant response of the conifer forest to heat and drought events led the summer months in all years

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to greatly control the forests annual carbon sink-source status. Additionally, prolonged dry periods with increased Ta were shown to greatly reduce ET (i.e. 2016). Both sites saw average ET, but increased NEP (against the 6-year study mean) during climatologically (30-year mean) 'normal' years, but only the conifer forest saw annual reductions in carbon sequestration during drought years. We also found that drought-induced RE increases or GEP decreases may impact the overall net carbon uptake in the coniferous stand. Our study suggests that the deciduous forest will continue to be a net carbon sink under increased temperatures and larger variability in precipitation under future climate changes, while the response of the coniferous forest will continue to remain uncertain.

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Data availability. The data presented in this study are available at: http://dx.doi.org/10.17190/AMF/1246152 (deciduous forest) and http://dx.doi.org/10.17190/AMF/1246012 (coniferous forest).

Author contributions. ERB collected, cleaned, and processed the data with help from JJB and BMB. ERB, MAA, and MK designed the experiment, with grants received by MAA. ERB and JJB performed the statistical analyses. ERB interpreted the data, prepared the figures, and wrote the manuscript with editorial contributions from all authors.

Competing interests. The authors declare no competing interests.

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Table 1. Site characteristics of the deciduous (TPD) and coniferous (TP39) forest stands. The TP39 values in brackets indicate pre-thinning (2003 – 2011) values, prior to the period of focus.

	Turkey Point 1939 (TP39)	Turkey Point Deciduous (TPD)
	42.71°N, 80.357°W	42.635°N, 80.558°W
Stand Previous Land Use	Afforested on oak savanna, cleared for afforestation	Naturally regenerated on abandoned agricultural land
Age (in 2017)	78 years	70 – 110 years
Elevation (m)	184	265
DBH (cm)	39.0 (37.2)	23.1
Density (trees ha^{-1})	321 (413)	504
Tree Height (m)	23.4 (22.9)	25.7
LAI (m^2 m^{-2})	5.3 (8.5)	8.0
Dominant Species	*Pinus Stobus L.*	*Quercus Alba*
Secondary & Understory	*Abies Balsamea, Q. Velutina, A. Rubrum, Prunus Serotina*	*Acer Saccharum, A. Rubrum, Fagus Grandifolia, Q. Velutina, Q. Rubra, Fraxinus Americana*
Ground	*M. Canadense, Rubus Spp., Rhus Radicans, Ferns, Mosses*	*Maianthemum Canadense, Aplectrum Hyemale, Equisetum*
Soil		
Drainage	Well-drained	Rapid to well-drained
Classification	Brunisolic grey brown luvisol	Brunisolic grey brown luvisol
Texture	Very fine sandy-loam	Predominantly sandy
Bulk Density (kg m^{-3})	1.35 g m^{-3}	1.15 g m^{-3}

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Table 2. The top section of the table contains the annual calculated phenological dates (reported as day of year) for both the conifer (TP39, **bolded C**) and deciduous (TPD, *italicized D*) forests from year 2012 to year 2017. Phenological dates were calculated following Gonsamo et al. (2013) from eddy covariance measured GEP_{Max} data. The six-year mean values and standard deviations are included in the final column. The resulting phenological periods (seasons) and their duration in days are also shown, in the lower section of the table.

Phenology Transition Dates		**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**
Start of Season (SOS, bud-break)	**C**	**70**	**96**	**96**	**91**	**74**	**79**	**84 ± 12**
	D	*120*	*116*	*127*	*118*	*126*	*125*	122 ± 5
Mid of Greenup (MOG, fastest green-up)	**C**	**119**	**137**	**132**	**122**	**127**	**130**	**128 ± 7**
	D	*136*	*141*	*148*	*136*	*144*	*147*	*142 ± 5*
End of Greenup (EOG, end of leaf-out)	**C**	**147**	**160**	**153**	**140**	**158**	**159**	**153 ± 8**
	D	*145*	*155*	*160*	*146*	*154*	*159*	*153 ± 6*
Peak of Season (Midpoint between EOG & SOB)	**C**	**214**	**205**	**202**	**193**	**212**	**201**	**204 ± 8**
	D	*198*	*199*	*205*	*193*	*203*	*207*	*201 ± 5*
Start of Browndown (SOB, start of senescence)	**C**	**271**	**258**	**258**	**257**	**270**	**248**	**260 ± 9**
	D	*257*	*249*	*255*	*249*	*262*	*261*	*255 ± 6*
Mid of Browndown (MOB, fastest senescence)	**C**	**287**	**292**	**287**	**289**	**305**	**287**	**291 ± 7**
	D	*275*	*273*	*274*	*271*	*286*	*282*	*277 ± 6*
End of Season (EOS)	**C**	**314**	**351**	**338**	**345**	**366**	**354**	**345 ± 17**
	D	*306*	*314*	*307*	*309*	*328*	*318*	*314 ± 8*
Phenologically-Defined Seasons		**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**
Spring (EOG – SOS)	**C**	**78**	**64**	**58**	**48**	**84**	**80**	**69 ± 14**
	D	*25*	*39*	*34*	*28*\	*28*	*34*	*31 ± 5*
Summer (SOB – EOG) (LOCC, Length of Canopy Closure)	**C**	**124**	**97**	**105**	**117**	**112**	**89**	**107 ± 13**
	D	*112*	*94*	*95*	*103*	*107*	*102*	*102 ± 7*
Autumn (EOS – SOB)	**C**	**43**	**94**	**80**	**89**	**96**	**106**	**85 ± 22**
	D	*49*	*65*	*52*	*61*	*67*	*57*	*58 ± 7*
Length of Growing Season (LOS)	**C**	**245**	**255**	**242**	**254**	**292**	**275**	**260 ± 19**
	D	*186*	*198*	*180*	*191*	*202*	*193*	*192 ± 8*

Table 3. Seasonal and annual sums of eddy covariance (EC) measured carbon (GEP, RE, and NEP, g C m^{-2} yr^{-1}) and water fluxes (ET, mm yr^{-1}) from 2012 to 2017 for both the conifer (TP39, **bolded C**) and deciduous (TPD, *italicized D*) forests. The phenologically-defined seasonal dates were calculated using the timing of transitions in phenological dates, outlined in Table 2. The six-year mean and standard deviations are also included for each row.

	Season		2012	2013	2014	2015	2016	2017	Mean
GEP Sum	Jan 1 to SOS	--	--	--	--	--	--	--	--
	Spring (SOS to EOG)	**C**	**308**	**306**	**279**	**213**	**359**	**418**	**314 ± 70**
		D	*104*	*197*	*165*	*117*	*129*	*174*	*148 ± 36*
	Summer (EOG to SOB)	**C**	**990**	**942**	**1070**	**1160**	**1014**	**930**	**1018 ± 86**
		D	*942*	*949*	*1023*	*1006*	*1084*	*1070*	*1012 ± 59*
	Autumn (SOB to EOS)	**C**	**132**	**264**	**265**	**340**	**249**	**377**	**271 ± 85**
		D	*147*	*239*	*200*	*240*	*219*	*213*	*210 ± 34*
	EOS to Dec 31	--	--	--	--	--	--	--	--
	Annual	**C**	**1452**	**1501**	**1601**	**1701**	**1617**	**1709**	**1597 ± 104**
		D	*1198*	*1369*	*1382*	*1347*	*1420*	*1447*	*1360 ± 87*
RE Sum	Jan 1 to SOS	**C**	**66**	**83**	**78**	**79**	**82**	**81**	**78 ± 6**
		D	*167*	*107*	*129*	*109*	*163*	*170*	*141 ± 30*
	Spring (SOS to EOG)	**C**	**205**	**205**	**169**	**122**	**233**	**276**	**202 ± 53**
		D	*78*	*151*	*133*	*109*	*109*	*144*	*121 ± 27*
	Summer (EOG to SOB)	**C**	**908**	**718**	**809**	**790**	**888**	**735**	**808 ± 78**
		D	*500*	*672*	*581*	*714*	*684*	*700*	*642 ± 84*
	Autumn (SOB to EOS)	**C**	**142**	**272**	**269**	**310**	**302**	**434**	**288 ± 94**
		D	*138*	*269*	*196*	*259*	*266*	*252*	*230 ± 52*
	EOS to Dec 31	**C**	**77**	**14**	**33**	**39**	**--**	**13**	**35 ± 26**
		D	*82*	*64*	*84*	*110*	*55*	*65*	*77 ± 20*
	Annual	**C**	**1386**	**1282**	**1345**	**1328**	**1492**	**1525**	**1393 ± 96**
		D	*954*	*1250*	*1110*	*1283*	*1260*	*1317*	*1196 ± 138*
NEP Sum	Jan 1 to SOS	**C**	**-58**	**-74**	**-68**	**-73**	**-66**	**-66**	**-67 ± 6**
		D	*-117*	*-79*	*-88*	*-82*	*-129*	*-130*	*-104 ± 24*
	Spring (SOS to EOG)	**C**	**103**	**101**	**110**	**92**	**128**	**144**	**113 ± 19**
		D	*25*	*45*	*30*	*4*	*18*	*29*	*25 ± 14*
	Summer (EOG to SOB)	**C**	**80**	**223**	**262**	**374**	**127**	**196**	**210 ± 104**
		D	*442*	*276*	*441*	*288*	*398*	*371*	*369 ± 73*
	Autumn (SOB to EOS)	**C**	**-12**	**-5**	**-6**	**33**	**-48**	**-51**	**-15 ± 31**
		D	*16*	*-26*	*4*	*-18*	*-46*	*-37*	*-18 ± 24*
	EOS to Dec 31	**C**	**-35**	**-12**	**-30**	**-24**	**--**	**-12**	**-23 ± 10**
		D	*-68*	*-56*	*-79*	*-103*	*-51*	*-58*	*-69 ± 19*
	Annual	**C**	**76**	**228**	**263**	**395**	**139**	**208**	**218 ± 109**
		D	*292*	*156*	*305*	*90*	*185*	*169*	*200 ± 83*
ET Sum	Jan 1 to SOS	**C**	**22**	**23**	**11**	**19**	**13**	**15**	**17 ± 5**
		D	*56*	*28*	*33*	*24*	*39*	*44*	*37 ± 12*
	Spring (SOS to EOG)	**C**	**105**	**97**	**67**	**65**	**85**	**106**	**87 ± 18**
		D	*36*	*55*	*45*	*31*	*39*	*48*	*42 ± 9*
	Summer (EOG to SOB)	**C**	**315**	**277**	**260**	**286**	**249**	**210**	**266 ± 36**
		D	*283*	*231*	*213*	*219*	*266*	*237*	*242 ± 27*
	Autumn (SOB to EOS)	**C**	**43**	**73**	**82**	**67**	**64**	**97**	**71 ± 18**
		D	*45*	*63*	*50*	*66*	*69*	*64*	*60 ± 9*
	EOS to Dec 31	**C**	**15**	**2**	**6**	**4**	**--**	**3**	**6 ± 5**
		D	*14*	*9*	*12*	*14*	*11*	*15*	*12 ± 2*
	Annual	**C**	**495**	**468**	**421**	**436**	**408**	**424**	**442 ± 33**
		D	*428*	*381*	*350*	*349*	*417*	*403*	*388 ± 34*

Table 4. Select linear relationships between total annual water (ET, mm yr^{-1}) and carbon (RE and NEP, g C m^{-2} yr^{-1}) flux measurements and both meteorological (i.e. VPD, Ta, $\theta_{0\text{-}30cm}$) and phenological (i.e. spring length, carbon uptake start) variables (annual or seasonal) from 2012 to 2017. In each section, the R^2 is for the relationship to the specified annual flux.

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Conifer	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**R^2**
Annual RE (g C m^{-2} yr^{-1})	1386	1282	1345	1328	1492	1525	--
Summer $\theta_{0\text{-}30cm}$ (m^3 m^{-3})	0.083	0.097	0.090	0.096	0.071	0.076	0.89
Annual NEP (g C m^{-2} yr^{-1})	76	228	263	395	139	208	--
Spring Length (Days)	78	64	58	48	84	80	0.75
Summer Ta (°C)	21.1	20.3	19.9	20.0	21.1	20.7	0.73
Summer NEP (g C m^{-2})	80	223	262	374	127	196	0.99

Deciduous	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**R^2**
Annual ET (mm yr^{-1})	428	381	350	349	417	403	--
Annual Ta (°C)	11.8	9.2	8.0	9.2	10.6	10.0	0.84
Winter $\theta_{0\text{-}30cm}$ (m^3 m^{-3})	0.131	0.118	0.116	0.101	0.133	0.127	0.83
Annual RE (g C m^{-2} yr^{-1})	954	1250	1110	1283	1260	1317	--
Spring Ta (°C)	16.6	15.1	16.1	15.1	15.6	14.0	0.77
Annual NEP (g C m^{-2} yr^{-1})	292	156	305	90	185	169	--
Summer RE (g C m^{-2})	500	672	581	714	684	700	0.80

Table 5. Results of the two-step parameterization process used to explore interannual differences in controlling meteorological variables (i.e. Ta, VPD, PAR, $\theta_{0\text{-}30cm}$) and their impacts on annual RE and GEP during the phenological summer (end of greenup to the start of browndown) for the coniferous and deciduous forests from 2012 to 2017. These normalized values show the cumulative effect of the meteorological variable in reducing GEP and RE from their theoretical maximum values. Higher values (closer to 1) represent more favorable summer conditions for GEP and RE.

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Conifer	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
GEP: Ta	0.994	0.990	0.987	0.981	1.00	0.997
GEP: VPD	0.939	1.00	1.00	0.981	0.914	0.975
GEP: PAR	0.949	0.950	0.946	0.956	1.00	0.950
GEP: $\theta_{0\text{-}30cm}$	0.956	1.00	0.998	0.993	0.976	0.973
GEP: All	0.846	0.941	0.932	0.914	0.892	0.899
RE: $\theta_{0\text{-}30cm}$	0.958	1.00	0.996	0.991	0.968	0.965

Deciduous	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
GEP: Ta	1.00	0.971	0.974	0.967	0.989	0.974
GEP: VPD	0.871	1.00	0.998	0.998	0.946	0.989
GEP: PAR	0.978	0.938	0.955	0.953	1.00	0.956
GEP: $\theta_{0\text{-}30cm}$	1.00	1.00	1.00	1.00	1.00	1.00
GEP: All	0.852	0.911	0.929	0.920	0.936	0.920
RE: $\theta_{0\text{-}30cm}$	0.976	1.00	0.997	1.00	0.965	0.992

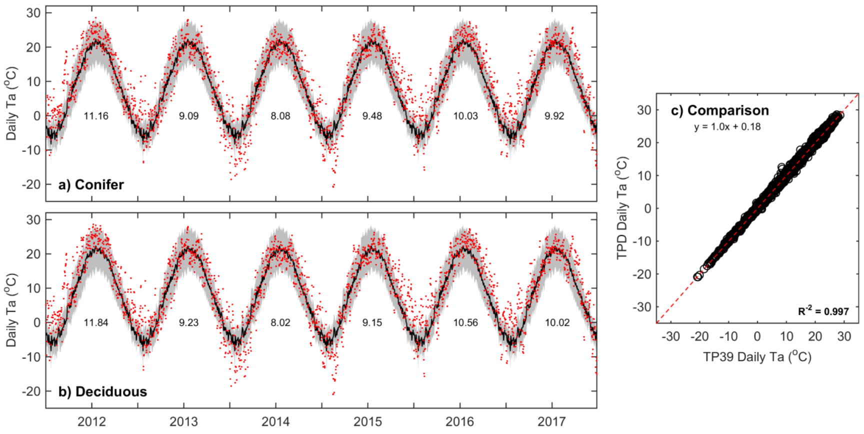

Figure 1. Daily above canopy air temperature (Ta, red dots) measured from 2012 to 2017 at the (a) conifer forest (TP39) and (b) deciduous forest (TPD), with the grey shading and black line corresponding to the 30-year Environment Canada (Delhi station) minimum and maximum range of daily Ta and mean daily Ta, respectively. Values shown represent the annual mean Ta for each year of measurements. Also included is the (c) comparison of daily Ta at TP39 and TPD.

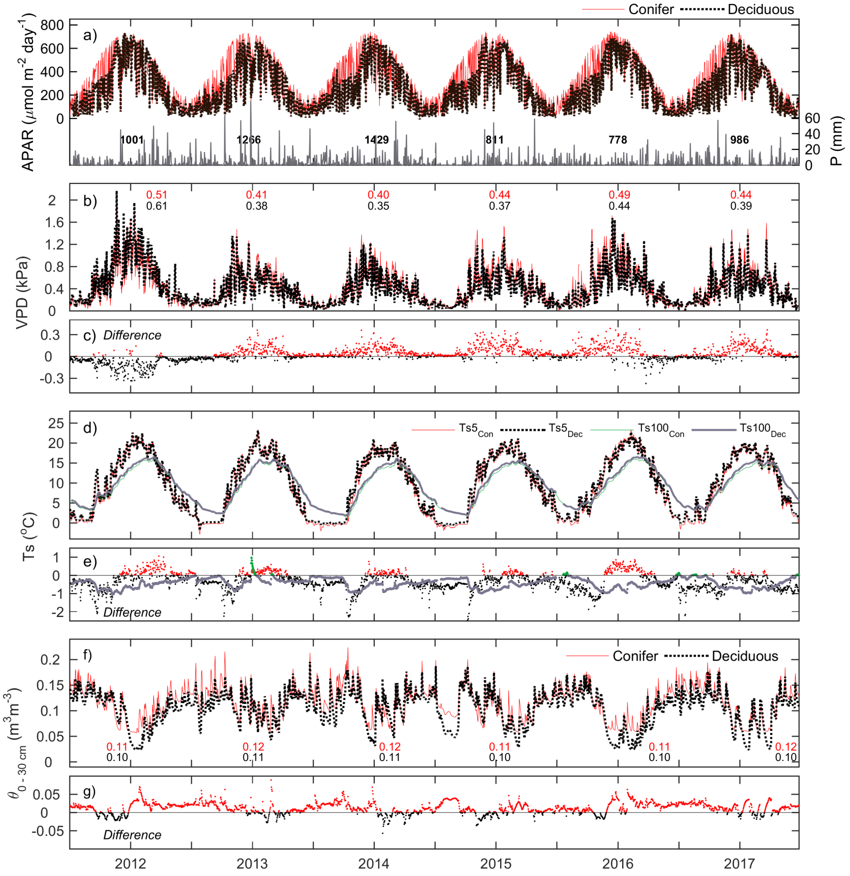

Figure 2. Time series of daily mean meteorological variables measured at the conifer (TP39, red line) and deciduous (TPD, black dashed line) forests from 2012 to 2017, including: (a, left) absorbed photosynthetically active radiation (APAR), (a, right) total precipitation (P), (b) vapor pressure deficit (VPD), (c) the difference in VPD between the two forests (conifer – deciduous), (d) soil temperatures (Ts) at 5 cm and 100 cm depths, (e) the difference in Ts at both depths, (f) soil volumetric water content from 0-30 cm depths ($\theta_{0\text{-}30cm}$), and (g) the difference in θ between the two forests.

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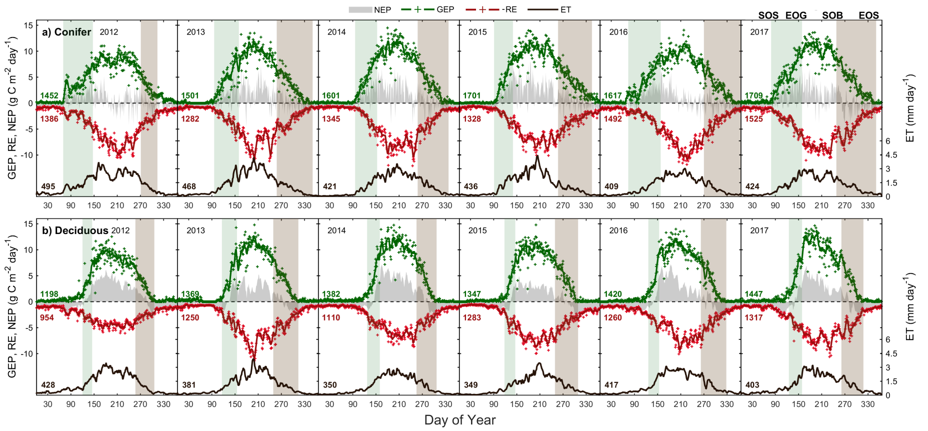

Figure 3. Time series from 2012 to 2017 of the daily total gross ecosystem productivity (GEP, green +), ecosystem respiration (RE, red +), net ecosystem productivity (NEP, grey shading), and evapotranspiration (ET, black [right]) for the (a) conifer forest (TP39), and the (b) deciduous forest (TPD). Solid lines of GEP, RE, NEP, and ET are derived from 5-day moving averages of the measured data, while the colored values for each year correspond to annual GEP (green), RE (red), and ET (black) for each site. The annual EC-derived phenological spring (green shading) and autumn (brown shading) are included for each site, and can be found in Table 2.

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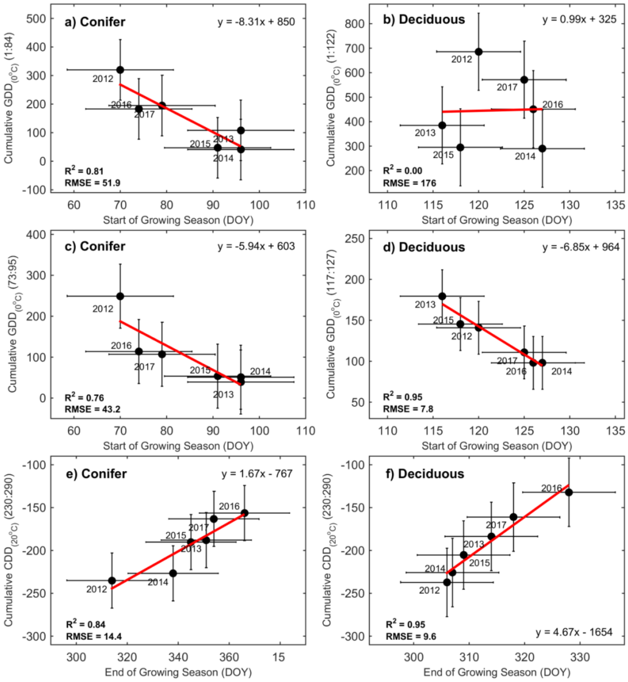

Figure 4. Correlations between growing degree days (GDD), cooling degree days (CDD) and phenological start of the growing season (SOS) and end of the growing season (EOS) from 2012 to 2017 at both the conifer and deciduous forests. Shown are: (a) cumulative GDD from January 1st to the mean SOS at TP39 and (b) TPD, (c) cumulative GDD from the mean SOS ± standard deviation at TP39 and (d) TPD, and (e) the cumulative CDD from DOY 230:290 at TP39 and (f) TPD. Error bars represent the standard deviation of the data, with R^2, RMSE, and linear fit equations included for each correlation.

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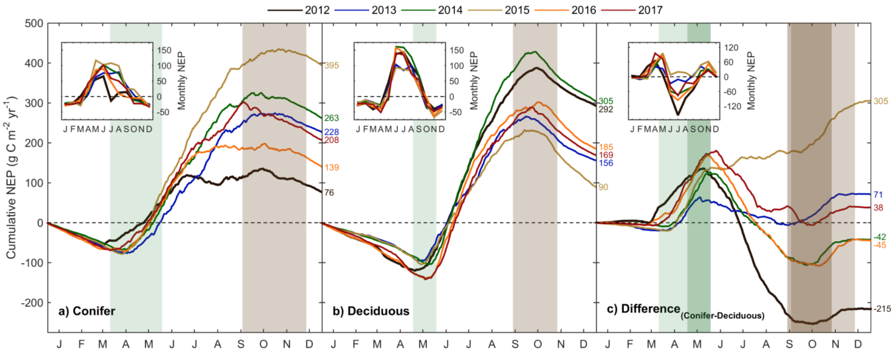

Figure 5. Cumulative daily sums of net ecosystem productivity (NEP) at the (a) conifer forest (TP39), the (b) deciduous forest (TPD), and (c) the cumulative difference (conifer – deciduous), with appropriate monthly NEP sums in each figure inset, from 2012 to 2017. Green shading in each panel corresponds to the site-specific 6-year mean phenological spring duration, while brown shading corresponds to the 6-year mean phenological autumn duration (Table 2). Dark shading in panel (c) represents the deciduous forest seasons overlaid on the conifer seasons. Cumulative annual values are shown for each site and year, with colors found in the key.

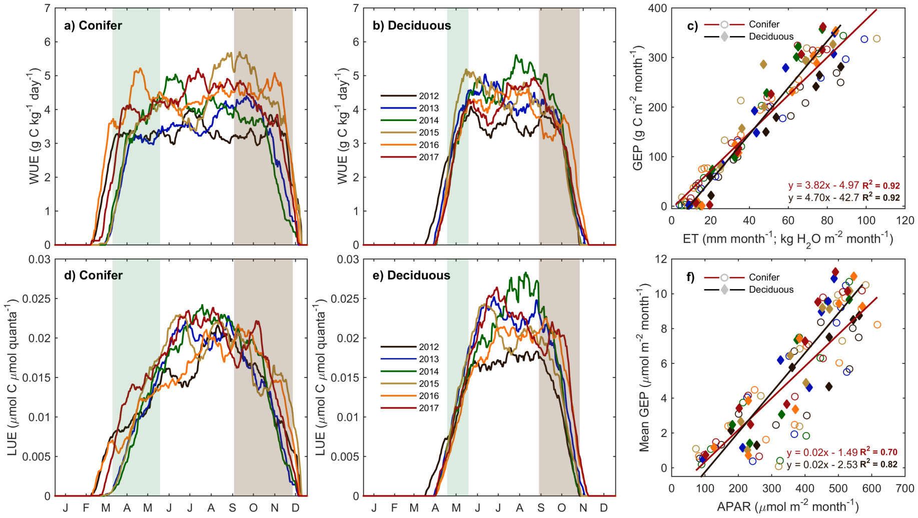

Figure 6. Annual smoothed (1-month moving average) time series of the (a) conifer (TP39) and (b) deciduous forest water use efficiency (WUE; GEP ET^{-1}), and (c) monthly linear relationships between GEP and ET at both sites from 2012 to 2017. Similarly, light use efficiency (LUE; GEP APAR^{-1}) calculations are shown for (d) the conifer and (e) deciduous forests, with linear relationships (f) of monthly GEP and APAR also shown. Green and brown shading corresponds to site-specific 6-year mean phenological spring and autumn periods (Table 2), respectively. Linear fit equations and R^2 values also shown (c & f).

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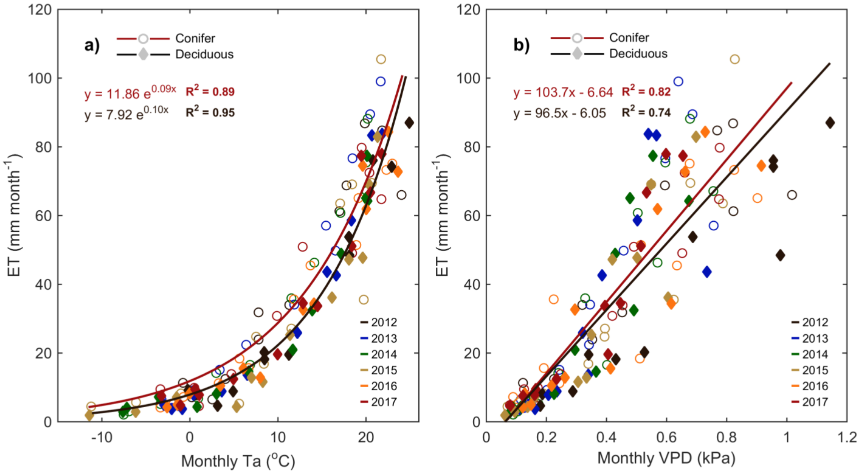

Figure 7. (a) Monthly exponential relationships between monthly mean air temperature (Ta) and total monthly evapotranspiration (ET) from 2012 to 2017 for the conifer (TP39, open circle) and deciduous (TPD, diamond) forests. Also shown are the six-year (b) linear relationships between monthly mean vapor pressure deficit (VPD) and monthly ET. Fit equations and R^2 also shown.

Table A1. Descriptions of the eddy covariance (EC) instrumentation and meteorological sensors used at both sites during the period of measurements. *Note: IRGA = infrared gas analyzer*

	Turkey Point 1939 (TP39)	Turkey Point Deciduous (TPD)
Canopy IRGA	LI-7000 (LI-COR)	LI-7200 (LI-COR)
Sonic Anemometer	CSAT3 (CSI)	CSAT3 (CSI)
Height	28 m (2003 – May 2016) 34 m (May 2016 – Present)	36 m (2012 – Present)
Orientation	Oriented west (270°)	Oriented west (270°)
Intake Tube	4 m long intake tube	1 m long intake tube
Flow	15 L/min	15 L/min
Mid-Canopy IRGA	LI-800 (LI-COR) Measured at 14 m height	LI-820 (LI-COR) Measured at 16 m height
Air Temperature (Ta) Relative Humidity (RH)	HMP45C (CSI)	HMP155A (CSI)
Wind Speed & Direction	Model 05103 (R.M. Young)	Model 85000 (2012 – 2015) Model 05013 (2015 – Present)
Photosynthetically Active Radiation (PAR)	PAR-Lite (Kipp & Zonen)	PQSI (Kipp & Zonen)
Net Radiation (Rn)	CNR1 (Kipp & Zonen)	CNR4 (Kipp & Zonen)
Soil Temperature (Ts)	107B (CSI)	107B (CSI)
Soil Water Content (θ)	CS615-L/CS616 (CSI)	CS650 (CSI)
Precipitation (P)	T-200B (GEONOR)	CS700H-L (CSI)