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Site C Climate & Air Quality Monitoring Annual Report 2015

Fort St. John, BC

Final Report

RWDI # 0920007A
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SUBMITTED TO

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1. INTRODUCTION

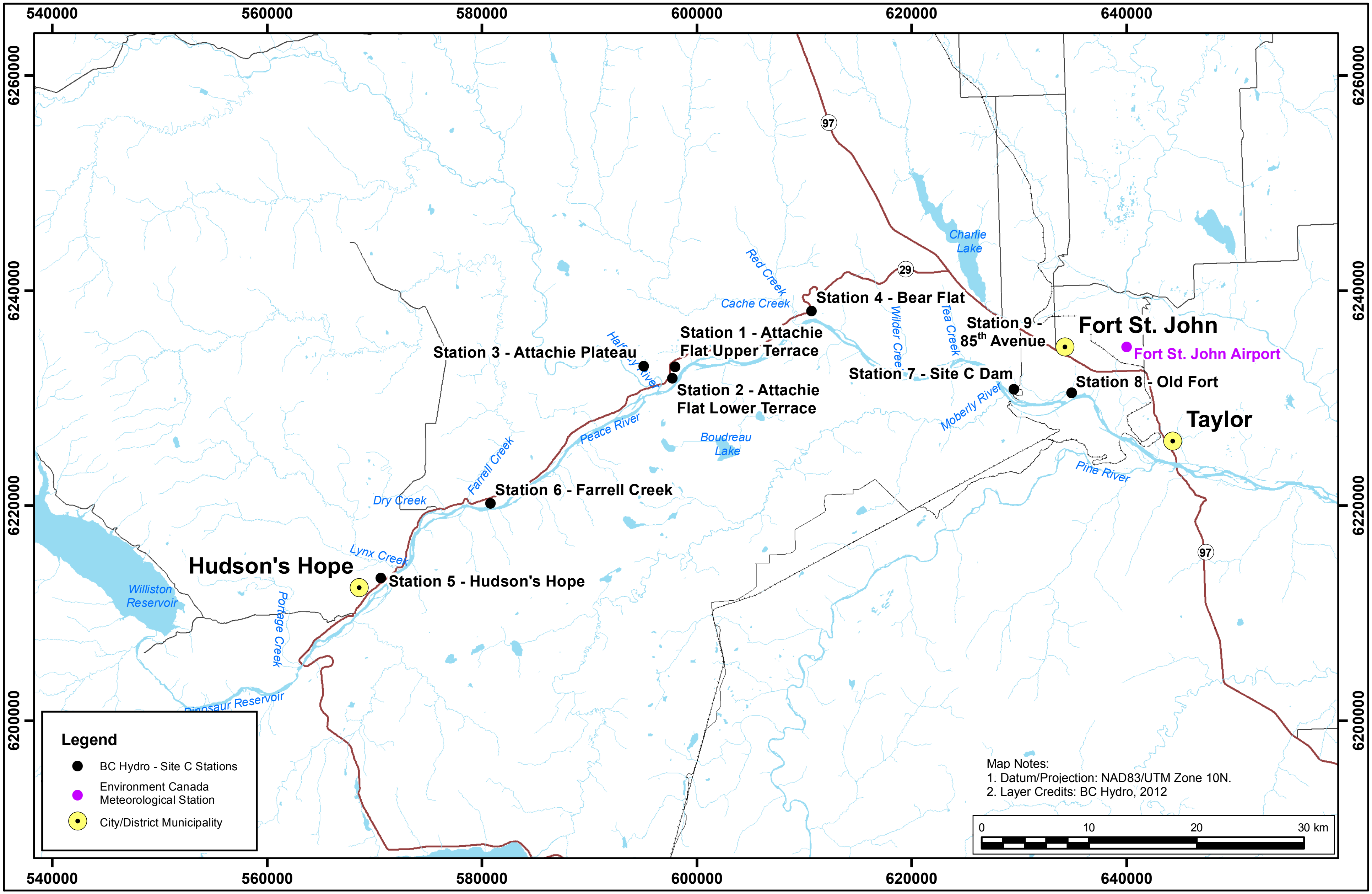
BC Hydro's Site C Clean Energy Project (the Project) in British Columbia's Peace region aims to create a new hydroelectric dam on the Peace River in the vicinity of the city of Fort St. John. A modelling study of the effects of the new dam and associated reservoir would have on the local and regional climate (termed "microclimate") was required as part of the environmental impact assessment process. To characterize the current microclimate and to provide a baseline against which to compare future changes brought on as a result of the Project, BC Hydro installed a network of monitoring stations in the Peace River Valley. This network has been active since 2011. A technical data report (TDR) (RWDI AIR Inc. 2012) containing a section discussing the area's microclimate was released in December 2012. Therein, results from the network's first year of observations, from January 16, 2011 to January 15, 2012, were discussed. Three subsequent annual monitoring reports describing the state of the climate and air quality for the years of observations, coinciding with the 2012, 2013 and 2014 calendar years were released since then (RWDI AIR Inc. 2015a, 2015b, 2015c). The network has remained in operation and has continued to collect valuable climate data in the Peace region.

This document serves to similarly describe the state of the climate and air quality for the fifth year of observations, coinciding with the 2015 calendar year. This will allow for comparisons to the previous data collected by the network and to 30-year climate normals from the Environment Canada station at Fort St John Airport (EC, 2012). Parameters such as temperature, relative humidity, precipitation, wind speed and direction, soil temperature, soil volumetric water content and particulate matter (PM) are presented below.

2. MONITORING NETWORK

Figure 2-1 shows the location of the network stations in relation to local communities and the Peace River. Table 2-1 and Table 2-2 show locations and parameters measured at these stations. Note that Station 5 was decommissioned on June 22, 2015. Instruments from Station 5 were used to upgrade Station 6 from wind monitoring only to a full meteorological station. The upgrade took place on September 23, 2015.

Tipping bucket precipitation gauges were replaced with weighing precipitation gauges (Ott Pluvio 2) at Station 2, Station 3, Station 4 and Station 7 in late September and early October. The tipping bucket precipitation gauge co-located with the existing Station 1 weighing precipitation gauge was removed and the latter was relocated to the concrete base originally intended for the former. A weighing precipitation gauge was also installed at Station 6 when it was upgraded.



Map of Station Locations in the Site C Climate Monitoring Network

True North

Drawn by: DJH	Figure: 2-1
Approx. Scale:	1:500,000
Date Revised:	May 17, 2016

RWDI

Site C Climate Report - Peace Region, BC

Project #0920007A

Table 2-1: BC Hydro Site C network station locations and elevations

Station	UTM NAD 83 (m)	Latitude, Longitude (decimal degrees)	Elevation (m)
Station 1 - Attachie Flat Upper Terrace	597983 E, 6232938 N	56.23N, -121.41W	479
Station 2 – Attachie Flat Lower Terrace	597721 E, 6231898 N	56.22N, -121.42W	441
Station 3 – Attachie Plateau	595065 E, 6233032 N	56.23N, -121.46W	645
Station 4 – Bear Flat	610669 E,6238135 N	56.27N, -121.21W	474
Station 5 – Hudson's Hope(1)	570577 E, 6213303 N	56.05N, -121.86W	514
Station 6 – Farrell Creek	580779 E, 6220238 N	56.12N, -121.70W	471
Station 7 – Site C Dam	629517 E, 6230875 N	56.20N, -120.91W	607
Station 8 – Old Fort	634890 E, 6230532 N	56.20N, -120.82W	423
Station 9 – 85th Avenue	633033 E, 6233949 N	56.23N, -120.85W	686
Fort St. John Airport (Environment Canada)	640053 E, 6234872 N	56.24N, -120.74W	695

Notes: (1): Measurements at Station 5 discontinued as of June 22, 2015

Table 2-2: BC Hydro Site C network stations and the Fort St. John Airport Environment Canada station with parameters measured

Station	Air Temp. and RH	Wind Speed and Direction	Precipitation	Barometric Pressure	All Radiation Components	Solar Radiation	Turbulent Fluxes	Visibility	Soil Temperature	Soil Moisture	Soil heat Flux	PM
Station 1 – Attachie Flat Upper Terrace	X	X	X(3)	X	X		X	X	X	X	X	X
Station 2 – Attachie Flat Lower Terrace	X	X	X(4)	X	X		X		X	X	X	
Station 3 – Attachie Plateau	X	X	X(5)	X		X						
Station 4 – Bear Flat	X	X	X(4)	X	X		X		X	X	X	
Station 5 – Hudson's Hope(1)	X	X	X	X		X						
Station 6 – Farrell Creek(2)	X(2)	X	X(2)	X(2)		X(2)						
Station 7 – Site C Dam	X	X	X(5)	X		X						
Station 8 – Old Fort												X
Station 9 – 85th Avenue		X										X
Fort St. John Airport (Environment Canada)	X	X	X	X								

Notes: (1): Station 5 decommissioned on June 22, 2015
(2): Station 6 upgraded on September 23, 2015
(3): Tipping bucket precipitation gauge decommissioned on September 25, 2015
(4): Tipping bucket precipitation gauge upgraded to weighing precipitation gauge on September 29, 2015
(5): Tipping bucket precipitation gauge upgraded to weighing precipitation gauge on October 19, 2015

2.1 Data Collection and Quality Assurance / Quality Control (QA/QC)

Data from the Site C network stations were remotely downloaded to RWDI servers using Campbell Scientific's Loggernet software over cellular and satellite modem connections at the following intervals:

- Stations with AC power (Stations 1, 8 and 9) had download intervals of one hour whereas solar powered stations (Station 2, Station 3, Station 5, Station 6, Station 7) had their data collected on a daily interval to preserve battery power at the stations.
- Station 4 was connected to AC power but also used a satellite modem connection. Downloads from Station 4 were conducted on a daily basis to reduce connection charges.

Quality control was carried out on the data three times per week. This involved running a Mathworks Matlab script which identifies and alerts the operator of missing or duplicate timestamps, data out of range and other anomalous readings (e.g. large spikes in particulate matter).The script then plots the data over the past month and the past 14 days to allow for a visual inspection so the operator can detect anomalous trends or data outliers. This frequency of QA was maintained to allow rapid detection and repair of any instrumental breakdown.

A second QA/QC operation was conducted on a monthly basis to remove or flag any anomalous data points. Corrections were also applied to the data where appropriate. For example, precipitation was set to 0 mm when a large value was recorded on the same hour that maintenance was performed on the precipitation gauge in question.

3. RESULTS

The year of results discussed in this report corresponds to the 2015 calendar year. Table 3-1 provides a summary of some of the parameters discussed in this report as well as 30-year climate normals from Fort St. John Airport for the period from 1981 to 2010. Climate normals are calculated from 30 year records of meteorological observations of wind speeds, temperature, precipitation and other related weather conditions at the location of interest. They are provided by Environment Canada and updated on a 10-year basis. The period from 1981-2010 is the most recent period for which Environment Canada climate normals are available.

Table 3-1: Summary of measured climate parameters during 2015 and comparison with climate normals

Data Record	Mean Temp (°C)	Maximum Temp (°C)	Minimum Temp (°C)	Total Annual Precipitation (mm)	Mean wind speed (m/s)
Station 1 – Attachie Flat Upper Terrace	4.1	33.4	-33.5	342.4	2.3
Station 2 – Attachie Flat Lower Terrace	3.7	31.8	-34.7	331.7	2.1
Station 3 – Attachie Plateau	4.2	29.9	-35.3	324.7	2.6
Station 4 – Bear Flat	4.2	32.6	-34.8	376.0	1.5
Station 6 – Farrell Creek	-	-	-	-	1.6
Station 7 – Site C Dam	4.8	31.4	-32.3	343.5	2.7
Station 9 – 85th Avenue	-	-	-	-	2.6
Fort St. John Airport	3.7	30.2	-33.2	444.4	4.2
30 year climate normals (1981 – 2010)	2.3	30.2(1)	-36.6(2)	444.7	3.8
Max difference from normals	2.5	3.2	4.3	120.0	2.3

Notes: Temperatures are based on maximum hourly averages
Station 5 is not included due it having been decommissioned as of June 22, 2015
— indicates no data collected
1) 30-year average of annual maximum hourly temperature
2) 30-year average of annual minimum hourly temperature

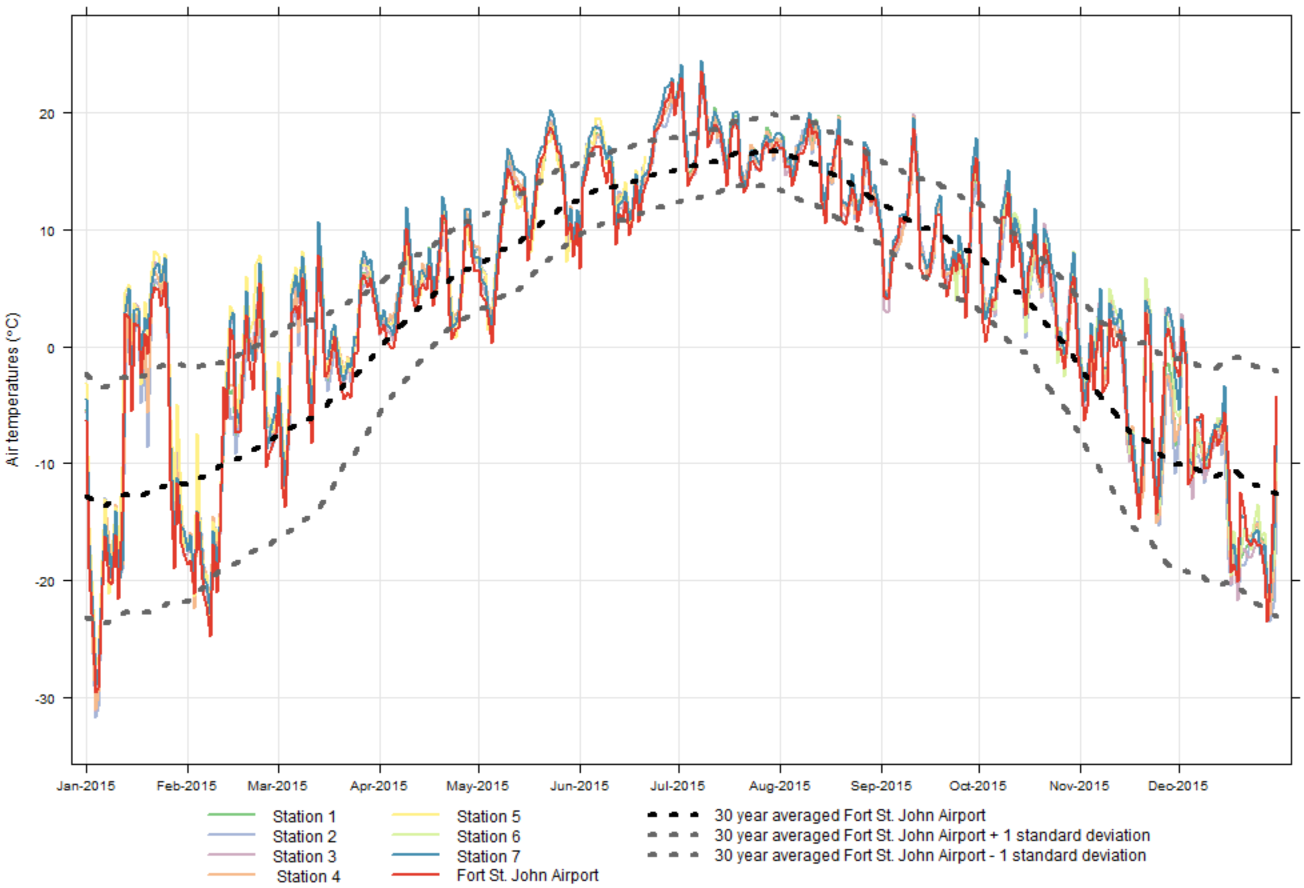
3.1 Air Temperature and Relative Humidity

Figure 3-1 shows a time series plot of the mean daily temperature at all Site C network stations as well as the Fort St. John Airport for 2015. As was noted in the previous monitoring reports (RWDI AIR Inc. 2015a, 2015b, 2015c), much greater day to day variability is observed in the winter months (January to March, and November and December) than in the summer months (April to October). This is also observed in the 30-year averaged data from Fort St. John Airport and was attributed to the passage of warm and cold weather fronts in the winter, bringing with them large swings in temperature. In the summer, the cold arctic air masses which dominate in winter are much farther north and there is less frontal activity in the region, resulting in less extreme temperature fluctuations.

The inter-station variation is generally very small compared to the observed diurnal variations. When averaged over the entire year, the largest difference between all stations is 1.2 °C (Table 3-1), which is similar to the 1.2 °C, 1.4 °C and 1.0 °C stated for the 2012, 2013 and 2014 monitoring years respectively (RWDI AIR Inc. 2015a, 2015b, 2015c). Temperature differences of 1 to 2 °C are reasonable given the absence of steep terrain, a maximum horizontal separation of 70 km between Fort St. John Airport and the most distant station in the network (Station 5 – Hudson's Hope), and a maximum difference in station elevations of 254 m (from 441 m at Station 2 to 695 m at Fort St. John Airport).

Annual average temperatures at all Site C network stations with the exception of Station 2 are greater than those reported for 2015 at Fort St. John Airport. Fort St. John Airport recorded an annual average temperature that was 1.4°C greater than the 30-year climate normal for that station.

The monthly average temperatures tabulated in Appendix A (Table A-1) show that all Site C network stations recorded warmer temperatures than Fort St. John Airport from January to April, and from June to September. There were no months during which all Site C network stations recorded colder temperatures than the Fort St. John Airport. Fort St. John Airport recorded below normal temperatures in August, September and December. Warmer than normal temperatures were recorded at Fort St. John Airport in January, from March to July, and from October to November.



Notes: The 30 year mean and mean ± 1 standard deviation curves are smoothed using a 21 day centered rolling average

Figure 3-1: Daily average temperatures at all Site C network stations for the year 2015 and comparison with the mean ± 1 standard deviation of 30-year climate normals.

Figure 3-2 shows a time-series of relative humidity (RH) recorded daily at 15:00 LST at each of the stations. This single hour of the day was used instead of a daily average due to the normally large fluctuation in RH over the course of a day and to allow comparisons with climate normals. Relative humidity at Station 2 most frequently had the highest monthly averaged values of all the stations (7 months).

When compared to Fort St. John Airport (Appendix A, Table A-2), annual average RH at all stations was lower. RH values at all stations were lower than Fort St. John Airport for the months of March, April, June, August and September. Fort St. John Airport recorded lower than normal RH values for March through May, and July to November.

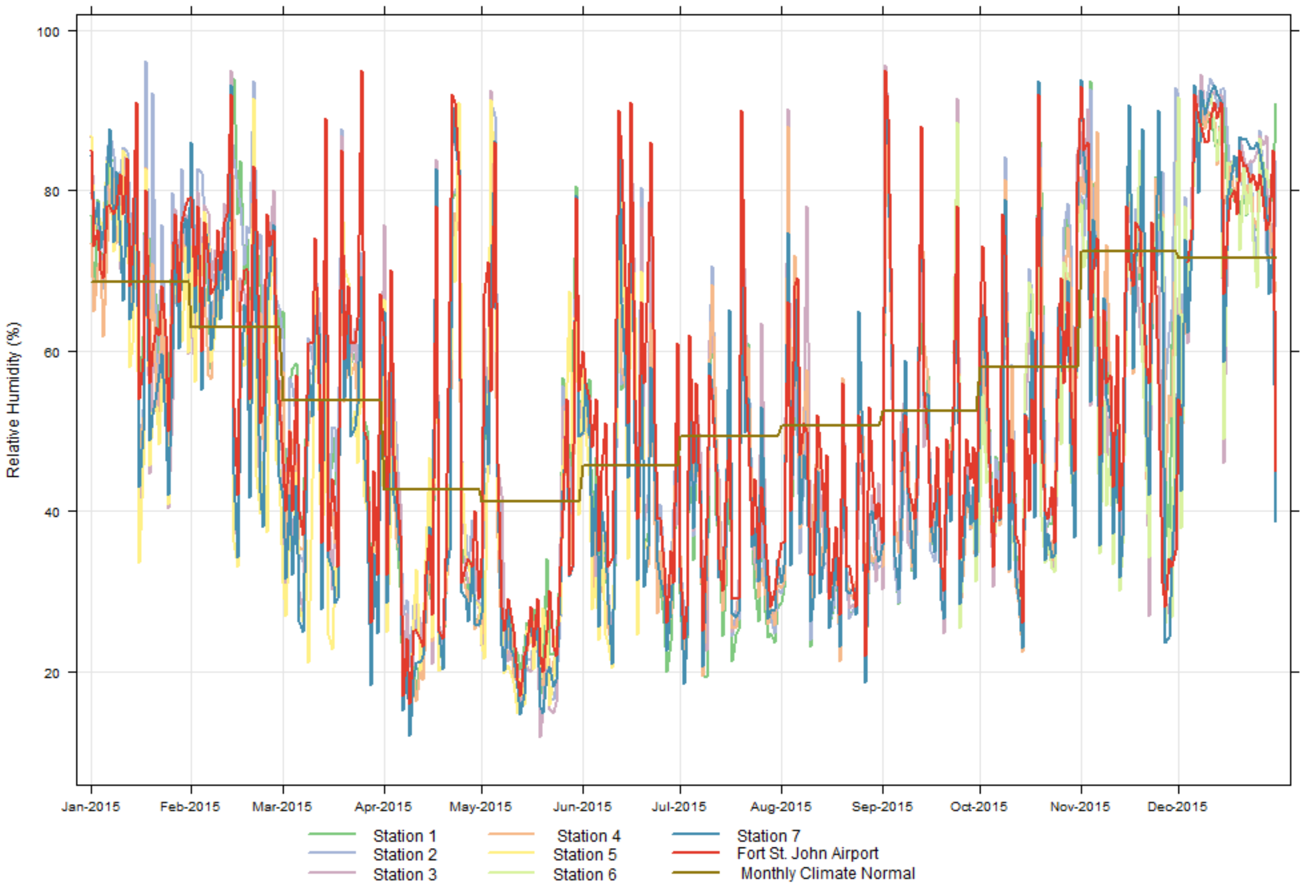


Figure 3-2: Daily 15:00 LST RH at all Site C network stations for the year 2015

3.2 Wind Characteristics

Wind speed and direction were also measured at all stations except Station 8. Figure 3-3 shows wind roses for all stations with a complete year of data including Fort St. John Airport for 2015. Mean annual wind speed for 2015 ranges between 1.5 m/s (Station 4) and 2.7 m/s (Station 7) at the Site C network stations. Fort St. John Airport has a mean annual wind speed of 4.2 m/s which is greater than the 30-year climate normal of 3.8 m/s (Table 3-1).

The differences between stations in wind speed and direction that are apparent in the wind roses are attributed to differences between small scale surface features such as proximity of trees and local topography to the network station and location within the meandering Peace River Valley. The higher wind speed at Fort St. John Airport is likely due to this station being on the plateau above the Peace River Valley and its very open location with a large fetch in all directions.

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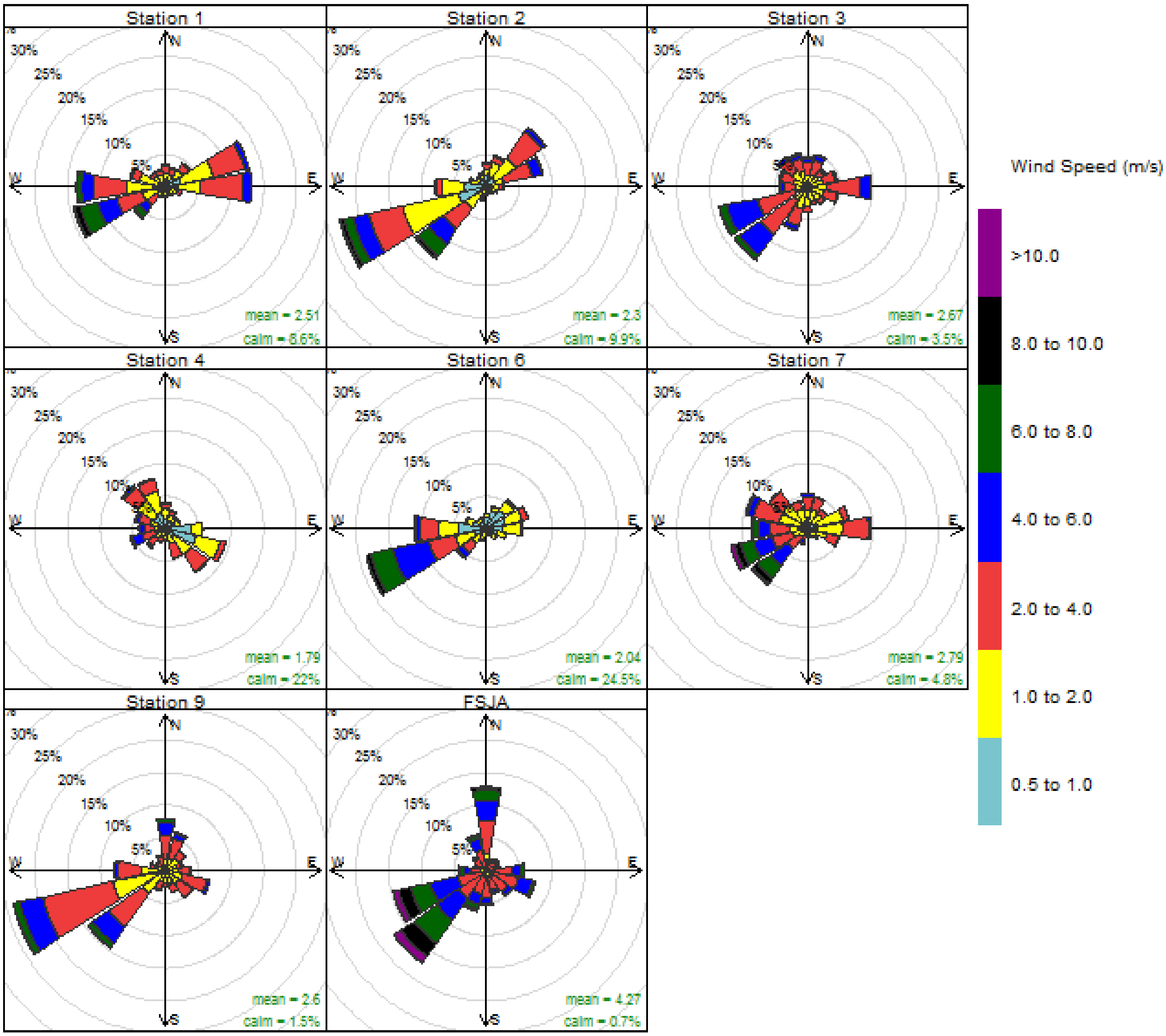


Figure 3-3: Wind roses for all stations for 2015

3.3 Precipitation

Figure 3-4 shows the total monthly precipitation over the course of 2015 for each of the Site C network stations as well as for Fort St. John Airport. Data from the automated weighing precipitation gauges are shown when available. Data from the tipping bucket precipitation gauges are used for the remainder of the year (e.g. prior to the upgrades to Station 2, Station 3, Station 4 and Station 7). Values from this plot are also presented in Appendix A (Table A-3).

Of the Site C network stations, Station 4 recorded the greatest amount of precipitation (376 mm). All of the Site C network stations recorded lower annual cumulative precipitation than the Fort St. John Airport. This is true for monthly totals as well, except for the months of April, May, July, August and November when monthly totals recorded at Fort St. John Airport were less than those measured at least one Site C network station.

Annual cumulative precipitation recorded at Fort St. John Airport (444.4 mm) was almost the same as the 30-year climate normal (444.7 mm). Monthly cumulative precipitation at Fort St. John Airport exceeded the 30-year climate normal for the months of January through April and September.

Considerable attention was paid to topping up the antifreeze used in the tipping bucket precipitation gauges for the months of January through April to prevent the problems observed in 2014 in which the antifreeze would become diluted by precipitation and gelling of the antifreeze would occur, resulting in under-measurement of precipitation. This measure was successful for the most part in that the months of February through April recorded similar precipitation between the stations. The additional interference with the precipitation gauges increased uncertainty in the quality control of the data which may have resulted in greater uncertainty regarding precipitation totals for the month of January when the process was still being refined. This problem was eliminated when the tipping bucket precipitation gauges were upgraded to weighing precipitation gauges.

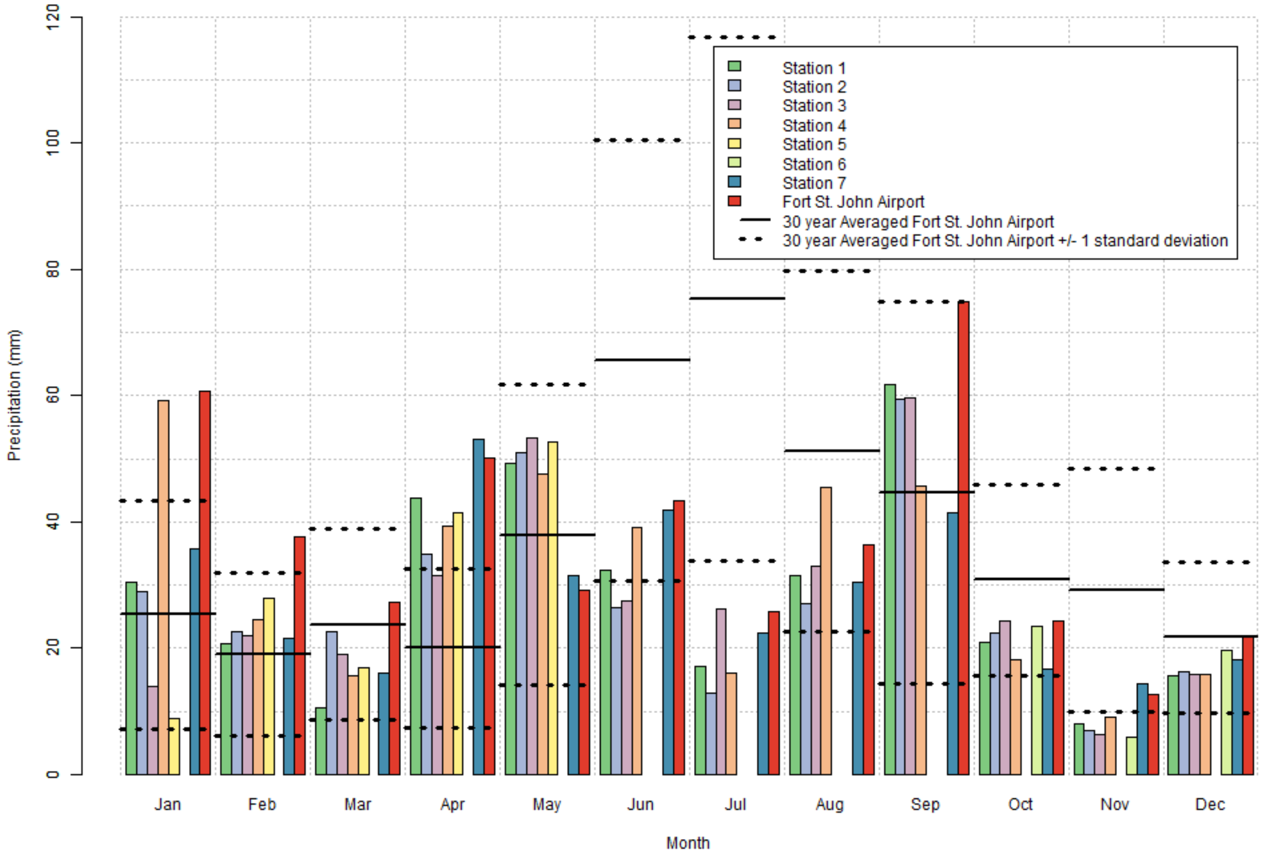


Figure 3-4: Monthly precipitation at all of the Site C network stations for 2015 and comparison with the mean ± 1 standard deviation of 30-year climate normals

As in previous reports, Fort St. John Airport records greater total annual precipitation than any of the Site C stations. This discrepancy arises primarily during the cold months of the year when most precipitation falls as snow. A possible explanation is that the Fort St. John Airport precipitation gauge is located in a wide open area where winds are stronger and is therefore subject to blowing snow. Snow clearing operations at the airport may further increase the amount of blowing snow captured by the precipitation gauge. Another possibility is that the precipitation gauge at Fort St. John airport is equipped with a Nipher edge whereas precipitation gauges at Site C network stations are equipped with an alter shield as a mechanism to reduce turbulence and mitigate undercatch. These two methods may not be operating with the same efficiency.

Precipitation during the growing season (May to September) and how it relates to the energy balance at Station 1, Station 2 and Station 4 is further discussed in Appendix B.

3.4 Soil Moisture and Temperature

Figure 3-5 and Figure 3-6 provide the daily averaged soil temperature and soil moisture respectively for Station 1, Station 2 and Station 4. Overall, there is very little difference in soil temperature between the stations except for a period between mid-May and early August during which temperatures at Station 2 were noticeably greater than at the other two stations.

The soil temperature at all three stations was observed to approach 0 °C during warm periods between January and March prior to increasing to greater than 0 °C in the spring. The soil temperature at Station 1 was the earliest of the three stations to increase above 0 °C in the spring, and Station 2 was the earliest to decrease below 0 °C in the fall. The soil temperature at Station 1, Station 2 and Station 4 rose above 0 °C on March 29, April 1 and April 2 respectively. Station 2 reached the highest daily average temperature of 23.7 °C on July 9, 2015. The soil temperature at Station 1, Station 2 and Station 4 decreased below 0 °C on November 15, 12 and 15 respectively.

Notes: The green, violet and orange triangles indicate when soil temperature increased beyond or very near to 0 °C at Station 1, Station 2 and Station 4, respectively

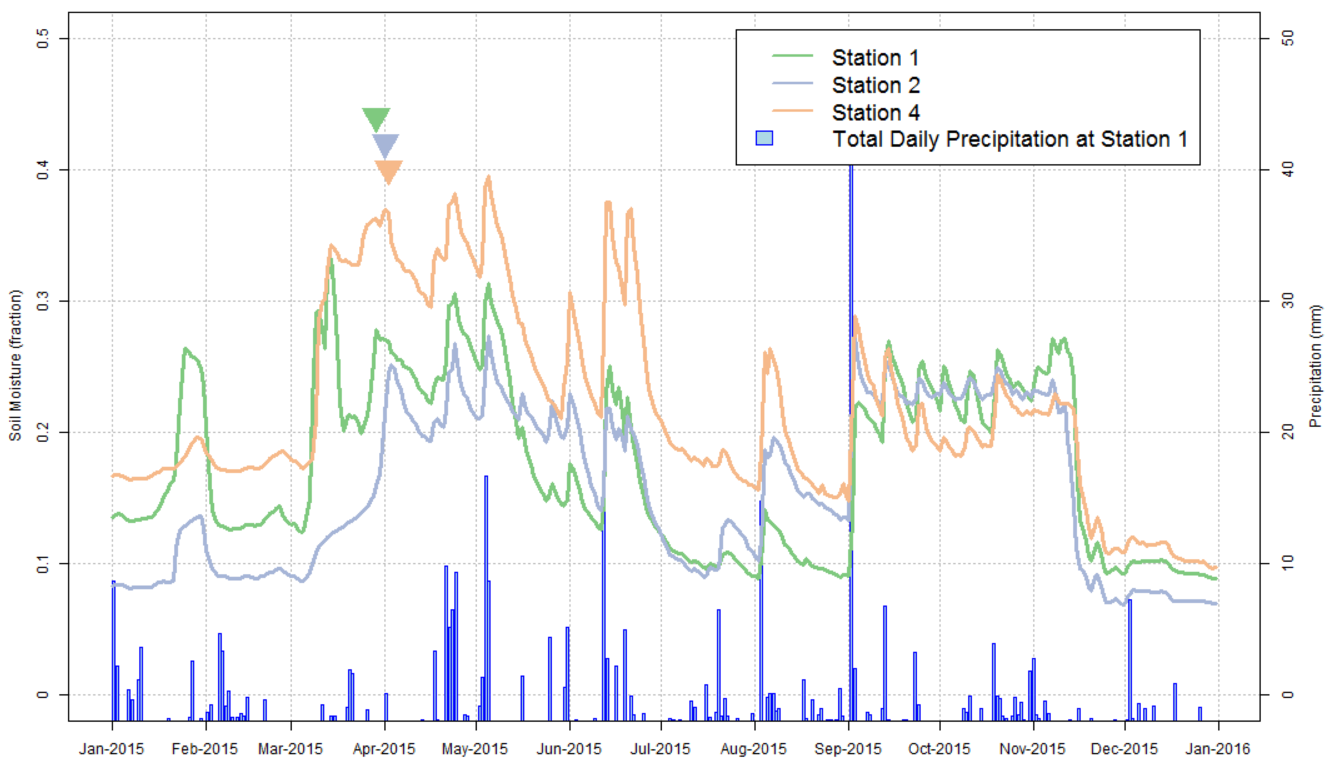
Figure 3-5: 24-hour average soil temperatures for Stations 1, 2 and 4 for 2015

Soil moisture follows a similar response pattern between all three stations wherein liquid precipitation (rain) events are clearly reflected as sudden increases in moisture followed by a gradual decline. An increase of soil moisture is also recorded when soil temperature increases beyond or very near to 0°C when the soil becomes permeable to surface water produced by the snowmelt. Differences between stations are attributable to different soil types (Table 3-2:) and agricultural land management practices (Figure 3-7) between locations.

Further discussion concerning soil temperatures and how this relates to the energy balance is presented in Appendix B.

Table 3-2: Soil types at the Site C Eddy Covariance stations.

	Station 1 – Attachie Flat Upper Terrace	Station 2 – Attachie Flat Lower Terrace	Station 4 – Bear Flat
Soil type[a]	TY3-4 (Taylor) Regosolic Black with Eutric Brunisol	BF1 (Bear Flat)-Cumulic Regosol	AH (Attachie) Regosolic Dark Grey, regosolic Black Chernozemic



Notes: The green, violet and orange triangles indicate when soil temperature increased beyond or very near to 0°C at Station 1, Station 2 and Station 4, respectively.

Total daily precipitation values are from the Station 1 weighing precipitation gauge.

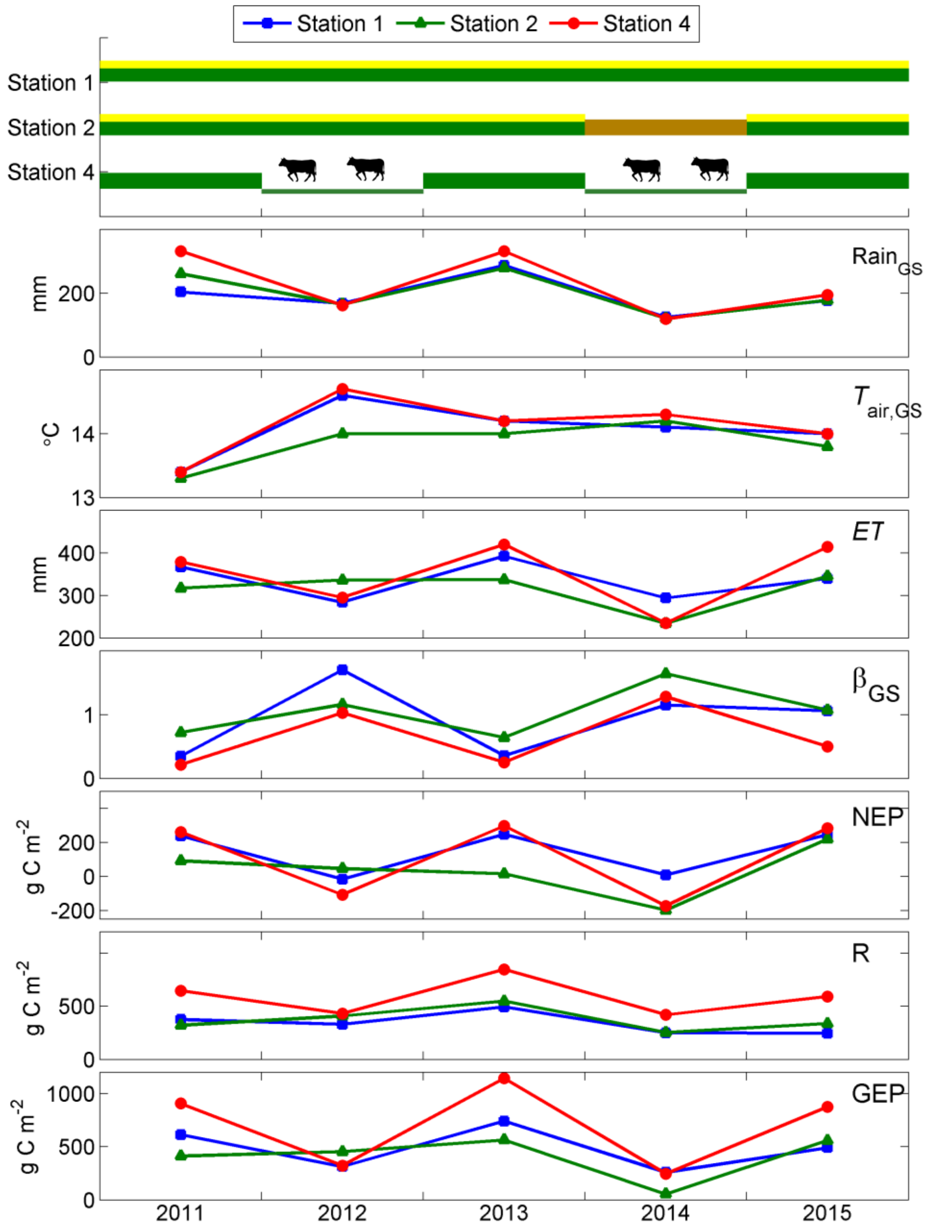
Figure 3-6: 24-hour average soil moisture readings for Stations 1, 2 and 4 for 2015

3.5 Energy and Carbon Balance

A study of the energy and carbon balances at Station 1, Station 2 and Station 4 was performed in 2015. The following is a summary of the findings. A more detailed analysis is available in Appendix B. Growing season (May-Sept) conditions at all three Eddy Covariance (EC) stations were slightly wetter than conditions in 2014. However, 2015 growing season rainfall was comparable to 2012 which was a comparatively dry year compared to other years. Growing season rainfall was 176, 178 and 195 mm for Station 1, Station 2 and Station 4, respectively.

2015 Annual evapotranspiration (ET) at the three EC stations recovered from 2014. At Stations 1 (340 mm) and Station 4 (414 mm) ET was higher than in 2014 (294 and 235 mm respectively) and was closer to the annual values during the wet years of 2011 and 2013. While ET at Station 2 (345 mm) increased from the 2014 dry year (234 mm) in which the field surrounding the tower had been left unplanted (Fig. 6) it remained close to the mean annual ET measured from 2011 to 2013 (330 mm) where the field was planted with crop. Winter soil temperatures were uniformly warmer at all three of the EC stations hence during spring thaw the soil heated up faster than in any previous year, and hence at all stations, April, May and June showed record or near-record monthly ET values.

All EC stations were carbon sinks (C-sinks) for 2015 with Stations 1 and 2 showing the influences of agricultural intervention and different stages of the growing season. Station 1 was a C-sink with an annual net ecosystem production (NEP) of 245 g C m-2 (2014: 9 g C m-2) with most of the gains in C uptake made in May and June before the site was harvested, thereafter respiration (R) from the soils dominated. Station 2 was also a C-sink with an annual NEP value of 220 g C m-2 (2014: -198 g C m-2). Carbon losses at Station 2 accelerated beginning in August compared to the other sites because conditions for higher soil respiration were helped when the already warmer soil temperatures at that site combined with significant rainfall at the beginning of the month. Station 4 was also a significant C-sink in 2015 with an annual NEP of 283 g C m-2. This was a dramatic increase from 2014 (NEP = -173 g C m-2) in which the field surrounding the Station 4 tower had been grazed with cattle and the animals’ clipping and consumption of the grass vegetation dramatically reduced GEP.



Notes: Top panel indicates the agricultural land management status for each station for each year (green and yellow bars = cultivated with crops, green bars = ungrazed pasture; thin green bar and cattle icon = graze d pasture; brown bar=bare soil) The panels below summarize, respectively: growing season rainfall, mean growing season air temperature, annual ET, mean growing season Bowen ratio (β = H/λE), and annual NEP, R and GEP.

Figure 3-7: Summary of eddy covariance results 2011-2015

3.6 Air Quality

Station 1, Station 8 and Station 9 are each equipped with monitors that measure suspended particulate matter (PM) with diameters of less than 10 µm and 2.5 µm (PM_{10} and $PM_{2.5}$ respectively). Table 3-3 gives an overview of the completeness of the datasets for $PM_{2.5}$ and PM_{10} at these stations as well as the number of excursions and/or exceedances (both terms defined in table notes) above the provincial 24-hour objectives and a comparison of the annual averages with the provincial annual objectives. The lower percentage complete for 24-hour averages than for hourly data stems from a requirement that, to consider a 24-hour average valid, it must contain at least 75% (18 hours) of valid data (BC MOE 2009). For PM_{10}, a value is considered an exceedance once it is greater than the BC provincial air quality objective (AQO), whereas for $PM_{2.5}$, there is only an exceedance if the 98th percentile of daily values in the year is greater than the AQO. If this condition is not met, $PM_{2.5}$ values above the AQO do not constitute exceedances and are classified as excursions.

$PM_{2.5}$ and PM_{10} at Station 9 both had a data completeness of less than 75% (typical of BC MOE permit requirements). This was caused by a power failure at the station that began on April 8, 2015, and lasted until the problem was corrected May 17, 2015. Further interruptions in operations at Station 9 were due to a complete failure of the sample pump and pressure control board of the PM_{10} and $PM_{2.5}$ analyzer from July 9, 2015 until August 30, 2015 and from September 1, 2015 until December 31, 2015 respectively. The long delays in repairing the instruments were caused by the unavailability, from the manufacturer, of the parts that were needed to conduct the repairs. To avoid long delays in acquiring failed parts, in the future a set of parts that typically fail will be kept on hand.

Two excursions above the 25 µg/m^3 AQO for $PM_{2.5}$ for a 24-hour averaging period and no exceedances of the 50 µg/m^3 AQO for PM_{10} for a 24-hour averaging period were observed at Station 1 in 2015. At Station 8, one excursion above the 24-hour $PM_{2.5}$ AQO and no exceedance above the 24-hour PM_{10} AQO were observed. No excursions above the 24-hour $PM_{2.5}$ AQO and two exceedances for the 24-hour PM_{10} AQO were observed at Station 9.

None of the stations recorded an exceedance of the 98th percentile of $PM_{2.5}$ over the provincial AQO of 25 µg/m^3. The annual average $PM_{2.5}$ B.C. provincial AQO of 8 µg/m^3 was not exceeded at any of the three stations in 2015.

Table 3-3: Summary of PM results for 2015

	Station 1 – Attachie Flat Upper Terrace		Station 8 – Old Fort		Station 9 – 85th Avenue	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
% data complete of hourly data	90.1	77.7	96.4	97.1	51.9	60.5
% data complete (24 hour averages)	86.6	75.1	94.8	96.2	49.9	58.4
24 hour AQO	25	50	25	50	25	50
24 hour AQO excursions / exceedances (1)	2	0	1	0	0	2
98th percentile of 24 hour daily averages	16.0	24.3	16.6	34.2	18.1	45.7
Annual AQO	8	NA(2)	8	NA(2)	8	NA(2)
Annual average	4.9	7.6	5.9	10.1	4.2	11.7

Notes: Sources: BC MOE 2009

1) Excursion is used here for $PM_{2.5}$ when the 24-hour average of $PM_{2.5}$ is greater than the 24 hour AQO without the 98th percentile of daily $PM_{2.5}$ exceeding the AQO. Exceedance is used here to refer to PM_{10} values above the 24 hour AQO.

2) NA is used where the quantity in question is not applicable to the measurement.

Figure 3-8 and Figure 3-9 show the 24-hour average of PM_{10} and $PM_{2.5}$ at the three AQ stations. $PM_{2.5}$ levels were below the AQO for most of the year except for the months of January and July. The reason for the January excursion is not known based on the current analysis of the available data. The July excursions coincided with the beginning of the Big Beaver Creek forest fire near Fort Nelson which was classified as a fire of note (BC MOF, 2016). Exceedances of PM_{10} were only observed at Station 9 in May. Typical sources of airborne particulate matter near Fort St. John are the use of firewood for heating homes, the sanding and salting of roads in winter and smoke from forest fires in the summer. It should be noted that construction for the Site C Clean Energy Project began on July 27, 2015 with instream construction commencing October 14, 2015. Therefore, the exceedances/excursions observed in 2015 are not associated with Site C Dam construction.

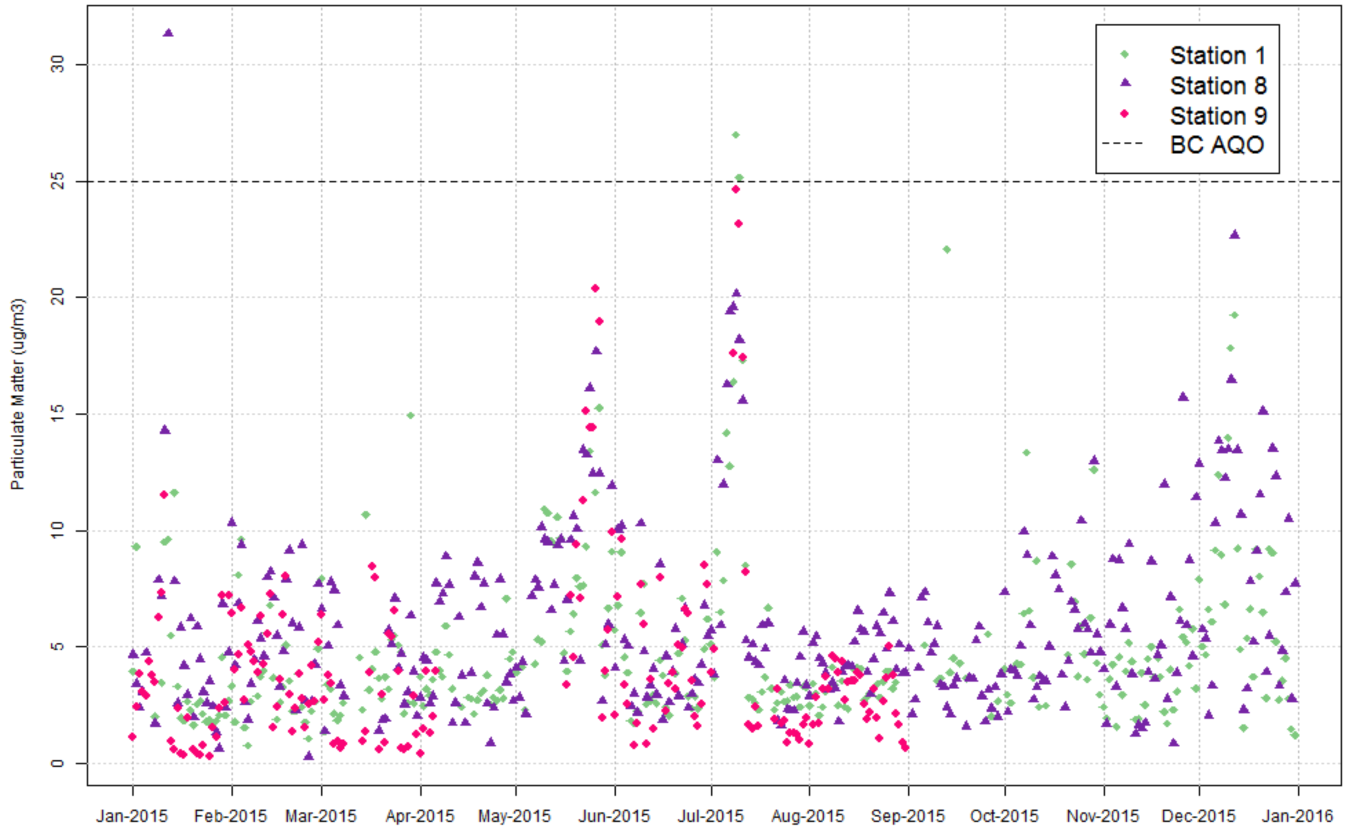


Figure 3-8: Daily average $PM_{2.5}$ measurements from Station 1, Station 8 and Station 9 for 2015

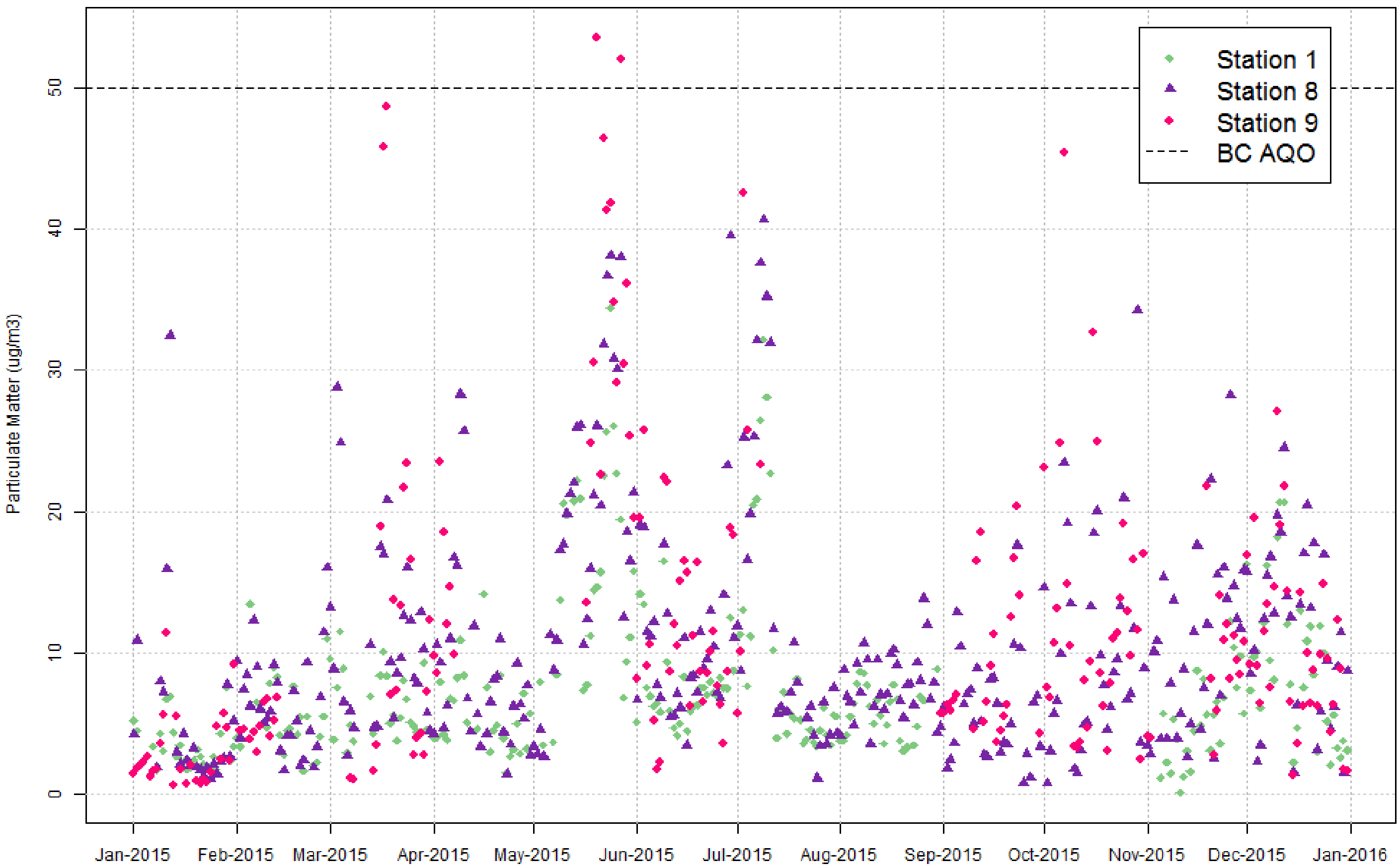


Figure 3-9: Daily average PM_{10} measurements from Station 1, Station 8 and Station 9 for 2015

4. CONCLUSIONS

This document reports on the climate and air quality as observed by the Site C monitoring network and the Environment Canada weather station at Fort St. John Airport during the year 2015. Very little difference between the stations in ambient air temperature or in relative humidity was found. This was attributed to the short distances and small elevation differences between stations. However, wind speed and direction were found to vary between stations. This was attributed to small scale surface features having a larger impact on the local air flow patterns.

Site C network stations observed a warmer annual average temperature, less precipitation and lower wind speeds than the Fort St. John Airport. The Fort St. John Airport annual average temperature was warmer than the 30-year climate normals and it observed the same precipitation and greater wind speeds.

Differences in soil temperature between the stations were most pronounced from May to August. During this period, Station 2 consistently recorded the highest temperatures. During the remaining months, soil temperatures are similar between the three stations. Soil temperatures and their relationship to soil properties are discussed in greater detail in the section about the annual energy balance analysis in Appendix B.

Two excursions above the 25 $\mu g/m^3$ AQO for $PM_{2.5}$ for a 24-hour averaging period and no exceedances of the 50 $\mu g/m_3$ AQO for PM_{10} for a 24-hour averaging period were observed at Station 1. At Station 8, one excursion for the 24-hour $PM_{2.5}$ AQO and no exceedances for the 24-hour PM_{10} AQO were observed. No excursions for the 24-hour $PM_{2.5}$ AQO and two exceedances for the 24-hour PM_{10} AQO were observed at Station 9.

$PM_{2.5}$ levels are below the AQO for most of the year except for the months of January and July. The July excursions coincided with the start of a forest fire of note that was burning at big beaver creek. PM_{10} concentrations followed a similar tend but without exceeding the AQO of 50 $\mu g/m^3$ except for two days in May at Station 9.

CONSULTING ENGINEERS
& SCIENTISTS

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APPENDIX A

Data Tables

Table A-1: Monthly average temperatures at all Site C network stations for the year 2015.

Month	Station 1 – Attachie Flat Upper Terrace	Station 2 – Attachie Flat Lower Terrace	Station 3 – Attachie Plateau	Station 4 – Bear Flat	Station 5 – Hudson's Hope	Station 6 – Farrell Creek	Station 7 – Site C Dam	FSJ Airport	Climate Normals
Jan	-8.7	-9.1	-8.1	-8.5	-6.6	-	-7.9	-9.3	-12.8
Feb	-8.8	-9.3	-8.3	-8.6	-6.9	-	-8.2	-9.6	-9.6
Mar	0.3	-0.1	0.8	0.6	1.5	-	1.4	-0.5	-4.6
Apr	5.7	5.6	5.6	6.0	5.6	-	6.2	5.0	3.9
May	12.0	11.9	11.8	12.3	11.3	-	12.7	11.4	9.8
Jun	15.8	15.6	15.8	15.8	-	-	16.2	15.0	14.1
Jul	17.9	17.3	17.5	17.8	-	-	18.2	17.2	16.2
Aug	15.2	15.0	15.0	15.1	-	-	15.7	14.7	14.9
Sep	9.0	8.9	9.1	9.1	-	-	9.8	8.8	10.1
Oct	5.6	5.3	6.2	5.8	-	6.0	6.8	5.5	3.6
Nov	-3.9	-4.4	-3.0	-4.2	-	-2.6	-2.6	-3.8	-6.6
Dec	-12.5	-13.3	-12.5	-12.2	-	-11.8	-11.3	-11.7	-11.4
Annual Average	4.1	3.7	4.2	4.2	-	-	4.8	3.7	2.3

Notes: - Measurements were discontinued at Station 5 on June 22, 2015
- Temperature measurements began at Station 6 following the upgrade on September 23, 2015
- Annual averages were not calculated for either of these two stations because of the incomplete datasets at each station

Table A-2: Monthly average 15:00 LST RH at all Site C network stations for the year 2015.

Month	Station 1 – Attachie Flat Upper Terrace	Station 2 – Attachie Flat Lower Terrace	Station 3 – Attachie Plateau	Station 4 – Bear Flat	Station 5 – Hudson's Hope	Station 6 – Farrell Creek	Station 7 – Site C Dam	FSJ Airport	Climate Normals
Jan	72.1	72.9	67.9	68.2	66.2	-	67.9	71.5	68.5
Feb	70.8	73.3	65.3	66.8	60.2	-	62.8	68.3	62.9
Mar	52.3	52.3	47.6	48.6	42.0	-	45.0	53.2	53.8
Apr	36.4	40.6	41.0	35.7	38.6	-	37.5	41.1	42.6
May	36.2	33.5	34.3	33.1	33.9	-	32.8	36.2	41.1
Jun	44.0	45.9	45.6	43.1	-	-	43.7	53.1	45.7
Jul	36.4	39.3	41.0	38.7	-	-	38.8	40.8	49.3
Aug	37.2	37.0	41.2	40.5	-	-	38.6	42.5	50.6
Sep	48.0	45.3	47.1	47.2	-	-	46.4	49.7	52.4
Oct	54.1	54.1	49.8	50.0	-	48.2	49.6	52.4	57.9
Nov	64.1	66.8	55.3	64.9	-	57.2	59.9	59.9	72.3
Dec	80.8	81.7	80.0	79.5	-	78.5	79.2	78.9	71.5
Annual Average	52.7	53.4	51.3	51.3	-	-	50.1	53.8	55.7

Notes: - Measurements were discontinued at Station 5 on June 22, 2015
- Relative Humidity measurements began at Station 6 following the upgrade on September 23, 2015
- Annual averages were not calculated for either of these two stations because of the incomplete datasets at each station

Table A-3: Monthly precipitation totals for 2015.

Month	Station 1 – Attachie Flat Upper Terrace	Station 2 – Attachie Flat Lower Terrace	Station 3 – Attachie Plateau	Station 4 – Bear Flat	Station 5 – Hudson's Hope	Station 6 – Farrell Creek	Station 7 – Site C Dam	FSJ Airport	Climate Normals
Jan	30.5	29.0	14.0	59.2	8.9	-	35.8	60.6	25.4
Feb	20.6	22.6	22.1	24.6	27.9	-	21.6	37.6	19.0
Mar	10.6	22.6	19.1	15.7	17.0	-	16.0	27.3	23.7
Apr	43.8	34.8	31.5	39.4	41.4	-	53.1	50.1	20.0
May	49.4	51.1	53.3	47.5	52.6	-	31.5	29.2	37.9
Jun	32.4	26.4	27.4	39.1	-	-	41.9	43.3	65.6
Jul	17.1	13.0	26.2	16.0	-	-	22.4	25.8	75.2
Aug	31.6	27.2	33.0	45.5	-	-	30.5	36.4	51.2
Sep	61.7	59.3	59.7	45.7	-	-	41.4	74.9	44.7
Oct	21.0	22.5	16.3	18.2	-	23.5	16.6	24.4	30.8
Nov	8.1	7.1	6.3	9.2	-	5.9	14.5	12.8	29.2
Dec	15.7	16.3	15.9	16.0	-	19.7	18.3	22.0	22.0
Total	342.4	331.7	324.7	376.0	-	-	343.5	444.4	444.7

Notes: Precipitation data from station 1 are taken from the Pluvio weighing precipitation gauge for the entire year 2015. Precipitation data for the other stations are from the tipping bucket precipitation gauges until they were replaced with weighing precipitation gauges. After which, data in this table are from the weighing precipitation gauge at each station.

- Measurements were discontinued at Station 5 on June 22, 2015
- Relative Humidity measurements began at Station 6 following the upgrade on September 23, 2015
- Annual averages were not calculated for either of these two stations because of the incomplete datasets at each station

APPENDIX B

Eddy Covariance Report

B1. INTRODUCTION AND METHODS

As part of the collection of baseline environmental data for the Site C project area, eddy covariance (EC) systems were installed at three meteorological stations: Station 1 (Upper Attachie), Station 2 (Lower Attachie) and Station 4 (Bear Flat). This report summarizes the results of the EC component of the baseline environmental measurement program for 2015.

The EC technique has become the standard method for measuring sensible heat flux (H), latent heat flux (λE) and CO_2 flux (F_c) over footprints of ≤ 1 km^2 (Baldocchi, 2003). Knowledge of the partitioning of available energy (R_n – G, or net radiation minus soil heat flux) between sensible and latent heat fluxes is critical for understanding the interaction of the measured ecosystem with the overall water cycle, atmospheric boundary layer development, weather, and climate (Wilson et al. 2002). Measurements of F_c yield the net ecosystem productivity (NEP)—the difference between gross ecosystem photosynthesis (GEP) and ecosystem respiration (R). NEP is a direct measure of whether an ecosystem is a source (NEP < 0), or a sink (NEP > 0) of atmospheric C over time and is a useful indicator of ecosystem health because it integrates the individual responses of GEP and R to weather and environmental variables. In addition, in managed forest or agricultural settings, NEP measurements can serve as a useful indicator of overall ecosystem response to a particular management practice (e.g. selective harvesting, no-tillage farming).

EC systems were installed at Station 2 and Station 4 on December 2, 2010. An additional EC system was installed at Station 1 on January 13, 2011. Since the installation at each of these stations, continuous 10 Hz measurements of the three components of the wind vector and air temperature have been made using a 3-dimensional ultrasonic anemometer (model CSAT3, Campbell Scientific Inc. (CSI), Logan, Utah), while 20 Hz turbulent fluctuations of CO_2 and H_2O have been measured using an open-path infrared gas analyser (IRGA) (model LI-7500A, LI-COR, Inc., Lincoln, Nebraska). Signals were measured with a data logger (CSI, model CR1000) with a synchronous-device-for-measurement (SDM) connection. High frequency (HF) data were stored on a compact flash card that was replaced every 2-3 weeks. Half-hourly covariances and other statistics were calculated on the data logger (to provide near-real time diagnostics), and as well from the raw HF data using in-house MATLAB processing code. H, λE and F_c fluxes were calculated as the half-hourly covariances of the sonic air temperature, H_2O or CO_2 mixing ratio with the vertical wind velocity (w), respectively. Further details of the flux calculations can be found in Brown et al. (2010). Briefly, sensible heat (H), latent heat (λE) and CO_2 (F_C) fluxes were calculated as the half-hourly covariances of the sonic air temperature, H_2O and CO_2 mixing ratios with the vertical wind velocity (w), respectively (Webb et al. 1980).

For example, in the case of H_2O, λE is calculated using

$$\lambda E = \lambda \rho_a \overline{w' s_v'} \tag{1}$$

where ρ_a is the dry air density, w is the vertical wind velocity, s_v is the H_2O mixing ratio, λ is the latent heat of vaporization, and the primes indicate fluctuations from the half-hourly mean value and the overbar indicates the time average. The calculation is therefore a 30-minute block average with no detrending applied.

B2. EC SYSTEM PERFORMANCE

B2.1 System uptime/data loss

Protocols for data recovery, extraction, and re-processing high frequency EC data, and cleaning (i.e., removal of unreliable data and gap-filling) of the resulting half-hourly CO_2 (F_c), sensible heat (H) and latent heat (λE) fluxes were unchanged from 2011-2014.

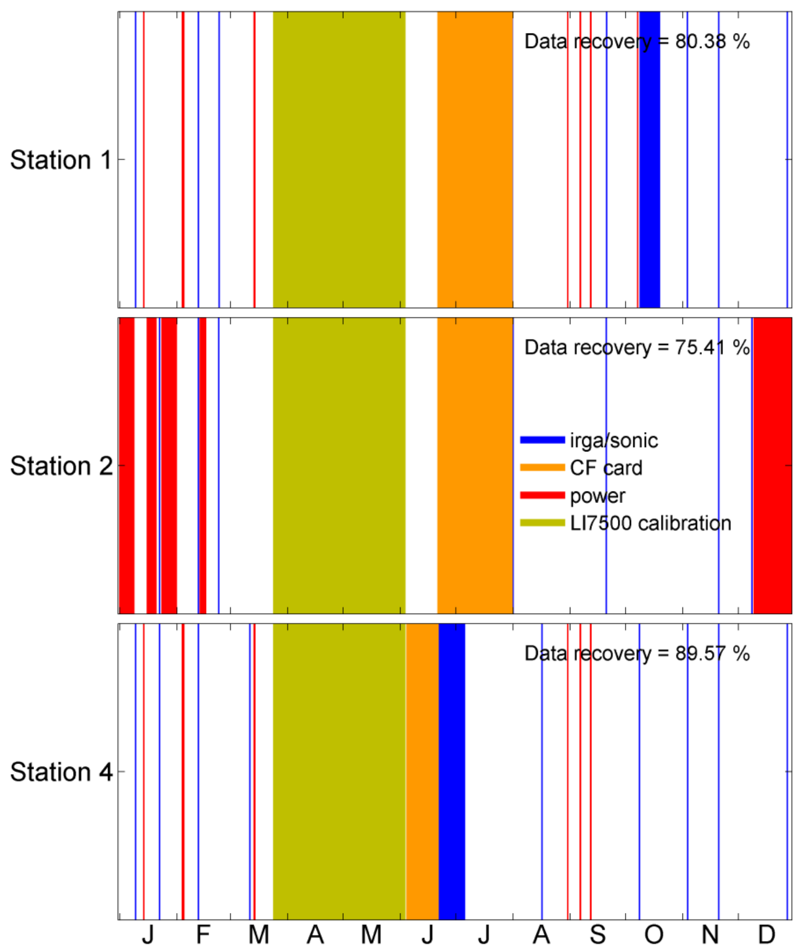

Figure B-1: EC system performance for Stations 1, 2, 4 in 2015 indicating sources (IRGA/sonic anemometer failure, CF card malfunction, power (low battery voltage), IRGA calibration) of data loss prior to manual QA/QC of the data. Vertical bars indicate flux data loss. Annual data recovery percentage indicated in each panel.

EC system uptime prior to manual data screening for quality assurance/quality control (QA/QC) continued to be close to 90% at Station 4, similar to the performance seen from 2011-2014. System uptime at Station 1 fell to 80% as a result of high frequency data loss on one of the CF cards, while at Station 2 high frequency data loss resulted from a poorly formatted CF card and frequent controlled power shutdowns of the gas analyzer by the automated solar battery charging system during prolonged overcast periods in January-March and December, 2015. Loss of high-frequency data was in all cases mitigated by the fact that the half-hour EC fluxes are calculated and stored on the EC datalogger itself as a redundancy; hence the fluxes for the periods when there was loss of data on the CF cards were always recovered from the logger. Factory calibration of the IRGA at each station required the instruments' removal during the period March 25-June 4, 2015.

B2.2 QA/QC issues

B2.2.1 CNR4 at Station 1

During the period from March 15-June 7, 2015, the CNR4 4-way net radiometer became loose on its mount and was no longer aligned with the vertical. When the 4 components of the net radiation, i.e.

$$R_{\mathrm{n}} = (L_{\mathrm{dw}} - L_{\mathrm{uw}}) + (S_{\mathrm{dw}} - S_{\mathrm{uw}})$$

where

L_{dw} is the downwelling longwave radiation,

L_{uw} is upwelling longwave radiation,

S_{dw} is the downwelling shortwave (solar) radiation

S_{uw} is the upwelling shortwave radiation.

were compared individually to the components as measured at Station 2 (using simple linear regression model fits), the effects of the skewness in its orientation were most noticeable in the shortwave irradiances (downwelling and upwelling) rather than the longwave components. Hence over the period March 15-June 7, S_{dw} and S_{uw} were replaced with modelled values from Station 2.

B2.2.2 Gap-filling

Gap-filling of the carbon balance components (NEP, GEP, and R) at all three stations was made more challenging for the 2015 calendar year by the relatively late removal of the IRGA units at all three EC stations for their annual calibration. The delay, which resulted from unavoidable scheduling conflicts, resulted in the loss of flux measurements at the start of the growing season. In previous years, the IRGA units had been returned to operation just prior to spring thaw and the onset of biologically-linked carbon and water fluxes from the agricultural soils.

In a natural forest or grassland ecosystem, filling data gaps in the λE and F_c fluxes this time interval would typically be accomplished using protocols slightly modified from those used in the Fluxnet Canada Research Network and the Canadian Carbon Program (Barr et al. 2004, Brown et al., 2010). This approach is best suited to natural ecosystems where the response of the local vegetation is largely the result of the integration of the phenological response of the individual species of plants and trees and environmental variables such as light, air temperature and soil temperature and moisture.

In the agricultural settings in which the Site C EC stations are situated, the biological response is affected by human factors, as the farmer is the one controlling the sowing and planting; hence the timing of the photosynthetic response cannot be captured in a model without more detailed knowledge of the actions of each individual farmer following spring thaw. While gap-filling the carbon balance flux components was accomplished using the same FCRN approach as in prior years, interpretation of changes the these fluxes during the gap-filled period should be done with some caution (discussed further below, see Section 3.5).

In contrast to the C-balance flux components, gap-filling of λE was accomplished using the same energy balance closure model approach (Amiro et al., 2006) of previous years and introduced no additional uncertainty as *H* continued to be measured throughout the IRGA calibration period.

B2.2.3 Uncertainty analysis

Uncertainties associated with calculating annual totals of *ET*, NEP, GEP, and R from the half-hour EC fluxes were determined using techniques detailed extensively elsewhere (Brown et al. 2010, Krishnan et al. 2006, Morgenstern et al 2004). Random error was assessed using propagation of errors following Morgenstern et al. (2004), in which up to a 20% error is randomly assigned to each half-hourly measured flux (NEP or λE). The uncertainty due to the gapfilling algorithms was estimated using Monte Carlo simulation following the procedure of Krishnan et al. (2006). Briefly, gaps were created in annual NEP or λE ranging from a half-hour to 10 days in length and a uniformly distributed random number generator was applied to day and night-time data separately so as to approximate the typical diurnal distribution of data gaps in the annual dataset for each site. For each iteration, the standard FCRN gapfilling approach as modified by Brown et al. (2010) discussed above was used to fill the gaps generated. This procedure was then repeated 1000 times, and the simulated annual values of NEP, R, GEP or *ET* were then sorted to determine the 95% confidence intervals. For the Site C EC stations, the combined random and systemic error introduced from the gap filling procedure amounted to ~10 mm for the annual *ET* and ~30 g C for the annual NEP. It should be noted that the IRGAs are removed for calibration at a time of year (February-March) when energy, water and carbon fluxes are very close to zero—hence they are relatively easy to model. The shift of the calibration period into the growing season necessarily increases the uncertainty involved in gap-filling from the values reported above as the daytime EC fluxes are higher and change more rapidly due to shifts in weather and agricultural practices.

Finally, as is standard Fluxnet protocol, the annual totals for *ET* and NEP reported below have not been corrected for energy balance closure. As noted in previous annual reports (Grant et al. 2012, 2013, 2014) the energy balance closure continues to be ~0.75 for each of Station 1, 2 and 4. Hence, the EC fluxes could be up to 25% underestimated.

B3. RESULTS

B3.2 Climate Measurements

RWDI continued to manage the climate instrumentation and data collection of at all three EC stations. Growing season (May-Sept) conditions at all three EC stations were slightly wetter than conditions in 2014. However, 2015 growing season rainfall was comparable to 2012 which was a comparatively dry year compared to other years. Growing season rainfall was 176, 178 and 195 mm for Station 1, Station 2 and Station 4, respectively (Fig. B-2). The Fort St. John Airport has a 30-year May Sept norm of 287 mm (1970-2000).

As observed in 2014, the most notable difference in the environmental conditions among the EC stations was the growing season soil temperature measured at Station 2. In contrast to 2014 in which it lay fallow, Station 2 was planted with crops in 2015 (see Fig. B-12). Relatively little rain fell between early June and early August hence it is possible the soils dried out stunted growth so that the normal shortwave reflectance by the crops was reduced and the soil warmed considerably more than that at the other two stations.

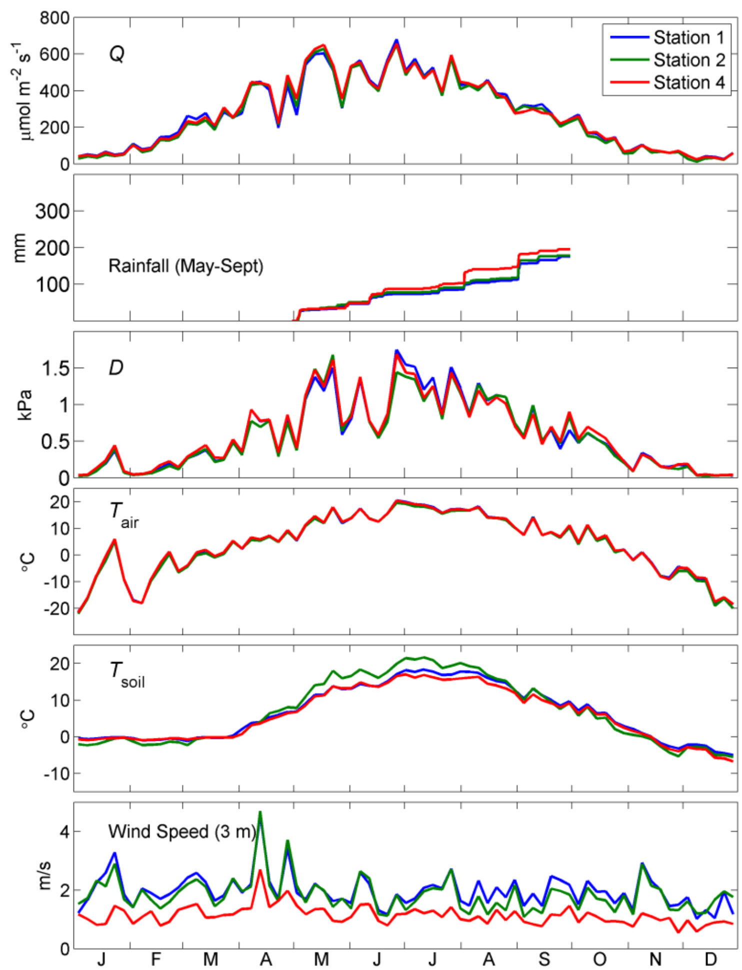

Figure B-2: Five-day-averaged climate variables for Stations 1, 2 and 4 for 2014: (a) daytime average downwelling photosynthetically active radiation (*Q*), (b) growing season cumulative rainfall, (c) daytime average vapour pressure deficit (*D*), (d) 24-h average air temperature (T_{air}), (e) 24-h average soil temperature (T_{soil}), and (f) 24-h sonic anemometer cup wind speed (3-m height).

When the conditions from 2011-2015 are plotted by station (Fig. B-3), the most notable differences are again related to the growing season rainfall and whether a particular year received below or average to above-average rainfall. Years with average to above-average rainfall (2011, 2013) show lower *D* during July and August compared to the three drier years (2012, 2014, 2015). Winter T_{soil} at all stations was coldest in 2011 and 2012, suggesting less snowcover was present to insulate the soil column. Soil temperatures warmed most rapidly following spring thaw at all stations in 2015.

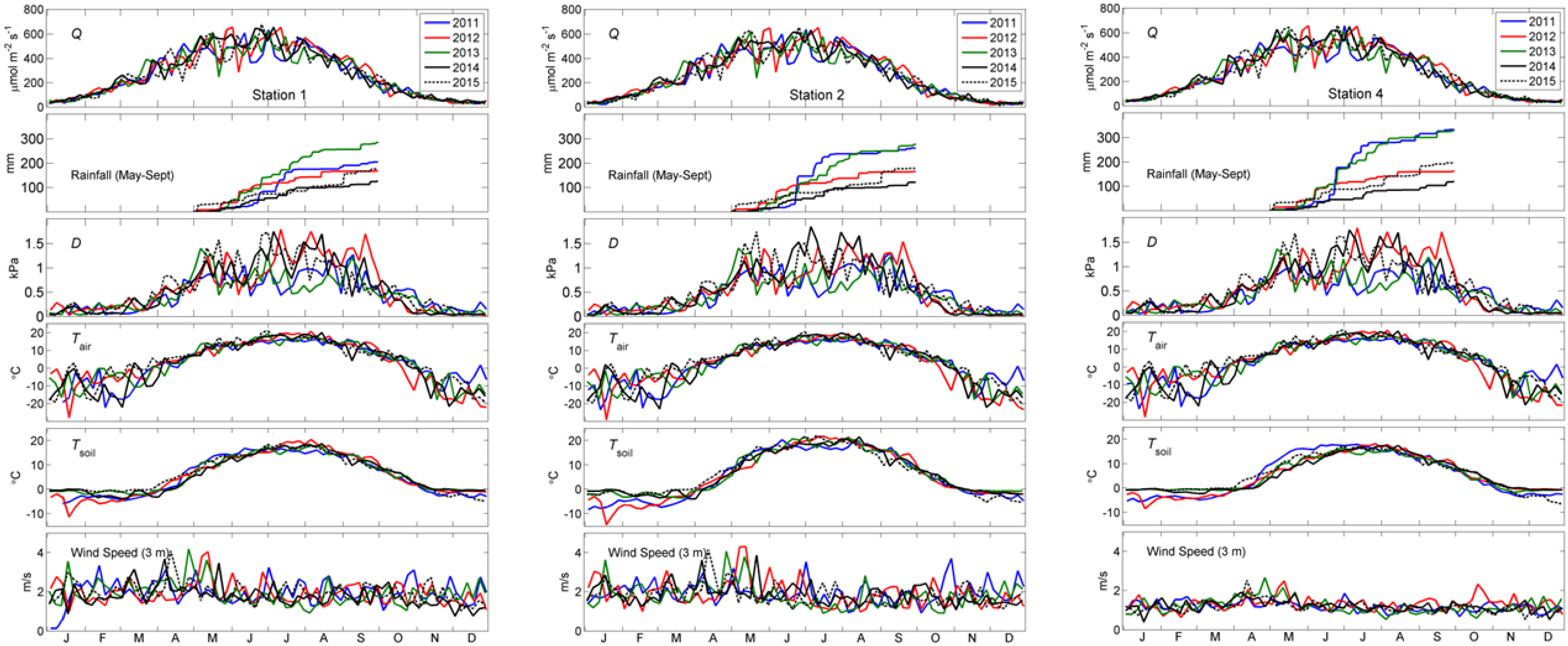

Figure B-3: **Five-day-averaged climate variables for Stations 1, 2 and 4 for 2011-2015: (a) daytime average downwelling photosynthetically active radiation (*Q*), (b) growing season cumulative rainfall, (c) daytime average vapour pressure deficit (*D*), (d) 24-h average air temperature (T_{air}), (e) 24-h average soil temperature (T_{soil}), and (f) 24-h sonic anemometer cup wind speed (3-m height).**

B3.3 Energy Balance Measurements

The 2015 seasonal pattern of variation in each component of the energy balance falls between the patterns last seen in dry years 2012 and 2014, and wet years 2011 and 2013, at each station (Fig. B-4). Winter soil temperatures were uniformly warmer at all three of the EC stations (see Fig. B-2) owing to less snow cover at those stations, hence during spring thaw the soil heated up faster than in any previous year. Hence the spring λE fluxes measured through April and May of 2015 are the highest in the 2011-2015 record for all stations. By July, λE was much higher at Station 4 compared Stations 1 and 2 because the land surrounding the tower was flush with growing grasses and animals were not being grazed. At Stations 1 and 2, λE fell off rapidly, and sensible heat flux (H) increased dramatically in July as drought conditions took hold and the farmer began to harvest the hay crop. Soil heat flux ($G+S_t$) lowest, at Station 2 where soil temperatures were higher in the bare soil (see Fig. B-2) than the plant-covered soils at Stations 1 or 4. The highest growing season $G+S_t$ values were measured at Station 1 and 4 where growing crops reduced wind speeds at the soil-air interfaces and hence reduced overall H.

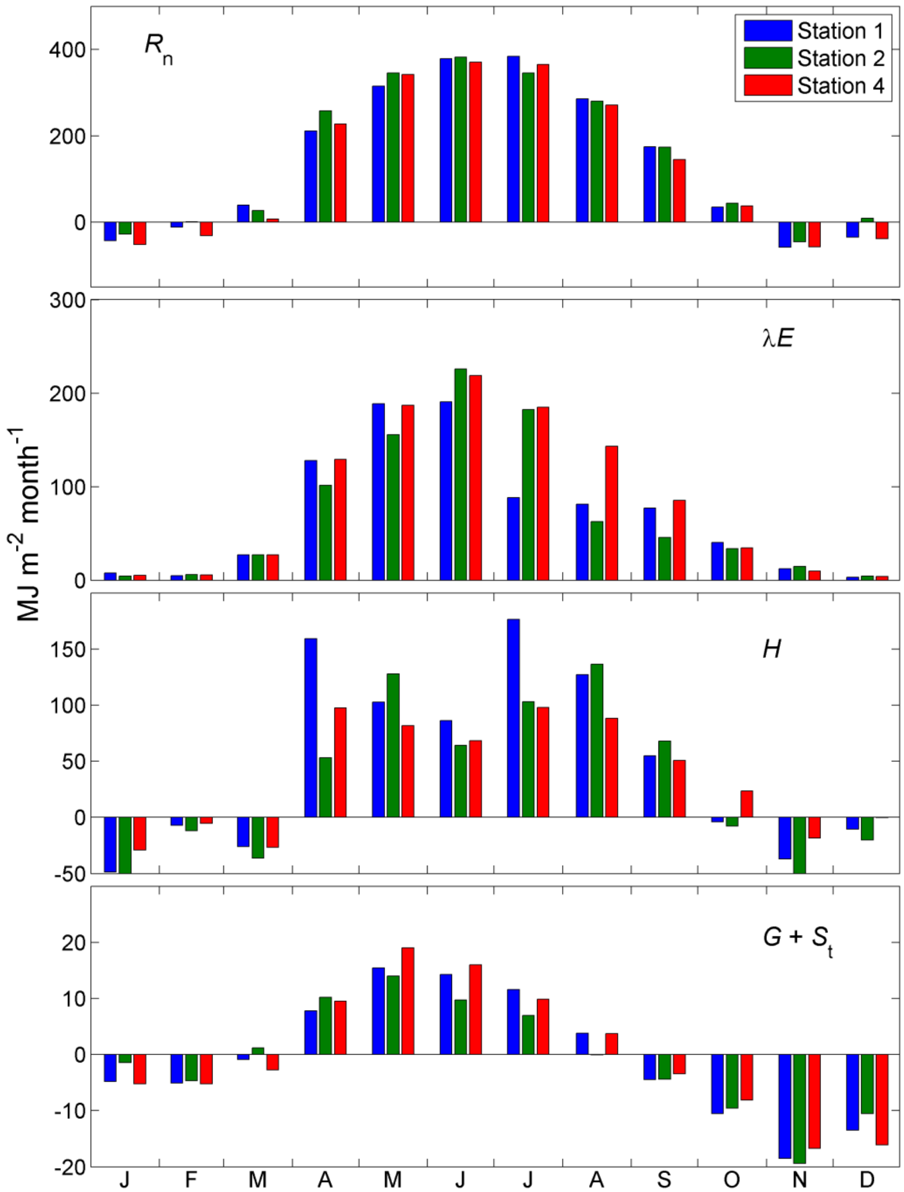

Figure B-4: 2015 Annual energy balance for Stations 1, 2 and 4, with monthly total energy flux by term (a) R_n, (b) λE, (c) H, and (d) $G + S_t$.

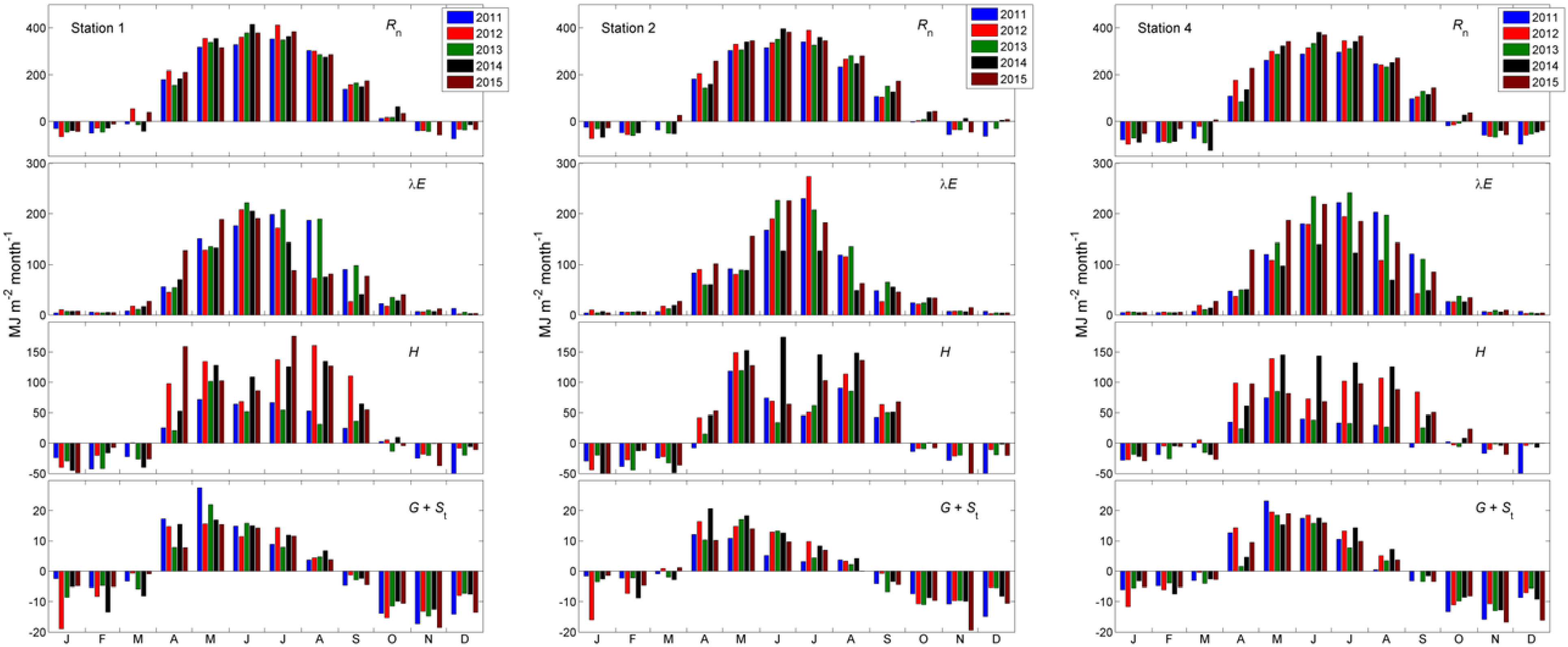

Figure B-5: Annual energy balance for Stations 1, 2 and 4, 2011-2014 with monthly total energy flux by term (a) R_n, (b) λE, (c) H, and (d) $G + S_t$.

An examination of the seasonal patterns of variation in the energy balance components at all of the stations for 2011-2015 (Fig. B-5) reveals similar patterns at Stations 1 and 4 in the two wetter years (2011, 2013) and the three drier years (2012, 2014, 2015). Specifically, in the two wetter years λE is dominant and remains higher later into the growing season while in dry years H dominates. At Station 4, the interannual pattern was strengthened by the fact that the agricultural land management practices were consistent between pairs wet and dry years: animals were grazed at Station 4 in two of the dry years (2012, 2014) whereas in the two wet years and in 2015, the pasture was left undisturbed.

B3.4 Evapotranspiration

2015 Annual evapotranspiration (*ET*) at the three EC stations recovered from 2014. At Stations 1 (340 mm) and Station 4 (414 mm) *ET* was higher than in 2014 (294 and 235 mm respectively) and was closer to the annual values during the wet years of 2011 and 2013. While *ET* at Station 2 (345 mm) increased from the 2014 dry year (234 mm) in which the field surrounding the tower had been left unplanted (Fig. B-6) it remained close to the mean annual *ET* measured from 2011 to 2013 (330 mm) where the field was planted with crop. At all stations, April, May and June showed record or near-record monthly *ET* values (see Fig. B-7) consistent with the early spring thaw. In previous reports it has been noted that Station 2 at Lower Attachie Flat is closest to the Peace River and had shown the least amount of interannual variability in annual *ET* after three years of data collection (Fig. B-7). If we confine our attention to years in which the field surrounding the Station 2 EC tower was planted (2011-2013, and 2015) the mean annual *ET* for those years is 334 mm, ±12 mm. In comparison, the mean annual *ET* for Station 1 over the same period is 346 mm, ±46 mm. As stated in previous years' reports, the lower interannual variability in *ET* at Station 2 could be the result of a higher water table near the river which maintains more consistent soil moisture levels in the root zone through capillary transport, even during years with lower-than-normal growing season precipitation.

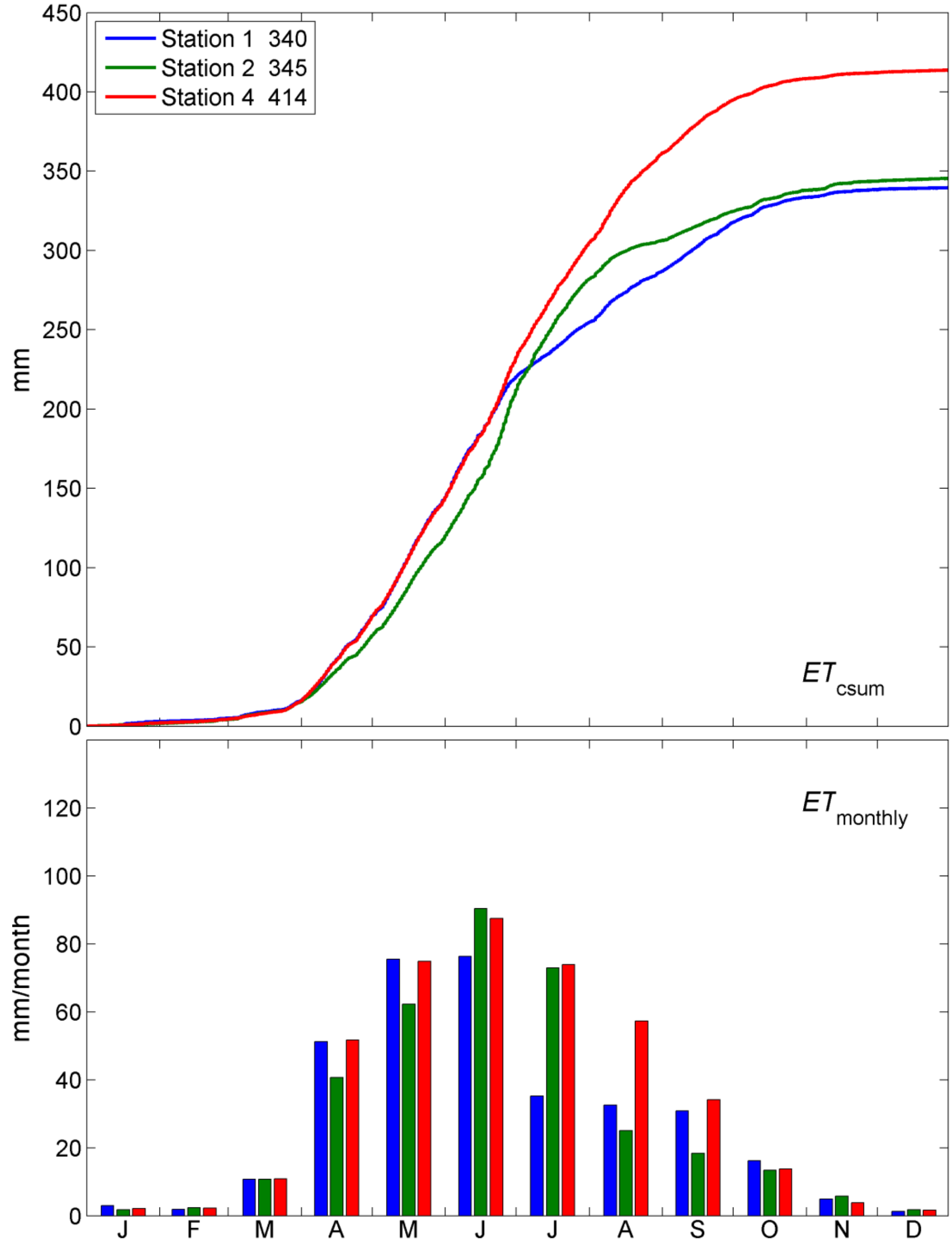

Figure B-6: **Cumulative (ET_{csum}) and monthly ($ET_{monthly}$) evapotranspiration at Station 1, Station 2 and Station 4 for 2014. Annual ET totals in mm are shown in the legend.**

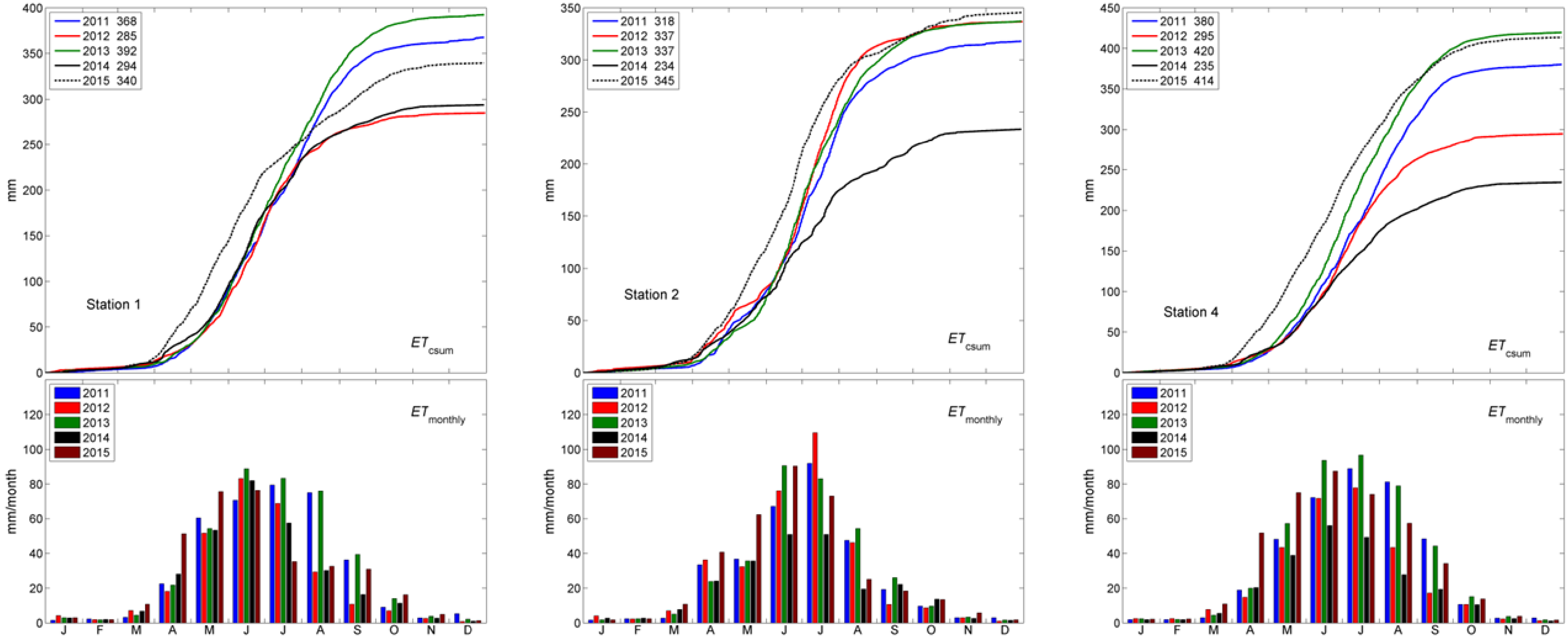

Figure B-7: Annual cumulative ET (upper panels) monthly ET (lower panels) for Stations 1, 2 and 4, 2011-2015.

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B3.5 C balance

All EC stations were C-sinks for 2015 with Stations 1 and 2 showing the influences of agricultural intervention and different stages of the growing season. Station 1 was a C-sink with an annual net ecosystem production (NEP) of 245 g C m^{-2} (2014: 9 g C m^{-2}) (Fig. B-8), however most in the gains in C uptake made from photosynthesis (GEP) were made in May and June before the site was harvested, thereafter respiration (R) from the soils dominated. Station 2 was also a C-sink with an annual NEP value of 220 g C m^{-2} (2014: -198 g C m^{-2}). The reason for the difference in 2015 and 2014 NEP at Station 2 was the 10-fold increase in GEP (558 g C m^{-2}) compared to 2014 (55 g C m^{-2}) when the soil at the site was bare and unseeded with crops. Carbon losses at Station 2 accelerated beginning in August compared to the other sites because conditions for higher soil respiration were helped when the already warmer soil temperatures at that site combined with significant rainfall at the beginning of the month. Station 4 was also a significant C-sink in 2015 with an annual NEP of 283 g C m^{-2}. This was a dramatic increase from 2014 (NEP = -173 g C m^{-2}) in which the field surrounding the Station 4 tower had been grazed with cattle and the animals' clipping and consumption of the grass vegetation dramatically reduced GEP.

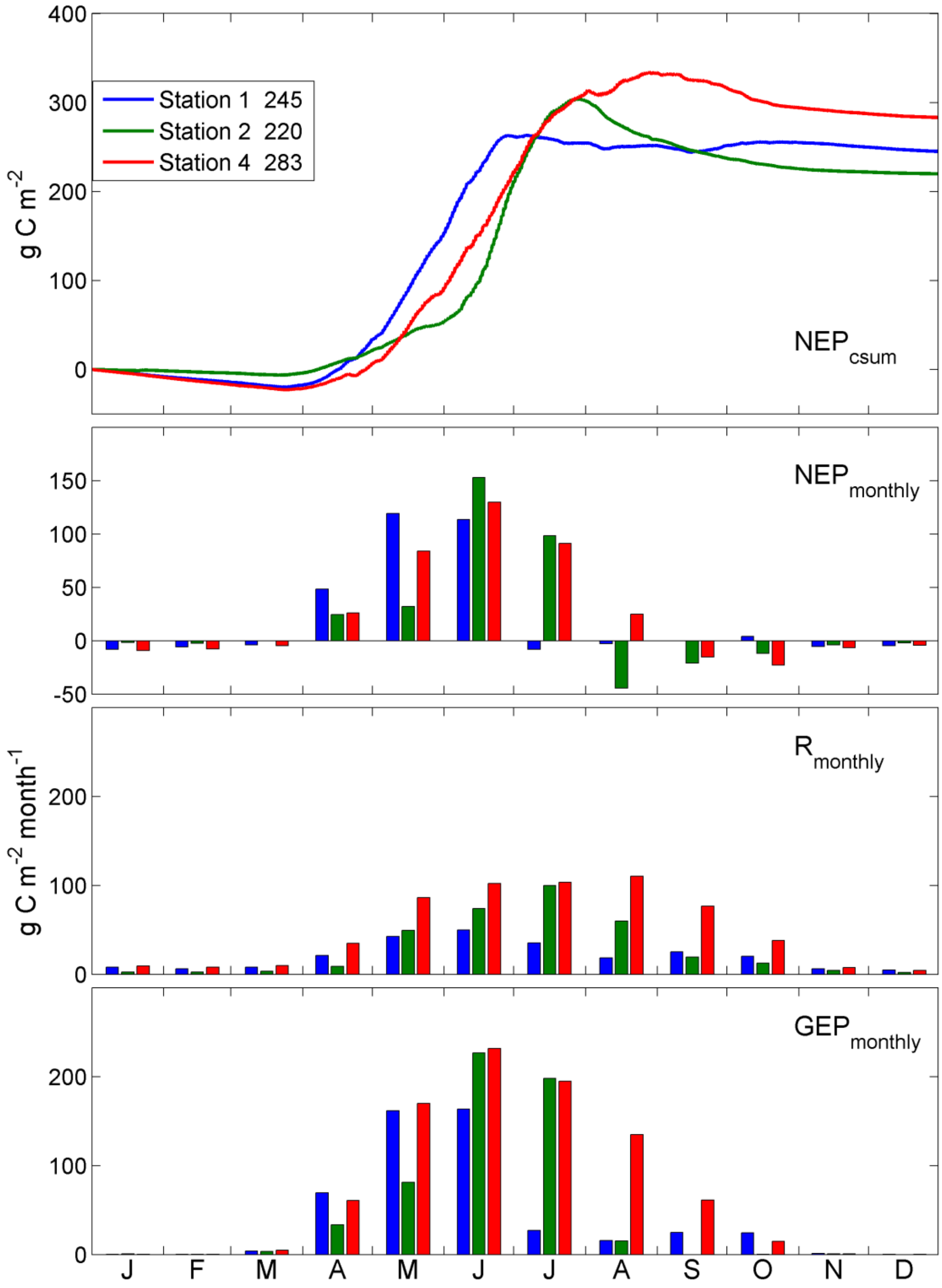

Figure B-8: **C balance components for 2015 at Station 1, Station 2 and Station 4. (a) Annual cumulative NEP, (b) monthly NEP, (c) monthly R and (d) monthly GEP.**

When the components of the C balance are examined by station for 2011-2015 (Fig. B-9), clear patterns of inter- and intra-annual variability in GEP and R emerge between normal-to-wet years and dry years. Stations 1 and 4 are C sinks (NEP > 0) during normal-to-wet years and become near C-neutral (Station 1) or C-sources (Station 4) during dry years. In each case, the pattern is reinforced by similar patterns of agricultural practice between wet and dry years (e.g. cattle grazing or undisturbed pasture, schedules of crop planting and harvesting, respectively).

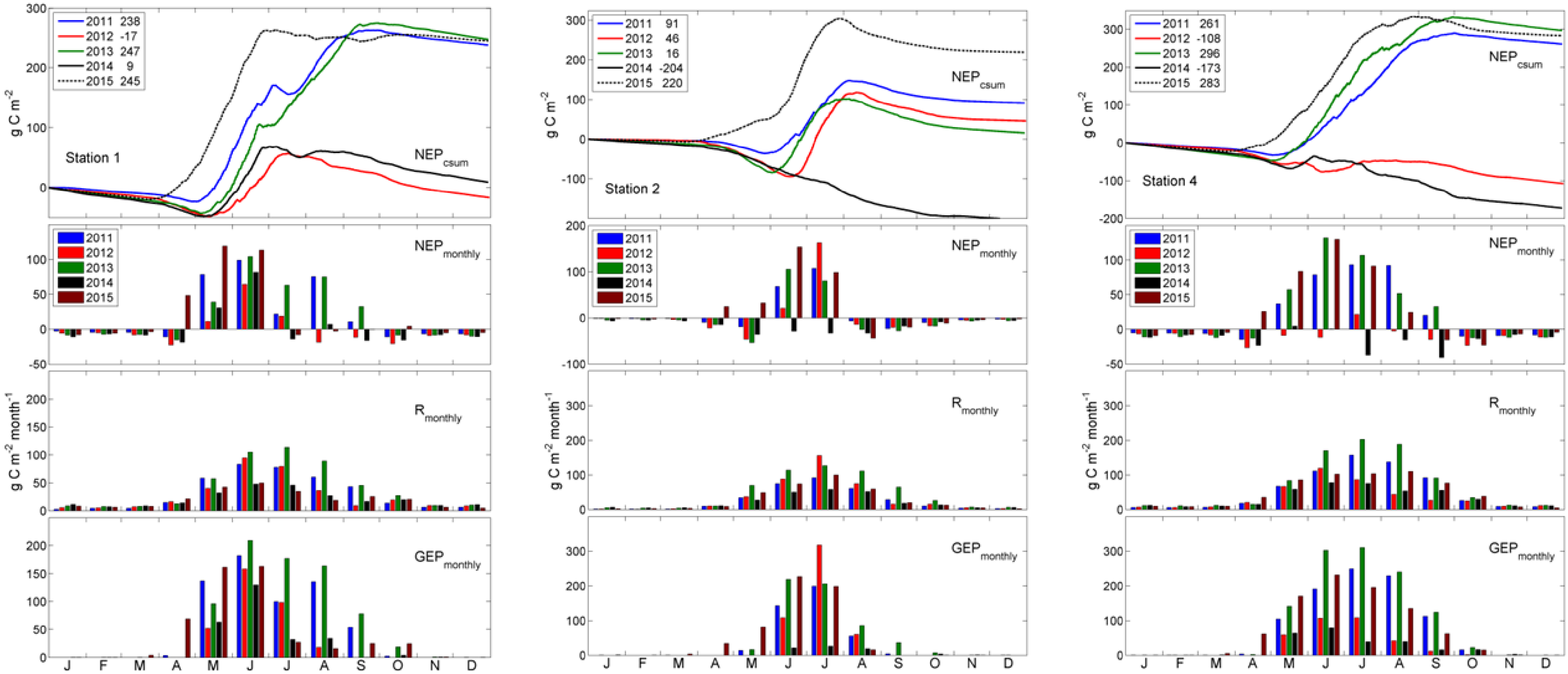

Figure B-9: **C balance components for 2011-2015 for Stations 1, 2 and 4. (a) Annual cumulative NEP, (b) monthly NEP, (c) monthly R and (d) monthly GEP.**

In previous reports, it has been pointed out that Station 2 is unique amongst the EC stations because the C balance between wet and dry years is so robust—the station has been an annual C sink in wet and dry years (Grant et al. 2012, 2013, 2014). Caution should be excercised when interpreting the C-balance traces for the 2015 year due to the aforementioned uncertainty produced from gap-filling the IRGA calibration period, which affects the partitioning of NEP (which is essentially measured by the IRGA) and the C components GEP and R which are derived from empirical models fit to filtered subsets of the NEP data (see Barr et al. 2004 for details). As explained previously, this approach works best in a natural ecosystem setting and would need to be informed with much more information regarding the precise timing and nature of agricultural practices (ploughing, sowing, irrigation, etc.) during the period the IRGA was not making measurements to yield the most accurate results. A relatively low-expense addition to the EC sites that would aid in this task is the use of a digital camera mounted to each EC tower and programmed to record an image every half-hour. Much detail can be gleaned from such images regarding the precise timing and nature of agricultural management practices, which can then be subsequently incorporated in the empirical models of GEP and R just described.

B3.6 EC flux measurement summary 2011-2015

Figure B-10 summarizes the EC results from 2011-2015; the data used in the figure is presented in the Appendix (Table A1) in tabular form. The top panel indicates the agricultural land management status for each station for each year, and the panels below summarize respectively: growing season rainfall, mean growing season air temperature, annual *ET*, mean growing season Bowen ratio ($\beta = H/\lambda E$), and finally annual NEP, R and GEP.

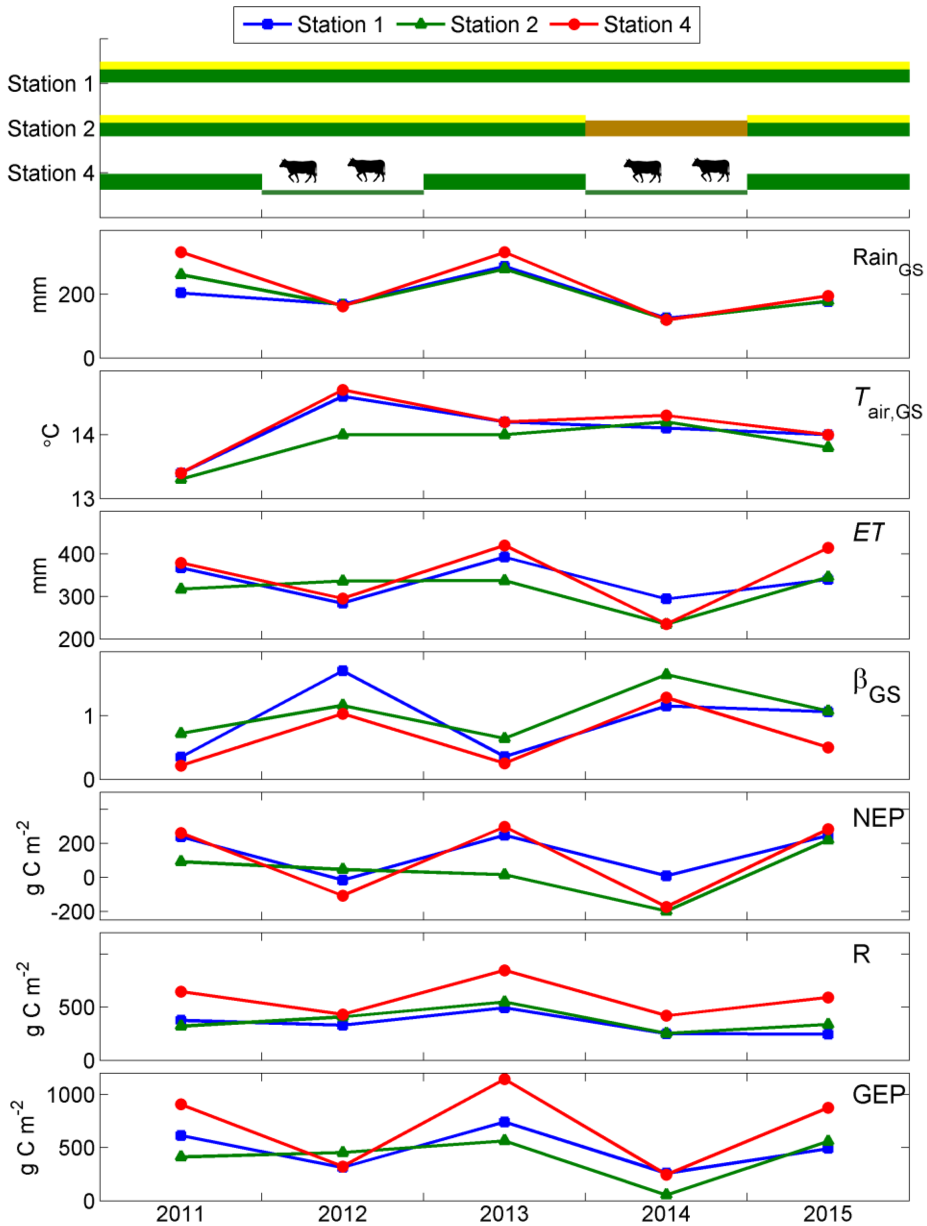

Figure B-10: Summary of eddy covariance results 2011-2015. The top panel indicates the agricultural land management status for each station for each year (green and yellow bars=cultivated with crops, green bars=ungrazed pasture; thin green bar and cattle icon=grazed pasture; brown bar=bare soil) and the panels below summarize, respectively: growing season rainfall, mean growing season air temperature, annual ET, mean growing season Bowen ratio (β = H/λE), and annual NEP, R and GEP.

The pattern of interannual differences in these variables between wet and dry years at Stations 1 and 4 are very similar, with sensible heat transfer dominating dry years ($\beta \geq 1$) and latent heat transfer dominating normal to wet years ($\beta < 1$). As discussed above, Station 2 shows far less interannual variability in all EC fluxes except in 2014 when the land surrounding the flux tower was left bare during the growing season.

B4. SUMMARY

1. Growing season (May-Sept) conditions at all three EC stations were slightly wetter than conditions in 2014. However, 2015 growing season rainfall was comparable to 2012 which was a comparatively dry year compared to other years. Growing season rainfall was 176, 178 and 195 mm for Station 1, Station 2 and Station 4, respectively.

2. 2015 Annual evapotranspiration (*ET*) at the three EC stations recovered from 2014. At Stations 1 (340 mm) and Station 4 (414 mm) *ET* was higher than in 2014 (294 and 235 mm respectively) and was closer to the annual values during the wet years of 2011 and 2013. While *ET* at Station 2 (345 mm) increased from the 2014 dry year (234 mm) in which the field surrounding the tower had been left unplanted (Fig. B-6) it remained close to the mean annual *ET* measured from 2011 to 2013 (330 mm) where the field was planted with crop. Winter soil temperatures were uniformly warmer at all three of the EC stations hence during spring thaw the soil heated up faster than in any previous year, and hence at all stations, April, May and June showed record or near-record monthly *ET* values.

3. All EC stations were C-sinks for 2015 with Stations 1 and 2 showing the influences of agricultural intervention and different stages of the growing season. Station 1 was a C-sink with an annual net ecosystem production (NEP) of 245 g C m^{-2} (2014: 9 g C m^{-2}) with most of the gains in C uptake made in May and June before the site was harvested, thereafter respiration (R) from the soils dominated. Station 2 was also a C-sink with an annual NEP value of 220 g C m^{-2} (2014: -198 g C m^{-2}). Carbon losses at Station 2 accelerated beginning in August compared to the other sites because conditions for higher soil respiration were helped when the already warmer soil temperatures at that site combined with significant rainfall at the beginning of the month. Station 4 was also a significant C-sink in 2015 with an annual NEP of 283 g C m^{-2}. This was a dramatic increase from 2014 (NEP = -173 g C m^{-2}) in which the field surrounding the Station 4 tower had been grazed with cattle and the animals' clipping and consumption of the grass vegetation dramatically reduced GEP.

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Table B-1: Climate and EC data at Stations 1, 2, 4 for 2011-2015.

	Station 1					Station 2					Station 4				
	2011	*2012*	*2013*	*2014*	*2015*	*2011*	*2012*	*2013*	*2014*	*2015*	*2011*	*2012*	*2013*	*2014*	*2015*
[b]Rainfall (mm)	204	168	287	125	176	261	165	279	121	178	332	162	331	119	195
[b]T_{air} (°C)	13.4	14.6	14.2	14.1	14.0	13.3	14.0	14.0	14.2	13.8	13.4	14.7	14.2	14.3	14.0
[c]ET (mm)	367	284	392	294	340	317	336	337	234	345	379	295	420	235	414
[b] β	0.347	1.70	0.356	1.15	1.06	0.718	1.16	0.640	1.64	1.07	0.218	1.03	0.253	1.28	0.5
[c]NEP (g C m^{-2})	238	-17	247	9	245	91	46	15	-198	220	261	-108	296	-173	283
[c]*R* (g C m^{-2})	376	330	494	250	246	321	408	549	253	338	645	430	846	419	591
[c]GEP (g C m^{-2})	614	313	741	259	491	412	454	564	55	558	906	322	1142	246	874

[b] denotes growing season total (Rainfall) or mean (T_{air}, β)
[c] denotes annual totals