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Developing monthly climate reports to aid in field research and expansion planning at the Rice Rivers Center

Joseph Robinson
Virginia Commonwealth University, robinsonjc7@mymail.vcu.edu

Vickie Connors
Virginia Commonwealth University, vsconnors@vcu.edu

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Surface layer climatological analysis of meteorological data at The VCU Rice Rivers Center

Joseph C. Robinson[1,2] and Vickie S. Connors[2]

[1]Department of Biology, Virginia Commonwealth University, Richmond, Virginia
[2]Center for Environmental Studies, Virginia Commonwealth University, Richmond, Virginia

Abstract

Air temperature, precipitation and wind direction are important atmospheric variables when developing a climatology for a certain region. A short-term climatology can be a useful reference for environmental and life science researchers to better understand the environmental conditions of their research. Data were acquired from the VCU Rice Rivers Center (RRC) bluff meteorological tower from 15 June 2008 through 21 July 2016 with a temporal resolution of ten minutes. Time series plots of daily average temperature were created for each year. Temperature and precipitation data were validated by comparison to similarly resolved weather data from a National Oceanic and Atmospheric Administration (NOAA) sponsored station in Hopewell, VA for the same time period. A two-sample t-test between the two data sets demonstrated that the RRC data were of high quality. Cumulative precipitation plots were produced for 2014, 2015 and 2016. Comparison of these plots to both Hopewell and the Richmond International Airport (RIC) showed high amounts of rainfall at the RRC in early 2016, which can be explained in part by strong positive phases of the El Niño Southern Oscillation (ENSO) and other climatic teleconnections. However, further investigation needs to be done to ensure the validity of solely these data. Wind direction was also investigated to determine whether or not channeling along the James River as well as air pollution transport from Hopewell to the RRC occurred. While data did not suggest channeling along the James River, direct transport of air from Hopewell to the RRC was implicated by the data analyzed. Wind direction data analyzed further showed wind shifts associated with the passage of frontal boundaries. The short-term climatology produced by this investigation provides valuable insight to the environment of the RRC and its surroundings, and is a useful tool for researchers seeking environmental information for their work.

Keywords: Climatology, ENSO Teleconnections, Surface Layer

1. Introduction

Climatology, broadly speaking, is the study of the climate in a scientific manner; this can be done on a global scale, such as is done by the NOAA Earth System Research Lab (ESRL), or on a more local scale, such as a climatology created by National Weather Service (NWS) stations. A climatology and the information within it can show how a wide range of atmospheric variables are behaving on a daily, monthly and yearly basis, compared to a long-term average.

1.1. VCU Rice Rivers Center

The RRC, founded in 2000 through the donation of 494 acres to the University, serves as a field station dedicated to environmental and life science research. A main mission of the RRC is to study the environment of the James River system and to expand the public knowledge of that environment so as to protect natural resources. Further, the RRC is home to a diverse assemblage of riparian ecosystems, making it an ideal location for teams of VCU faculty and students to engage in a wide array of research.

The forest ecosystems present at the RRC have been clear-cut and regrown, most heavily during the period of the American Civil War. Kimages Creek, the home of tidal freshwater wetland at the RRC was, for a long time, dammed, creating Lake Charles. In 2008, with the aid of NOAA and the Army Corps of Engineers, VCU and the RRC removed approximately a quarter of the dam (Figure 1.1). This restored tidal flow to Kimages Creek, allowing the permanent restoration of the wetland ecosystem to begin. Restoration of this critical habitat is one of the most prominent projects at the RRC.

Further projects being conducted at and around the RRC include conservation of the Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) as well as monitoring the water quality of the James River and surrounding creeks. Since 1987, VCU and its partners have been actively researching the breeding biology of the Prothonotary Warbler (*Protonotaria citrea*) not only at the Center, but also in Central and South America, where the species winters.

Even with the wide variety of biological and environmental research taking place at the RRC, weather data being collected on site had not been analyzed. Such weather data could be useful for researchers at the RRC, but it first must be quality controlled and compiled into forms that are more relatable. This project aimed to quality control the RRC weather data, compare it to nearby stations and to compile it into a summary report that researchers at the RRC would be able to use when planning, conducting research and ultimately interpreting their results.

Figure 1.1: Aerial views of the VCU Rice Rivers Center before dam removal in 2008 (left) and after dam removal restored flow to Kimages Creek (right).

1.2. climate of the South-Eastern United States and Virginia

The climate of the South-Eastern United States (SE) is influenced by proximity to large bodies of water.[1] Temperatures of the region tend to be mild and decrease with increasing latitude, while amounts of precipitation are largest on the Gulf-Atlantic coasts.[1] Annual precipitation accumulation for a large portion of the SE including Virginia has averaged 40-50in. over the past 30-year period.[2] Through the interplay of many climatic drivers including a high pressure system off the Atlantic coast called the Bermuda High, summers in the SE are warm and moist with frequent thunderstorms.[1] For much of Virginia average temperatures in the summer months hover in the 75-82°F range.[2] Winter in the SE can be variable and unpredictable, with the same climatic drivers leading to cold-air outbreaks reaching as far south as Florida.[1] Winter temperatures for Virginia have historically averaged 28-36°F.[2] Cyclones during the winter months can also carry large amounts of moisture from the Atlantic Ocean and Gulf of Mexico, leading to snow and ice storms in the northern SE.[1] Spring-time, which historically sees temperatures averaging 54-61°F, also sees unpredictable weather phenomena across much of the SE region, with contrasts in temperature and humidity promoting the formation of severe thunderstorms.[1,2]

ENSO also plays a large role in modulating the climate of the SE. The weather and climatic consequences that arise from the interactions of warm and cold waters in the Equatorial Pacific are felt strongly in the SE. ENSO exists in positive and negative phases, each often large and opposite effects on the SE climate. During positive ENSO phases, coined El Niño, changes in airflow aid in transporting moisture from the tropical regions of the Eastern Pacific Ocean to the southeastern United States, increasing precipitation in the region.[3-4] Understanding the backdrop of the SE climate is integral to interpreting the short-term climatology of the RRC, as it can help elucidate reasons as to how and why the meteorological data from the RRC behaved as it did.

2. Data Sources

All on site data from the RRC are taken from the ten-meter meteorological tower located on the Center's bluff overlooking the James River and retrieved from the RRC data coordinator (Jen Ciminelli; s2jmcimi@vcu.edu) in excel formats. The bluff tower continually collects data, which is catalogued every ten minutes. Further, all of the tower's sensors and gauges are calibrated in accordance with NOAA standards in an effort to accurately replicate a NOAA surface station.

Air temperature and precipitation data from Hopewell, VA used for comparisons were available online and retrieved from the NOAA Regional Climate Centers' Applied Climate Information System (ACIS) database. All ACIS data used was found online at: http://scacis.rcc-acis.org/.

Hopewell (37.30° N, 77.29° W) is an industrial town situated West/Southwest from the RRC (37.33° N, 77.21° W) at a distance of approximately 4.76 miles (Figure 2.1). Along this stretch of the James River, flow is in a West to East direction, as seen in Figure 2.1. Hopewell is the closest surface stations to the RRC, providing the best comparison for the RRC data used in this climatology study.

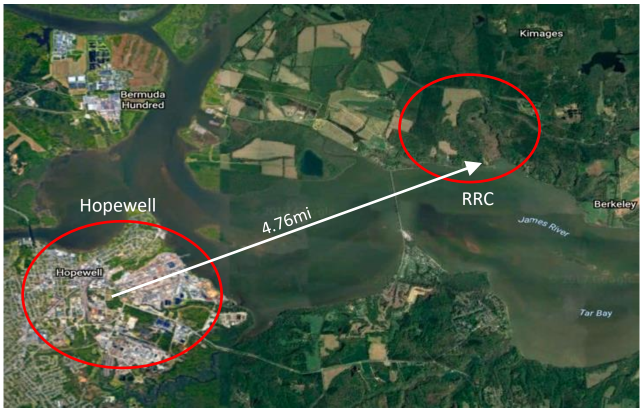

Figure 2.1: Locations of the VCU Rice Rivers Center and Hopewell, VA. North is towards the top of the image.

3. Analytical Approach

The main objective of this study is to create a climatology for the RRC that describes climate norms for: air temperature, precipitation and wind direction (channeling). Larry Brown, a lead forecaster at the NWS station at Wakefield, VA, was consulted on proper manipulation of data in accordance with NWS standards. Each parameter was handled in accordance with NOAA data protocol.

3.1. air temperature

Air temperature data were measured in degrees Fahrenheit (°F). To complete air temperature comparisons, temperature minima and maxima were needed on a daily basis. These temperature minima and maxima were calculated for every day over the period of the investigation and then used to calculate air temperature averages. The average daily air temperature for a day in this study is an average of the minimum and maximum air temperature values for each 24-hour period. Air temperature time series created for the RRC climatology have a time resolution of one day. A time series was created for each year being studied, in order to understand how air temperature behaved on a daily basis from year to year.

Comparisons between data gathered by the RRC meteorological tower and a nearby station, Hopewell, VA, were then made. The decision was made to compare the air temperature time series of both stations for the years 2014, 2015 and 2016, in order to show the RRC data was not significantly different from Hopewell data. Daily temperature data from both sites were transferred into IBM SPSS statistics (IBM Corp., 2016). SPSS was used to carry out a two-sample t-test to test for differences between average daily temperature of RRC and Hopewell over the course of these years. After statistical tests were carried out between the RRC and Hopewell temperature data, Hopewell data were plotted over top of RRC data in order to provide a graphical comparison of the two stations.

Note: the battery on the RRC meteorological tower was inoperable for a period of time between 27 July 2012 and 25 September 2012. No data, whether it be for air temperature, precipitation or wind direction could be included for this time period due to there simply being no data available.

3.2. cumulative precipitation

Precipitation data (inches) from the RRC were processed for years 2014, 2015 and 2016, following NWS protocol for climatological studies. Sporadic data existed for the other years of the study, but were not complete enough to be included.

Daily precipitation amounts were tallied for both stations for each of the years. The gauge at the RRC has a resolution of 0.01. The precipitation data were scaled to physical units (by multiplying each value by 0.01 inch) following the instructions of the gauge used.

Once daily amounts of precipitation were determined, a cumulative precipitation chart was developed to show the total amount of precipitation that had fallen over the course of the entire year at the RRC bluff. Further, a comparison was done between data gathered at the RRC meteorological tower and Hopewell, VA. Calendar years 2014, 2015 and 2016 were used for the comparison. Daily precipitation values from both sites were transferred into SPSS statistics (IBM Corp., 2016). SPSS was used to carry out a two-sample t-test to highlight the differences between average daily rainfall of the RRC and Hopewell over the course of the three years.

Cumulative precipitation time series were also created for Hopewell for 2014, 2015 and 2016, and from these time series, graphical comparisons could be made between the RRC precipitation data and the Hopewell precipitation data.

3.3. wind direction

Wind direction as a weather variable is useful to describe how air is moving. The protocol for listing wind direction is to determine from where the wind is coming. For example, a wind blowing South to North will have a degree measurement of 180°. Further, it is said to be a Southerly wind because it originates from the South. Degree measurements are the standard for wind direction, where a compass is broken down as 360° with 0° corresponding to North, 90° East, 180° South and 270° West (Figure 3.3).

Data for wind direction at the RRC were given in degrees. For each ten-minute period of the RRC data, the prevailing wind direction was recorded. Wind direction data were used in this study to show how often the prevailing wind was coming from different directions relative to the RRC; in particular, this study wanted to investigate whether or not prevailing winds were being channeled along the James River in a West to East fashion. The investigation further aimed to show whether or not airflow across the river from the West/Southwest occurred, which would have implications for air pollution transport from Hopewell onto the RRC.

To show how often prevailing winds were coming from a certain direction, the compass was split into equal sectors, each measuring 30° (0-29, 30-59, …, 330-360). The number of occurrences of prevailing winds coming from each sector were computed. To further organize the data, the percentage of occurrences in each sector was calculated.

Sectors of the compass were color coded to highlight the frequency of prevailing winds coming from the sectors encompassing the four cardinal directions (Figure 3.3). This elucidates the range of degrees and direction that the prevailing winds are most frequently coming from, and allows for conclusions to be made on airflow around the RRC. The frequencies of prevailing winds originating from each sector are shown for 2010 (Figure 4.3). Frequencies were inspected in order to determine if they showed a noticeable and discernable pattern in direction and whether or not there were any implications of wind channeling or pollution transport.

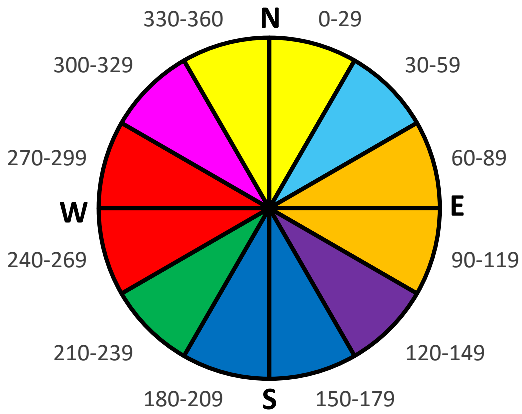

Figure 3.3: Color coordinated compass showing the 360° layout used for the study of wind direction

4. Results

Overall results for this climatology study show important climatic parameters of the RRC over a time period of 15 June 2008 to 21 July 2016. Emphasis was placed on 2014, 2015 and 2016 as data from these years were the most recent and complete. These years were also used for statistical analyses. During this entire time period, average daily temperature time series are presented and shown to be valid for the RRC. Starting in 2014 and encompassing both 2015 and 2016 as well, cumulative precipitation is presented graphically and shown to be valid when taken as a whole. Lastly, prevailing wind direction is presented in an effort to show any wind channeling along the James River and implications of pollution transport.

4.1. air temperature time series and validity

Daily air temperature time series for each year being studied are important for creating a reference for field researchers at the RRC. They allow for a better understanding of the current and past climatic conditions of the Center. The time series are also important for their use of comparing to the climate norms and reports the NWS produces for its stations and surrounding areas.

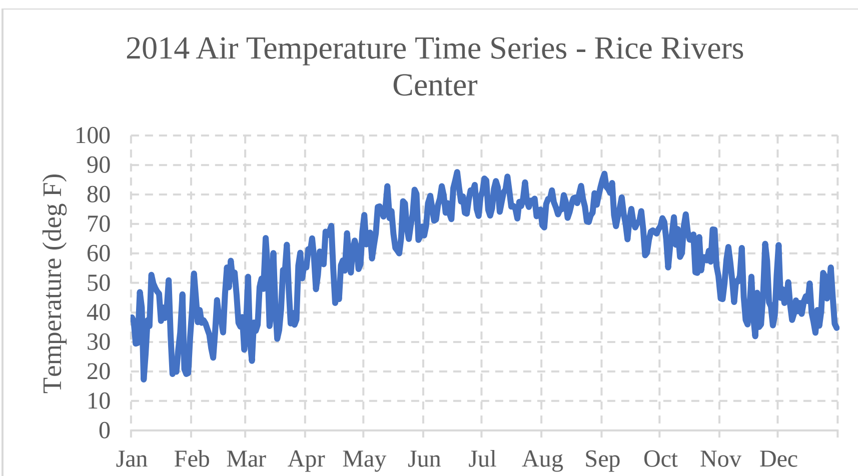

Figure 4.1.1: 2014 daily air temperature time series data (ºF) for the VCU Rice Rivers Center.

The validity of the RRC air temperature data is integral to developing a short-term climatology. Temperature data from the RRC were compared to temperature data from a nearby station in Hopewell, VA. The two stations were compared using a two-sample t-test at an α=0.05. Average daily temperature for the entire 2014, 2015 and 2016 calendar years were compared; the t-test returned a significance value of p=0.029 at α=0.01. This significance value means there is not enough evidence to reject a null hypothesis and that the mean daily temperatures at each station are not significantly different from each other.

For further verification of the RRC air temperature data, daily temperature data from Hopewell, VA were plotted on top of the time series of the RRC to provide a graphical comparison of whether or not the data from each station varied visibly from each other (Figure 4.1.2).

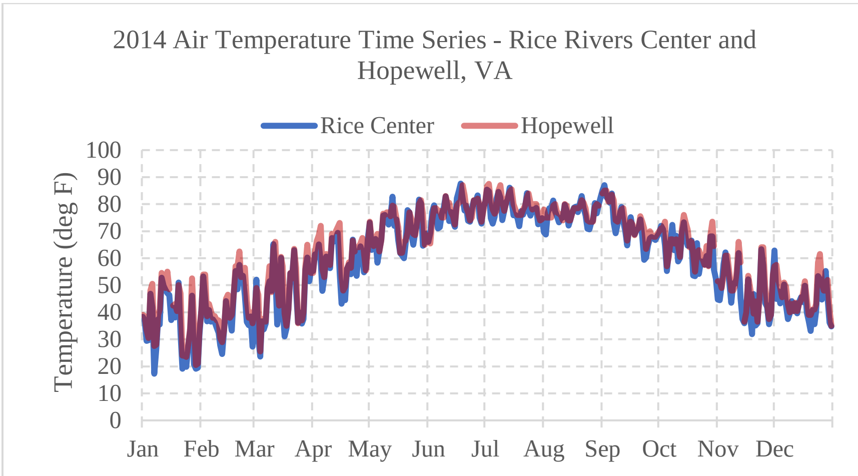

Figure 4.1.2: 2014 daily air temperature time series data (°F) for the VCU Rice Rivers Center and Hopewell, VA.

Air temperatures were also organized into a table that showed monthly average air temperature over the course of the study period. Average monthly air temperatures were calculated by taking the average of every day for that calendar month. This table is useful for comparison to official NOAA climate reports and long-term averages to elucidate any important signals of warming also present at the RRC in the future. One such signal is present in 2012, which NOAA concluded as the hottest year since record keeping began. Despite a battery outage, monthly data from the RRC can help corroborate this story, with the prime example being March 2012 (58.84°F), which was by far the warmest such month recorded at the RRC.

Table 4.1: Monthly average air temperature (°F) at the VCU Rice Rivers Center (dashes represent months outside of the study or with incomplete data).

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Jan	-	36.31	36.85	34.82	43.77	42.14	34.94	37.68	38.48
Feb	-	42.73	36.23	45.18	45.77	40.70	40.32	31.94	42.36
Mar	-	46.97	51.13	48.18	58.84	43.74	44.97	47.02	55.05
Apr	-	59.25	61.51	61.64	58.95	59.95	58.39	59.02	57.91
May	-	68.17	69.49	69.14	71.08	66.46	69.89	71.24	65.06
Jun	-	75.40	79.79	77.84	74.78	76.32	77.19	78.33	75.42
Jul	79.80	76.74	82.30	82.17	-	80.57	78.32	80.40	-
Aug	77.05	80.02	79.98	79.38	-	75.77	76.45	78.44	-
Sep	71.70	69.82	73.81	73.01	-	70.25	72.36	74.62	-
Oct	58.64	59.22	60.97	60.12	61.10	61.87	63.03	59.56	-
Nov	48.61	53.10	49.25	54.50	46.93	49.03	46.91	54.72	-
Dec	44.75	39.74	33.15	47.37	47.49	45.04	43.88	54.17	-

4.2. cumulative precipitation time series

An integral part of the research at the RRC revolves around the hydrology of the Center. Precipitation is an important part of this hydrology, and like air temperature time series, cumulative precipitation time series can help researchers see how wet or dry certain periods were during their research at the RRC.

Precipitation data were only deemed to complete enough during 2014, 2015 and 2016. Time series data are presented for these years only. The time series presented still provide valuable information of the hydrology of the RRC and can be used as the beginnings of a comparison to long-term averages and to other local stations.

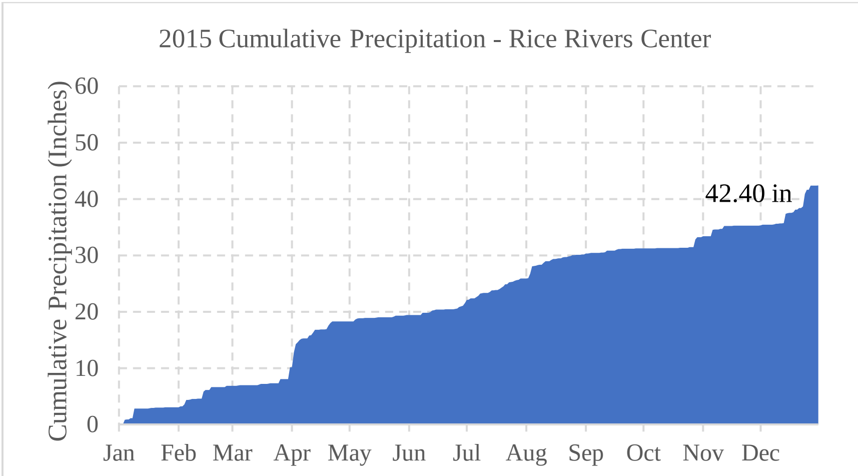

Figure 4.2.1: 2015 cumulative precipitation (inches) time series data at the VCU Rice Rivers Center.

Precipitation data from the RRC compare well to Hopewell statistically. Daily precipitation values for the entire 2014, 2015 and 2016 calendar years were compared between the two stations; the t-test returned a significance value of $p=0.325$ at $\alpha=0.01$. Just as with the air temperature data, this significance value means that the mean daily precipitation values at each station are not significantly different from each other.

Graphical comparisons were also done for cumulative precipitation between the RRC and Hopewell, much in the same way as air temperature (Figure 4.2.2). This allowed for a direct and visual comparison of the two stations in order to see which station saw more rainfall for a given year.

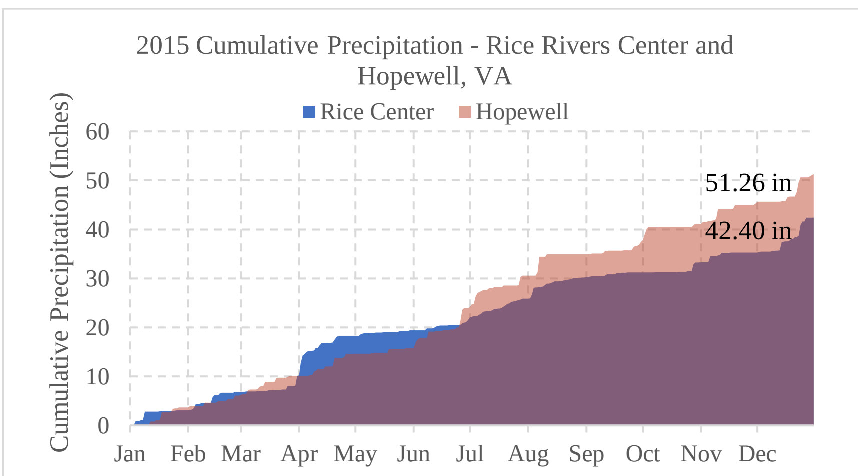

Figure 4.2.2: 2015 cumulative precipitation (inches) time series data for the VCU Rice Rivers Center (42.40 in) and Hopewell, VA (51.26 in).

Precipitation values at the RRC for 2016 showed anomalously large amounts of precipitation. The data for this investigation end on 21 July 2016, meaning the early part of 2016 was exceptionally wet at the RRC. The gauge at the RRC measured a total of 52.16 in. of precipitation falling over this time period in 2016, with a large majority (34.99 in.) falling in the spring-time months of March, April and May. A further statistical test was done to determine whether or not this increase precipitation was significant compared to the same time period in 2015. This test returned a significance value of $p=0.00$ at $\alpha=0.05$. This means there was a significant increase in rainfall at the RRC in early 2016. The increase in spring-time precipitation could be the result of errors in data collection as well as climatic drivers such as ENSO, which are discussed later.

4.3. wind direction and channeling and implications

Data for wind direction were processed and presented to show the percentage of observations that occurred from a certain range of degrees. In other words, how often the prevailing winds blew from a certain direction. This has implications on many fronts, including air pollution transportation along the James River from areas upstream towards the RRC.

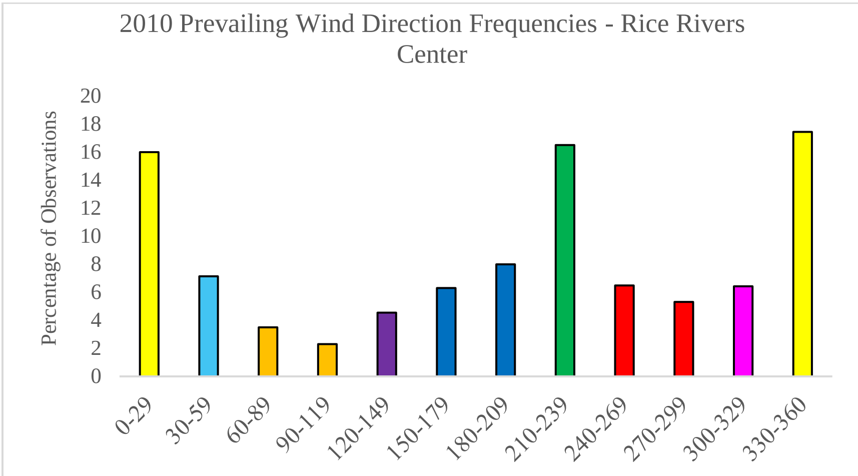

Figure 4.3: 2010 prevailing wind direction frequencies (%) for the Rice Rivers Center

The wind direction data processed were shown to be quite variable; while some years saw a large portion of prevailing winds from a certain direction, there were no discernable patterns that showed evidence of strong channeling along the James River in a West to East direction (red coloration) for any year. Wind direction patterns tended to follow more closely to the passing of frontal boundaries.

While significant channeling did not occur along the James River, there were large amounts of wind recorded originating from 210-270°, which is the general direction of Hopewell. Airborne pollution transport from Hopewell towards the RRC is implicated by the large amount airflow recorded across the James.

5. Discussion

5.1. air temperature

Integral to the success of this investigation is the validity of the air temperature time series data. This climatology is the first study done at the RRC to attempt to validate any amount of data gathered from the bluff meteorological tower. By showing that the air temperature data from the RRC were both statistically and graphically similar to the nearby NOAA sponsored co-op station in Hopewell, the air temperature time series data used in this climatology can be fully trusted for accuracy.

Graphical comparison of the RRC to Hopewell in 2015 in particular was very important in showing the validity of the RRC data. The end of 2015 was a time of anomalously warm temperatures for much of the United States.[4-6] Monthly average air temperatures show that December 2015 at the RRC was more similar to an average spring-time month than December (Table 4.1). Data from Hopewell and NWS stations in the area reflect this as well, and there is little departure from RRC data when Hopewell data is plotted over top of it for the year 2015.

Average monthly temperatures from the RRC compare well to the overall climatology of the SE. Average temperatures for the summer months at the RRC ranged between 74-82°F (Table 4.1). This range compares very well with summer temperature range calculated as a 30-year average for much of Virginia, which is cited as 75-82°F.[2] The same can be said about average temperature for winter months, which ranged from 32-45°F at the RRC, except for times when climate teleconnections caused extreme temperatures (Table 4.1). The range for the RRC is on the upper range of the climatology for the region, which cites the average temperature for winter months at 28-36°F.[2] Although a comparison of these ranges does not perfectly overlap, average monthly temperatures at the RRC compare well overall to the climatology of Virginia and the SE as a whole, further confirming the validity of the RRC air temperature data.

5.2. precipitation

While precipitation data could only be included in this climatology for the three most recent years, there was still valuable information gained from the data included. For example, the time series of cumulative precipitation created can show how precipitation fell over the course of the year; they can show whether it was a wet spring, or dry summer or a combination of both. By investigating and studying these time series, field researchers at the RRC can better conduct their research and explain factors that led to observations in their studies.

Precipitation records at the RRC are not complete enough for an in-depth comparison to long-term averages and trends of accumulation for the area. However, for the years in this study, yearly accumulation of precipitation at the RRC compares relatively well to climate records and long-term averages of Virginia and the SE as a whole. A 30-year average for precipitation accumulations for Virginia shows that 40-50in. of precipitation tends to fall in an average year throughout most of the state.[2] For the two complete years of precipitation data from the RRC, 2014 and 2015, precipitation accumulation values were 28.91in. and 42.40in., respectively (Figure 4.2.1). While accumulation was below the long-term average in 2014, many stations in the surrounding area also showed lower than average amounts of accumulation, including RIC (35.74in.). Accumulation for calendar year 2015, however, fell solidly within this range and compares very well to the long-term average. Further collection and validation of RRC precipitation data must be done in order to more completely develop a climatology of the RRC and compare it to overall trends for the region.

The precipitation time series for 2016, which only covers through 21 July 2016, shows a much wetter than average spring time at the RRC. This large amount of precipitation falling at the RRC in early 2016 could be due in part to the same factors discussed for December 2015 air temperature, namely ENSO. Positive ENSO teleconnections persisted in early to mid 2016, which routinely causes a wetter than average spring in the SE (Figure 5.2).[4]

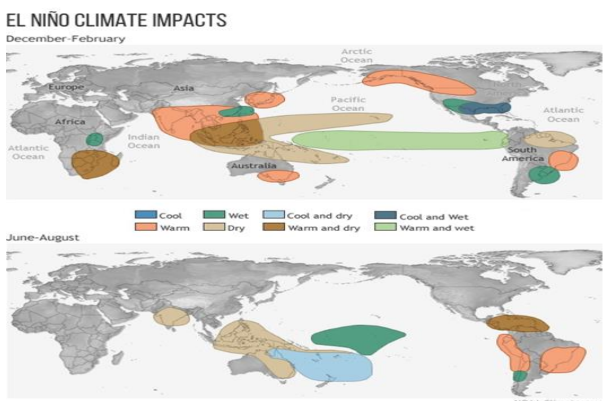

Figure 5.2: Global climate effects of a positive ENSO phase (adapted from the El Nino Theme Page, *Pacific Marine Environmental Laboratory*; http://www.pmel.noaa.gov/elnino/impacts-of-el-nino).

Air flow during ENSO phases can aid in carrying moisture from the Eastern tropical regions of the Pacific Ocean to the SE, increasing precipitation in the region.[3,4] The calendar year 2016 at many stations was on the whole much wetter than normal, and positive ENSO impacts may have contributed to an extremely wet early 2016 at the RRC. However, because many of the surrounding stations in proximity to the RRC still showed precipitation values much lower than the Center, further investigation must be done into 2016 to determine the validity of the precipitation data for this year. Severe storms in the area during early 2016 may have dropped large amounts of precipitation on the RRC, but further investigation to corroborate this is needed. The tipping bucket rain gauge at the RRC may have filled debris and been rinsed and cleaned, causing large and anomalous amounts of precipitation to be recorded.

5.3. wind direction

Wind direction data analyzed from the RRC shows a very sporadic nature in the direction of prevailing winds at the RRC. Prevailing wind directions can be very random at times, and may often change direction very quickly, particularly with the nature of passing thunderstorms in the SE.[1,7] Thus, even though the James River may create a geographic channel for prevailing winds to travel parallel along, data did not support this general pattern.[7] A pattern of channeling over the James River in this stretch would have shown prevailing winds travelling from the West to the East. Frequencies of prevailing wind directions did show patterns that are consistent with weather at the RRC and in the SE as a whole. The data are consistent with weather patterns in the region, where observed frequencies indicate winds flowing prior to and after the passage of frontal boundaries, which are common in the SE throughout much of the year.[1]

A further goal of this climatology study was to observe whether or not wind direction had any implications of transportation of air pollution from Hopewell to the RRC. If the prevailing winds could be shown to travel from a general West Southwest direction across the James River towards the RRC, then airborne pollution from Hopewell was transported onto the Center (Figure 2.1). Minimal wind channeling was found to occur along the James River, but cross river airflow existed that transported air from Hopewell towards the RRC. Because winds from these directions are associated with frontal boundaries, which the SE frequently experiences, pollution transport exists in this area and could benefit from further investigations.

6. Conclusions

Overall, air temperature and precipitation data from the RRC compared well with Hopewell data, both statistically and graphically. This provides insight that the data being gathered on site at the RRC are of high integrity. The time series created for both parameters follow closely the analysis of NOAA and the NWS. Calendar year 2012 at the RRC saw some of the warmest temperatures of data analyzed, for example. Further, the end of 2015 as well as beginning of 2016 were warm and wet, supporting links to a strong positive ENSO phase and other climatic drivers, as cited by the NWS. However, further investigation must be done into the RRC precipitation for 2016 in order to determine its validity.

Wind direction data did not show any patterns of channeling along the James River, but instead tended to follow the wind shifts associated with passing fronts. Although no wind channeling occurred, cross river airflow was observed originating from sectors in the direction of Hopewell, indicating air pollution transport from Hopewell onto the RRC. The short-term climatology created compares well overall to the established climatology for the region, making it a useful tool for researchers interpreting or planning studies at the RRC.

7. Acknowledgements

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