Assessing the Dallas-Fort Worth Urban Microclimate and Surface Ozone Variability Under Differing Drought Conditions

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1. Introduction

- DFW is classified as a humid subtropical climate, characterized by warm summers and wet spring/fall seasons (Köppen, 1936).
- The urban heat island (UHI) arises from temperature differences between urban and rural areas and is maximal in low wind speed conditions.
- Ozone (O_3) in the troposphere is a harmful air pollutant and is formed through the photochemical reaction of nitrogen dioxide (NO_2) , sulfur dioxide (SO_2), and various volatile organic compounds (VOCs) released from automobiles (Zhang et al. 2019).
- The DFW metroplex is the fastest growing metroplex in the United States; its population grew by nearly 93% from 1990-2020.

2. Objectives

- With the DFW metroplex expanding rapidly there is a need to understand how the microclimate responds to differing drought conditions, particularly in July.
- Assessing how drought conditions affect the temperature, NO_2, and O_3 will allow more informed decisions and preparation to be made towards both human and environmental health.

3. Methodology

Hourly data from 2008-2023 was gathered from the Continual Ambient Monitoring Stations (CAMS) implemented by the Texas Commission on Environmental Quality. The urban heat island (UHI) quantification was done to the approach of Runnalls and Oke (2000) and filtered for low wind speeds (≤3 m s^{-1}). The urban and rural stations are represented by C60 and C1044, respectively. Palmer drought severity index (PDSI) values were gathered from the National Center for Environmental Information. The maximum daily 8-hour average (MDA8) was quantified for the regional analysis.

4. Results

4.1 Formation and Evolution of the UHI

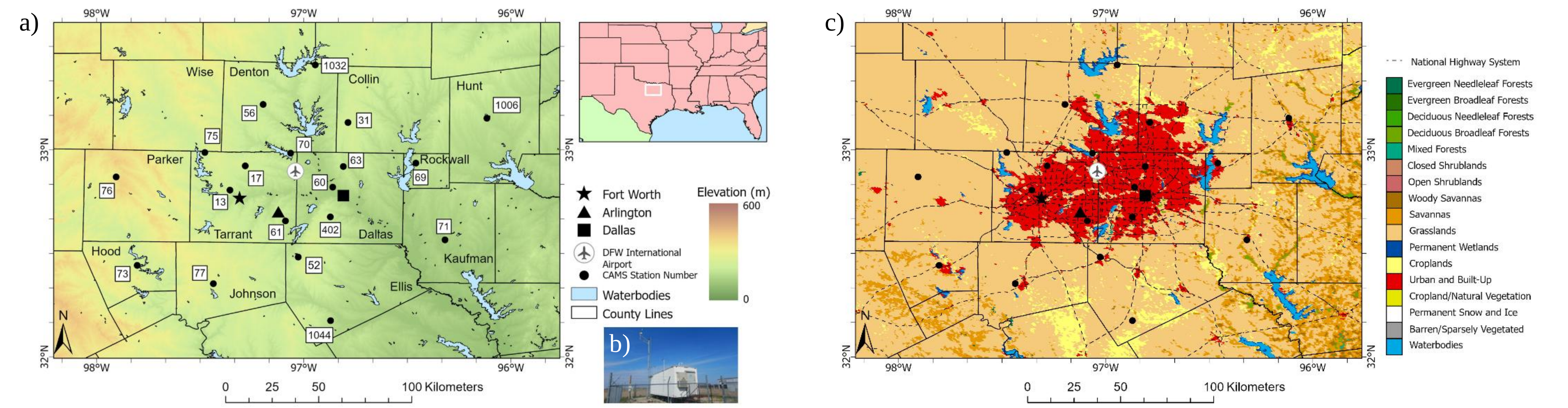

Figure 1. (a) The spatial distribution and location of major cities, DFW International Airport, CAMS stations, major waterbodies, extent of the county lines, and elevation in the region. Elevation data was acquired from USGS Earth Explorer Data Portal in the form of Digital Elevation Models (DEM). DEMs were selected from the National Elevation Dataset (NED) in 1/3 arc-second 1 x 1-degree ArcGrid resolution from 2021. Water body data was accessed through the Shuttle Radar Topography Mission (SRTM) with a resolution of 1 arc-second (~ 30 meters) and acquisition date of 2002.The CAMS stations across DFW are monitored by the TCEQ and function year-round. Pictured in (b) is C1044. (c) Remotely sensed land cover of the Dallas-Fort Worth metroplex from the Moderate Resolution Imaging Spectroradiometer (MODIS) on global 500-m sinusoidal grid from 01 Jan 2023 – 31 Dec 2023 from the Terra satellite. The land cover vegetation type classification is based on the International Biosphere Geosphere Program (IBGP), which is divided into 17 classes.

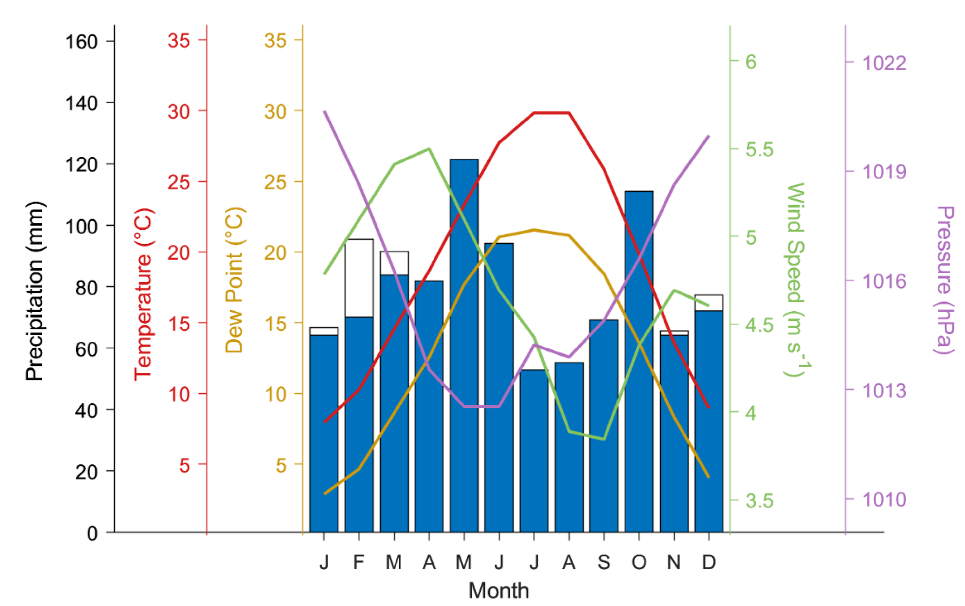

Figure 2. The average pressure, wind speed, dew point, temperature, rainfall (blue bar), and snowfall (white bar) in Dallas-Fort Worth from 1991-2020. Note, the November snowfall is reported as a trace amount (<2.54mm). Data is collected from the DFW International Airport.

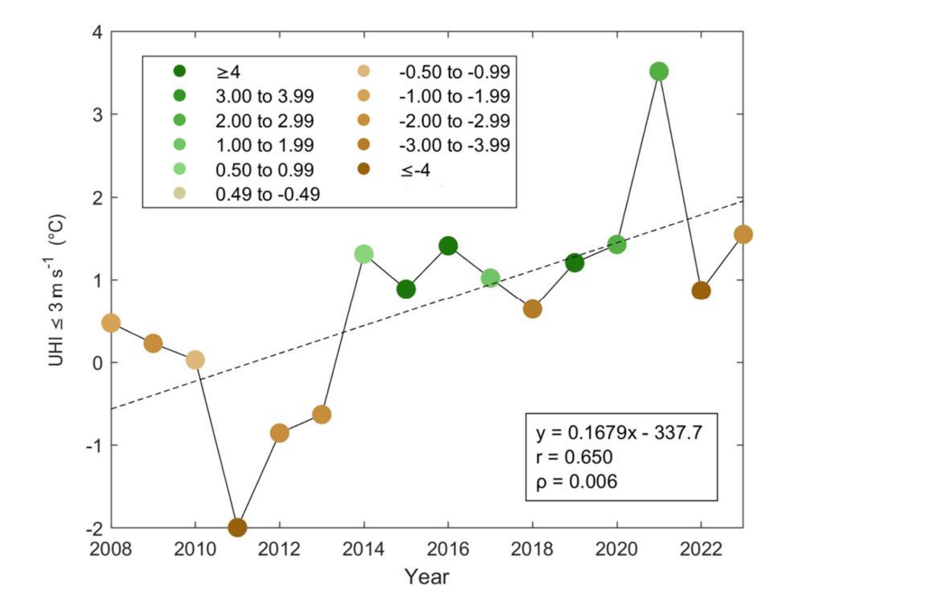

Figure 3. The maximum UHI at 1200 CST during July from 2008-2023. The Mann-Kendall test reveals a significant trend with the UHI increasing over time. The color-coded points are based on the PDSI for that month and year. Positive values are wet and negative values are dry conditions, increasing to extreme conditions past ±4.0. The range of 0.49 to -0.49 are normal conditions.

4.2 Land Use Variation of Temperature, NO_2, and O_3

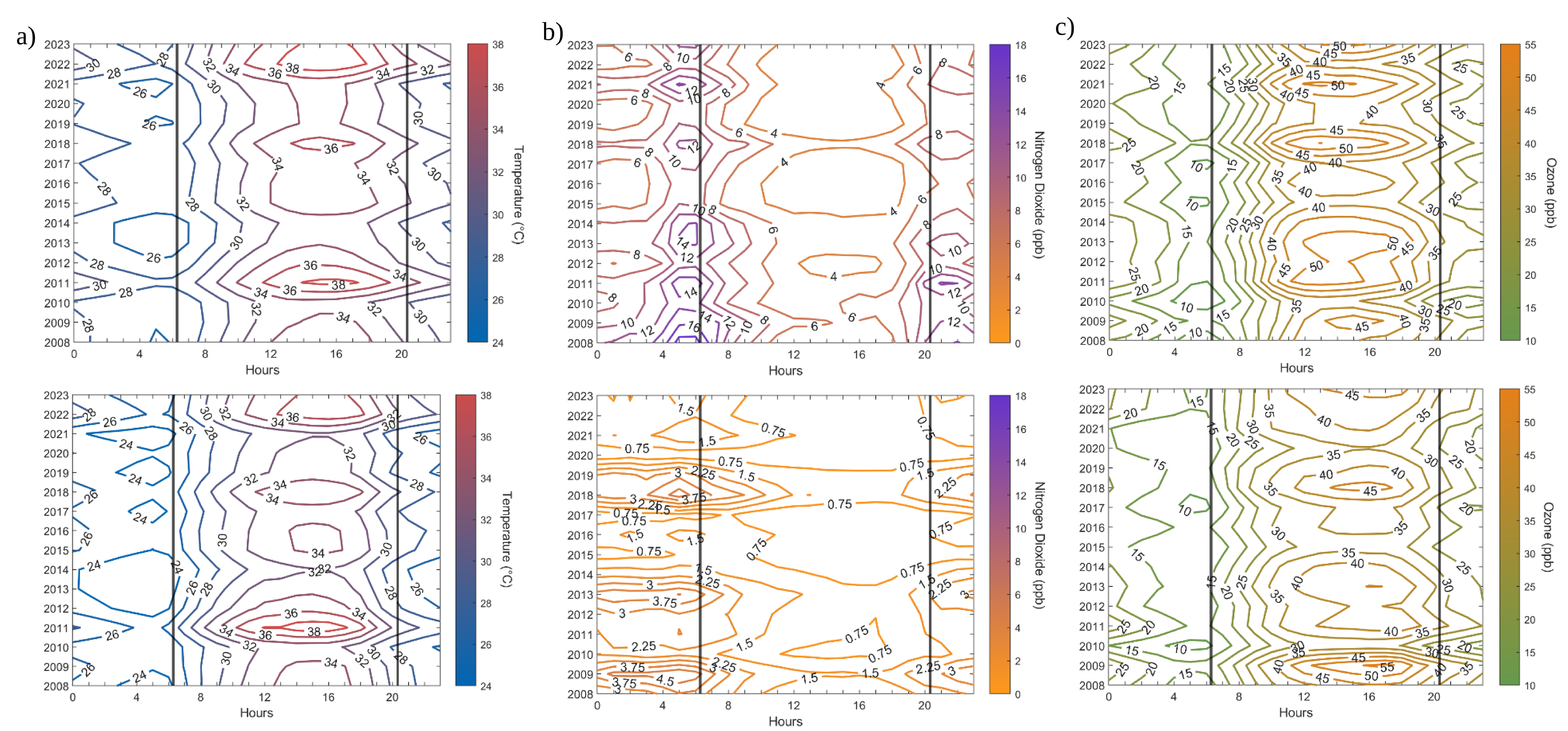

Figure 4. The DFW hourly variation of temperature (a), NO_2 (b), and O_3 (c) in July from 2008-2023. Top is C60 (urban) and bottom is C1044 (rural). Mean sunrise (0630 CST) and mean sunset (2033 CST) for July are displayed as solid vertical lines.

4.3 Regional Analysis of Parameters

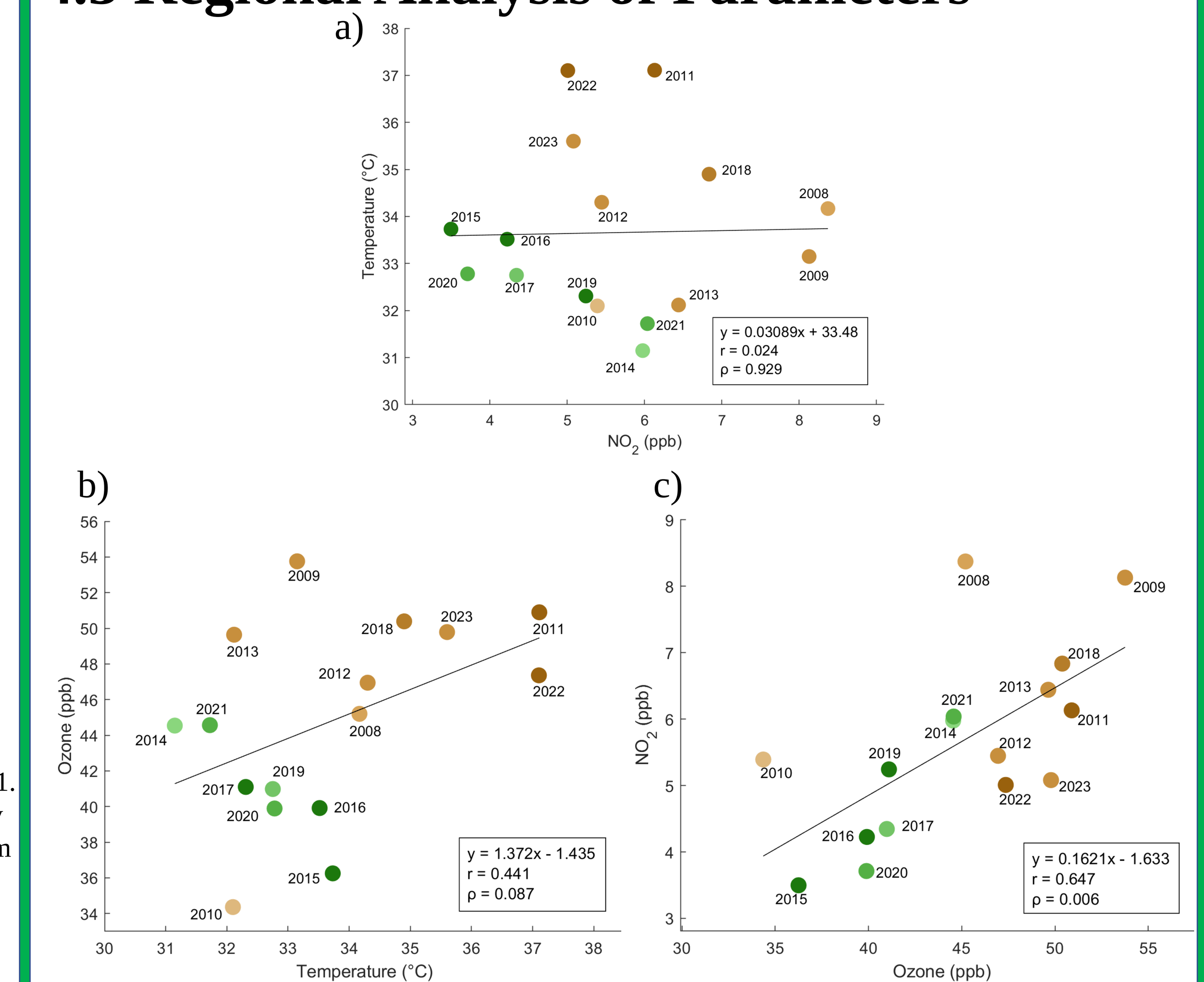

Figure 5. Pearson correlations with a 0.05 significance level of the maximum daily 8-hour average for all stations from 2008-2023. The MDA8 for all stations each year are averaged together to create a single MDA8 value for each year. This method is applied for NO_2 and temperature (a), O_3 and temperature (b), and O_3 and NO_2 (c). The color of each point is associated with the monthly Palmer drought severity index, see Fig. 3 for the index.

5. Conclusion

- During drought conditions, the UHI tended to stay below 1°C, but during wet conditions the UHI increased to >1°C at 1200 CST.
- In extreme drought, the UHI decreased by at least 2°C relative to the previous year.
- Differences in temperature, NO_2, and O_3 between C60 and C1044 were attributed to thermal admittance and surface roughness properties (Zhao et al. 2014).
- About 19% of the variability of O_3 can be attributed to the temperature. 41% of the variability is due to NO_2.
- The decrease of O_3 in wet conditions is likely due to an increase in water vapor from the Bermuda high pressure system and low-level jet that serves as a sink for O_3 (Wang et al. 2016).

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