# Trends in Rainfall Precipitation at Norfolk, VA

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## Introduction

Flooding has become a problem in Hampton Roads as evidenced by the recent impact of Hurricane Matthew in October 2016. It is believed that the increase in flood frequency is both due to increasing tidal and storm surge as well as heavy rainfall. For example, one particular low-lying area in the City of Norfolk, the “Hague,” has seen increased flooding from a dozen hours per year in the 1930s to hundreds of hours per year today (VIMS, 2013). It turns out that the measured local sea level rise is actually caused by both global sea level rise and local land subsidence (Atkinson *et al*, 2013). That is, while global sea level is rising due to the thermal expansion of ocean waters warming in response to anthropogenic greenhouse gas emissions (IPCC, 2007), the land in Southeastern Virginia is sinking due both to glacial isostatic adjustment and groundwater withdrawals (VIMS, 2010). Exacerbating this trend are recent findings that tidal flooding is worst when associated with tropical storms and that the intensity of land-falling tropical storms is increasing in response to climate change (Grinsted *et al*, 2012).

In addition to sea level rise, there is also evidence that the eastern U.S. are experiencing more extreme rainfall, which can overwhelm drainage systems and exacerbate flooding associated with increasing storm surge. Min *et al* (2011) showed that greenhouse gas emissions have contributed to the observed intensification of heavy precipitation events found over large parts of Northern Hemisphere land areas. Kunkel *et al* (2010) attributed increases in heavy precipitation in the United States to higher intensity tropical cyclones.

These observed changes call into question the current practice of designing civil infrastructure on the basis of precipitation Intensity-Duration-Frequency (IDF) curves that are derived with the assumption of a stationary precipitation record. Disregarding an increase in heavy precipitation events can cause increased flood risk and exascerbate infrastructure damage and failure. This paper provides a cursory analysis of the historical precipitation record for the Norfolk, Virginia area.

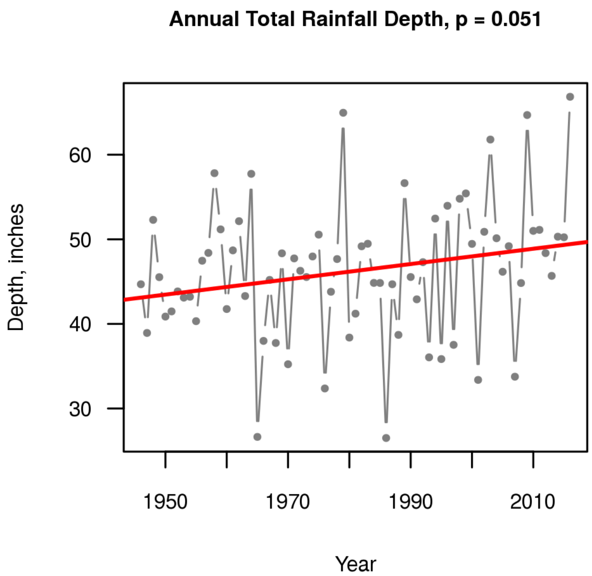
## Data and Methods

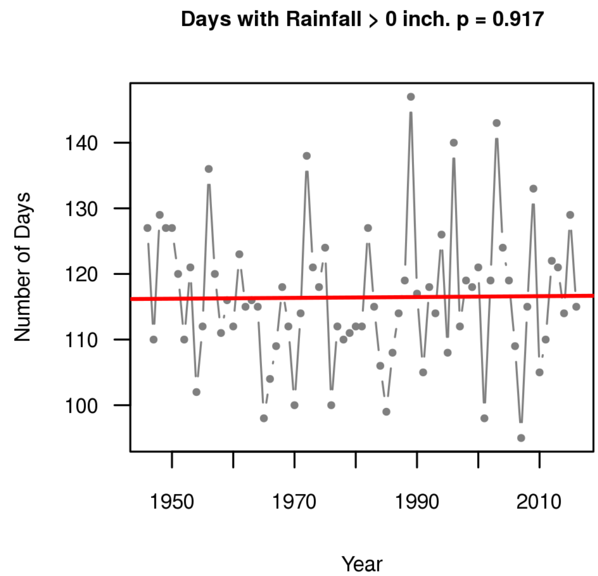
Daily rainfall totals for the Norfolk Airport rain gauge (GHCN ID: USW00013737) were obtained from the National Oceanic and Atmospheric Administration (NOAA) Global Historical Climatology Network ftp-server at ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/. The records of daily rainfall totals at the Norfolk Airport rain gauge extend from January 1, 1946 to the present.

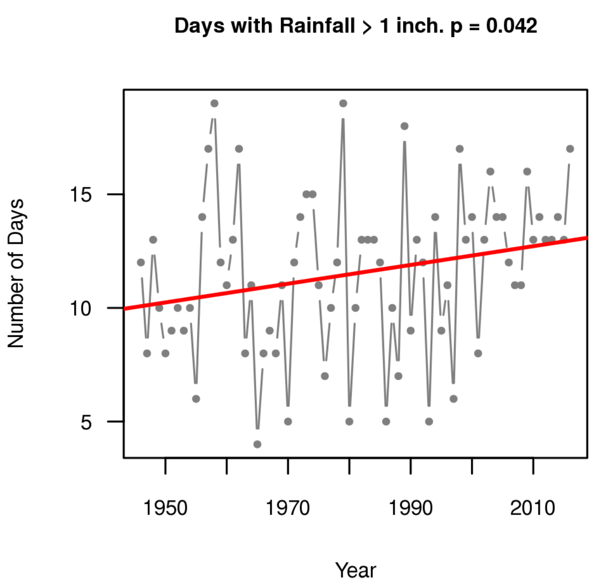
The official precipitation frequency estimates for Virginia were last revised in 2006 by the National Weather Service (NWS), and they were based on data extending through December 2000 (NOAA, 2006). The methodology to arrive at the official precipitation frequency estimates is described in detail elsewhere (NOAA, 2006), and no attempt was made here to replicate this approach. The NWS uses data from numerous rain gauges and area-weighted, spatial interpolation to determine point estimates, whereas only the rain gauge at the Norfolk Airport is considered here. In addition, the NWS performs frequency analyses on the series of annual maximum rainfall depths of various durations. Here a peaks-over-threshold (POT) model of daily rainfall totals is utilized, following the approach outlined by Coles (2001). Because intense rain events other than the annual maxima are not discarded, the POT approach can provide robust estimates even from a single rain gauge.

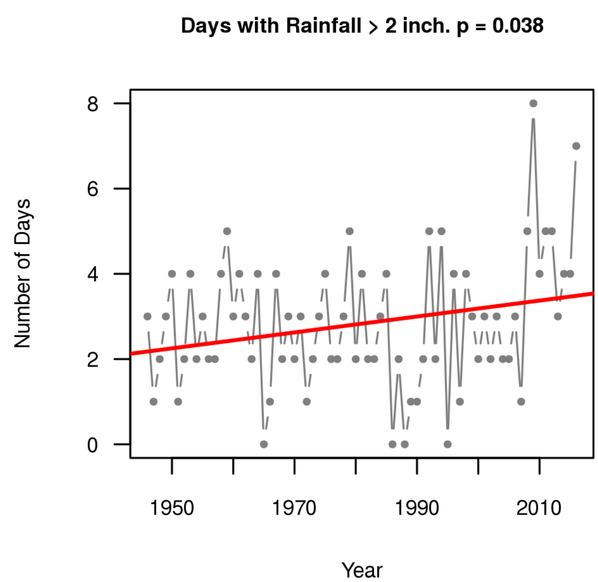
## Results

An overview of the Norfolk Airport daily rainfall records is presented in the graphs below. Based on ordinary linear regression, it can be observed that the total annual rainfall has trended up of the past 70 years from about 43 inches to nearly 50 inches while the number of rainy days has remained on average unchanged. Although the record for the current year (2016) is incomplete, the total annual rainfall has already exceeded 67 inches. Statistically significant increasing trends for the number of days with rainfall totals above 1 or 2 inches are also evident.



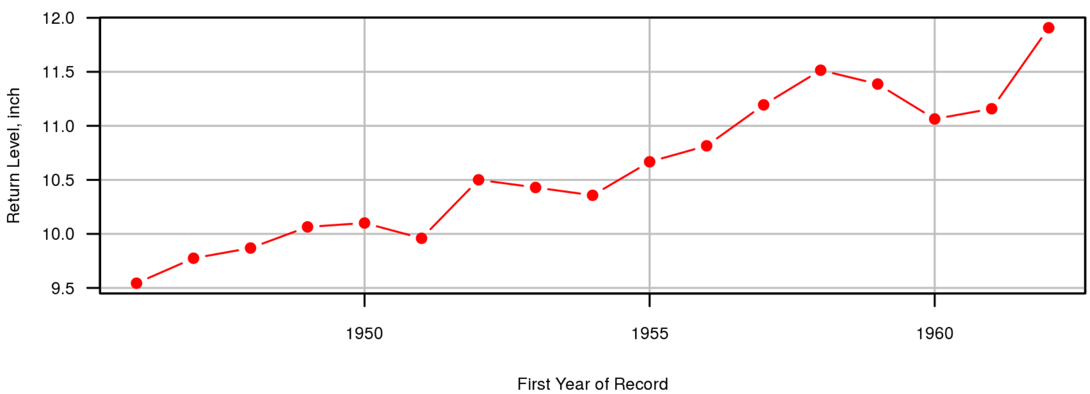



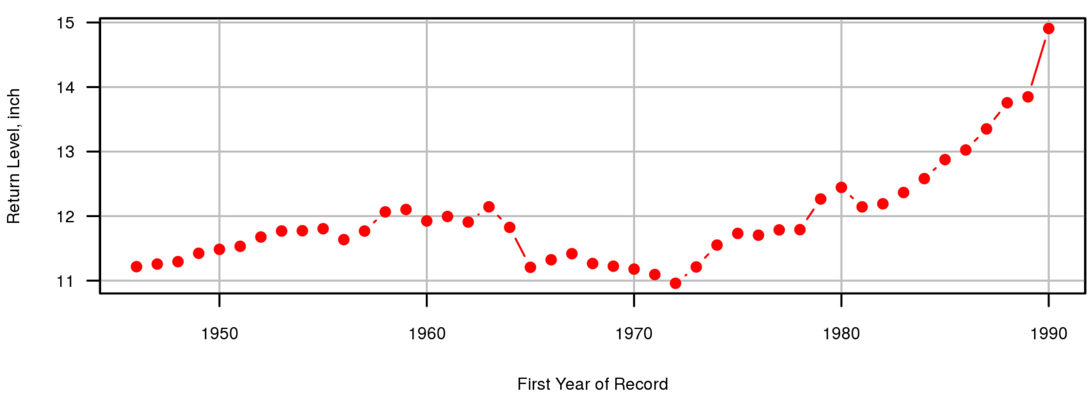




Precipitation frequency estimates for the Norfolk Airport daily rainfall data were carried out using the extRemes package in *R* (Gilleland and Katz, 2016). A threshold of 0.5 inches was selected based on the approach described by Coles (2001). First, a series of computations was performed to determine how extending the historical rainfall record would affect the return levels. The graphs below show that regardless of which time period is selected from the historical record, more recent data yield considerably higher estimates for a 1-day, 100-year rainfall event. The bottom plot illustrates that the 100-year return level estimate for the official record (through December 2000) is approximately 9.5 inches, which is in good agreement with the NOAA Atlas 14 point precipitation frequency estimates for a 24-hour event.

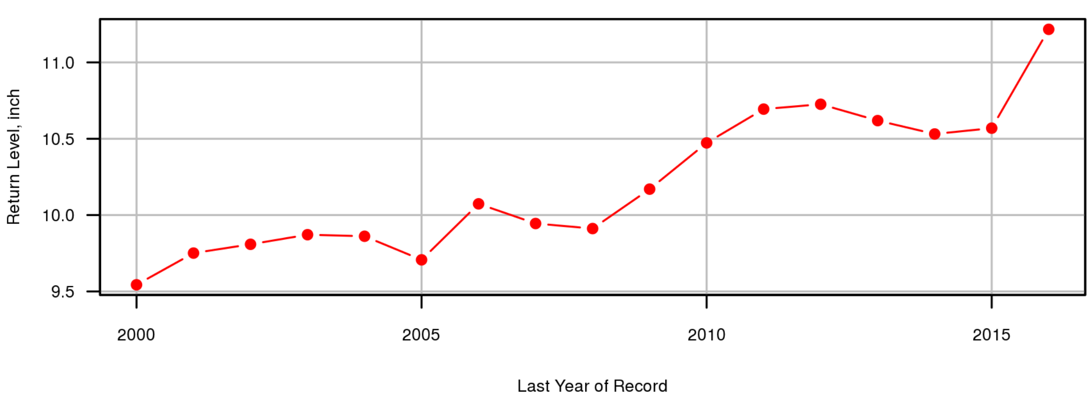
**100-year Return Level for 55-Year Rainfall Record**



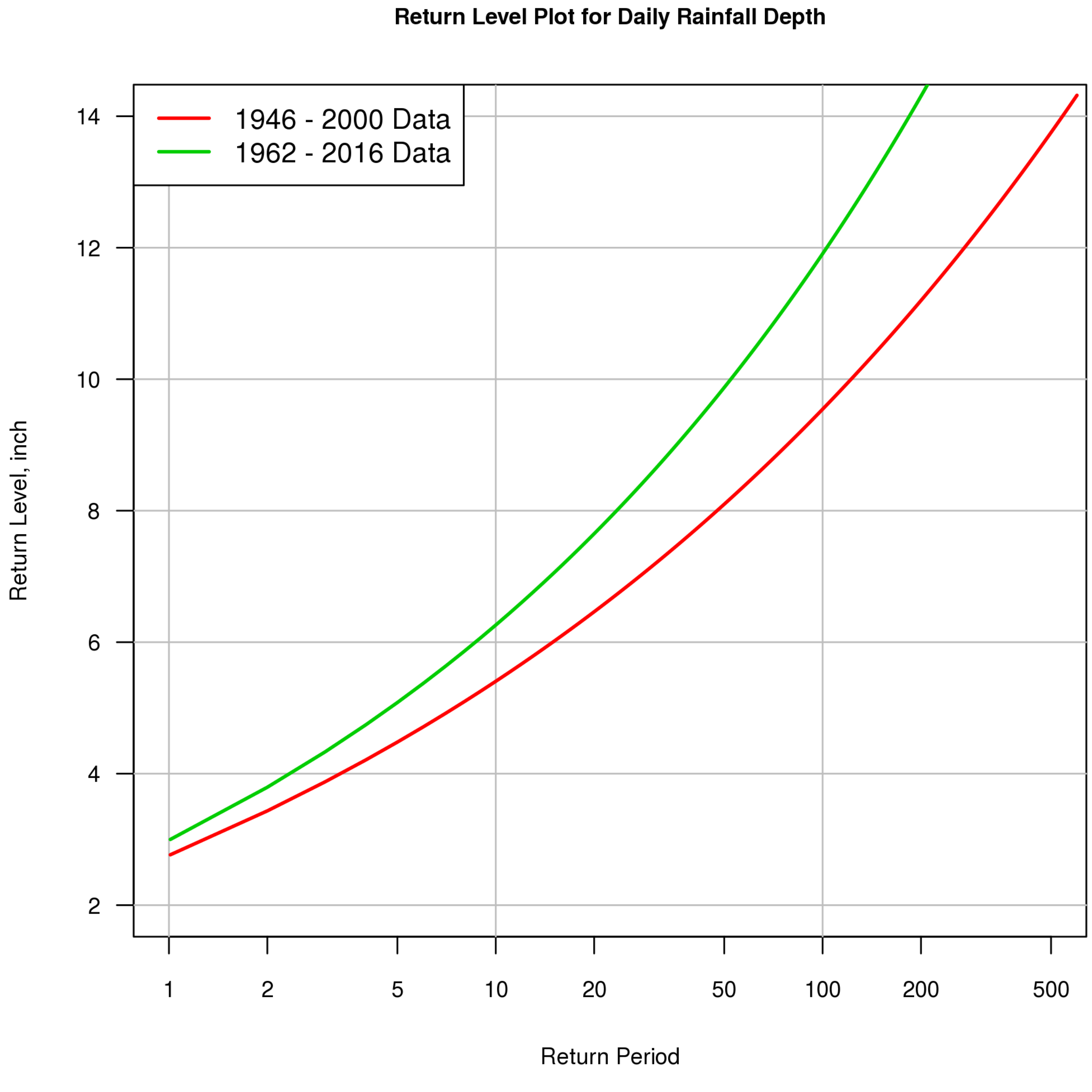

**100-year Return Level for Rainfall Record Ending in 2016**




**100-year Return Level for Rainfall Record Starting in 1946**



The data also show that including the last 16 years of rainfall data increases the 100-year return level from 9.5 to over 11 inches. This analysis can be performed for a range of return periods. The return level plot shown below compares two equal-length (55-year) data sets from the Norfolk rainfall record. It illustrates, for example, for an 1-day 8-inch event the return period has decreased from about 50 years to approximately 25 years.




## Summary

A review of the historical rainfall record for the Norfolk Airport confirms peer-reviewed research that suggests that extreme rainfall events are happening more frequently in parts of the Northern Hemisphere. It is recommended that design criteria for civil infrastructure be revised to take these trends into account.

## References


Atkinson LP, Ezer T, Smith E (2013). Sea Level Rise and Flooding Risk in Virginia . Sea Grant Law & Policy Journal Vol. 5.2 No. 2 p. 3-14. Available online: http://www.ccpo.odu.edu/~tezer/PAPERS/2013_SGLPJ_Atkinson_SLR.pdf

Coles, Stuart (2001). An Introduction to Statistical Modeling of Extreme Values. Springer Series in Statistics. Springer-Verlag London.

Eric Gilleland, Richard W. Katz (2016). extRemes 2.0: An Extreme Value Analysis Package in *R*. Journal of Statistical Software, 72(8), 1-39. http://dx.doi.org/10.18637/jss.v072.i08

Grinsted A, Moore JC, Jevrejeva S (2012) Homogeneous record of Atlantic hurricane surge threat since 1923. Proc Natl Acad Sci USA 109:19601–19605.

International Panel on Climate Change (IPCC) (2007) Fourth Assessment Report: Working Group I: The Physical Science Basis, Section 5.5.3 Ocean Density Changes. Internet: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch5s5-5-3.html. Accessed: October 2013.

Kunkel KE, Easterling DR, Kristovich DAR, Gleason B, Stoecker L, Smith R (2010) Recent increases in U.S. heavy precipitation associated with tropical cyclones . Geophysical Research Letters, 37, L24706 .

Min S-K, Zhang X, Zwiers FW, Hegerl GC (2011) Human contribution to more-intense precipitation extremes . Nature 470, 378-381.

National Oceanic and Atmospheric Administration (2006). NOAA Atlas 14: Precipitation-Frequency Atlas of the United States. Volume 2 Version 3.0. Internet: http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume2.pdf. Accessed: October 2016.

Virginia Institute of Marine Science (VIMS) (2010). Chesapeake Bay Land Subsidence and Sea Level Change - An Evaluation of Past and Present Trends and Future Outlook . Internet: http://web.vims.edu/GreyLit/VIMS/sramsoe425.pdf. Accessed: October 2013.

Virginia Institute of Marine Science (VIMS) (2013). Recurrent Flooding Study for Tidewater Virginia . Report submitted to the Virginia General Assembly January 2013 . Internet: http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf, Accessed: August 2013.