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Anatomy of the 2016 drought in the Northeastern United States: Implications for agriculture and water resources in humid climates

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ABSTRACT

2016 was one of the warmest and driest summers on record throughout much of the Northeastern United States (Northeast). Additionally, historically low winter snowfall preceding the summer of 2016 exacerbated drought conditions and led to record low streamflows in some regions. Climate models suggest that short-term summer droughts could increase in frequency and continue to pose challenges to farmers and water resource managers in the Northeast. Here we focus on the impacts of the drought on farmers in New York State (NY), an economically important agricultural state in the Northeast. We found that in several regions across NY 2015-16 winter snowfall, and 2016 growing season precipitation and streamflows were near or below the 10th percentile of the previous 60 years; and 2016 air temperatures were near or above the 90th percentile of the previous 60 years. Based on survey results, more than 70% of the 275 farmers surveyed across NY reported rainfed field crop and pasture yield losses greater than 30%, with some loses over 90%. In the hardest hit Western region of NY, substantial crop losses (> 30%) were reported for fruit and vegetable crops on farms with irrigation, due to limited irrigation equipment and water supplies (e.g. low streamflows, dry ponds or wells). After what they experienced in 2016, 32% of the 75 farmers in follow-up interviews invested in irrigation equipment and water sources in 2016, and 32% said they plan to do so in 2017. Thirty-two percent of farmers in follow-up interviews said they plan to take measures to improve soil health and soil organic matter to improve water holding capacity and better prepare for drought. Model estimates suggest NY state-wide crop irrigation water use could increase by 3–8 times in dry years compared to average growing seasons, increasing seasonal usage by millions of cubic meters. This highlights the potential for significant increases in water withdrawals in NY, with implications for water resources, particularly as the climate changes.

1. Introduction

Freshwater resources are becoming increasingly limited in many parts of the world, not only in arid regions, but also in humid and temperate regions where rainfall is typically abundant (Pereira et al., 2002). Because irrigated agriculture is a leading consumer of freshwater resources globally (Calzadilla et al., 2010; FAO, 2011) and in the United States, where agriculture accounts for 80% of national surface and ground water consumption (Gollehon and Quinby, 2006), understanding current and future agricultural water use is crucial to maintaining viable water and agricultural resources. Although irrigation is used more frequently in arid regions, supplemental irrigation is often economical and used in humid regions to optimize production and buffer effects of rainfall variability (Rey et al., 2016; Wriedt et al., 2009; Oweis, 2005; Wilks and Wolfe, 1997). For instance, in the Southeastern United States, where average annual precipitation is over 130 cm (Nuti and Lamb, 2009), irrigation of crops has increased considerably over the years due both to uncertainty associated with rainfall amounts and distribution as well as the fact that supplemental irrigation increases yields and profits (Salazar et al., 2012; Lamb et al., 2011).

In the Northeastern United States (Northeast), field crops and pasture are rain-fed, while many fruit and vegetable farmers have some irrigation equipment to supplement summer rainfall, typically moveable sprinklers for most crops and drip systems for some apple orchards. The Northeast does not have an elaborate infrastructure for water delivery to farms via canals or ditches as is common in some arid regions. Farmers instead pump from local streams, farm ponds, or wells and the irrigation capacity at the regional and farm level is not established to cope with prolonged summer drought (S. Fickbohm, New York Agriculture and markets, personal communication, 2017).

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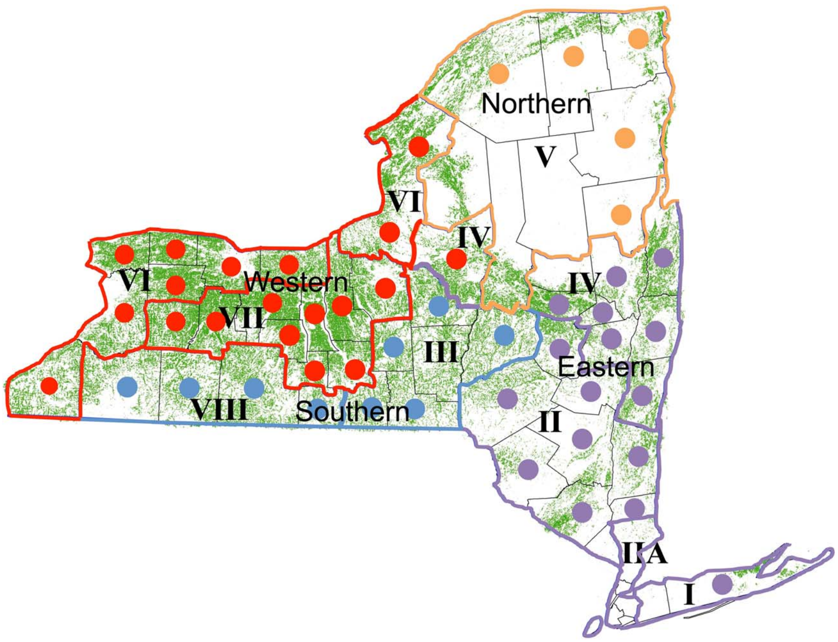

Fig. 1. New York State's agriculture (green areas), which includes cultivated crops and hay/pasture from the 2011 National Land Cover Database (NLCD: https://www.mrlc.gov/nlcd2011.php). Outlined areas labeled with Roman numerals are designated New York State Department of Environmental Conservation Drought Management Regions (NY DEC: http://www.dec.ny.gov/lands/5014.html). The eight drought regions are also grouped into four main regions (American Council of Engineering Companies of New York: http://www.acecny.org/page/regions-13.html): Northern (drought region V − orange), Eastern (drought regions I, II, and IV − purple), Southern (drought regions III and VIII − blue), and Western (drought regions VI and VII − red). Colored dots indicate counties where farmers in each region responded to the drought survey (see Methods section 2.3).

The Northeast is representative of many temperate and historically humid regions, where climate projections for longer frost-free periods and warmer summer temperatures (Hartman et al., 2013) may have both positive and negative effects on land suitable for agriculture (Zhang and Cai, 2011; Teixeira et al., 2013) and crop productivity (Tebaldi et al., 2006; Hatfield et al., 2011). Specifically in the Northeast, growing seasons in the last two decades are ~10 days longer compared to the first half of the 20th century (Walsh et al., 2014), and summer temperatures have increased by ~0.07 ± 0.01 °C per decade since 1900 (Hayhoe et al., 2007). These trends are likely to continue, with end of the century projections for the Northeast of an additional 20–50 frost free days per growing season (Walsh et al., 2014) and an increase of 3–7 °C during summer months (Horton et al., 2014), depending on the emissions scenario. While this may allow farmers to explore new markets and higher yielding crop varieties (Wolfe et al., 2008), climate projections for the region suggest the occurrence of extremely high temperatures (i.e. heat stress) and short-term summer droughts are likely to become more frequent (Hayhoe et al., 2007; Horton et al., 2014), with negative effects on yields (Wolfe et al., 2011; Walthall et al., 2012).

Most climate projections for the Northeast suggest that total annual precipitation will remain relatively stable, possibly with small decreases in summer months and small increases in winter months (Hayhoe et al., 2007; Horton et al., 2014). Some of the increased precipitation in winter months, however, is likely to be in the form of rainfall and not snowfall, reducing the winter snowpack (Hayhoe et al., 2007). In fact, this trend of a reduced winter snowpack has already been observed in the Northeast (Frumhoff et al., 2007; Horton et al., 2011). Further, more of the rain that does come in summer months will likely be in the form of heavy precipitation events, defined as events with more than 5–10 cm of rainfall at daily timescales (Horton et al., 2011). The frequency of heavy precipitation events has already increased by 71% in the Northeast over the last 50 years, and such events are projected to occur two to five times more often by the end of the century (Walsh et al., 2014). If more growing season precipitation comes in heavy rain events, yet the total annual amount of precipitation does not change much, it is possible that those heavy rain events will be interspersed with longer dry periods. These climate changes (higher temperatures, longer growing seasons, and longer dry periods) will increase drought risk. Furthermore, with these climate changes and as farmers in the Northeast shift to longer growing season crop varieties, crop water demand will increase. This, combined with the fact that farmers are recognizing the economic importance of irrigation even in humid regions, suggests that agricultural water use is likely to increase in the future in regions such as the Northeast.

In this study, we evaluate the severity and impacts of the 2016 drought in New York State (NY) as a case study relevant to identifying water resource vulnerabilities of the region to a changing climate where the risk of drought and agricultural water use may increase with climate change. To see how the 2016 drought compared to historical climatological and hydrological conditions across NY, as well as to examine the risk of future droughts, we analyzed 60 years of snowfall, precipitation, air temperature, and streamflow data. To better understand how the drought affected the agricultural sector and whether or not farmers in NY were able to cope with drought, we surveyed and interviewed farmers across the state. Lastly, to get a sense of possible ecological implications in terms of water use during a drought, we modeled potential agricultural crop irrigation water use in both "average" years (mean of last 15 years) and in 2016 (which is representative of a relatively severe drought year). Modelling crop irrigation water use in a state such as NY is important because, although NY is one of the leading producers of many agricultural commodities nationally and the top agricultural producer in the Northeast (DiNapoli, 2015), agricultural water use in NY is not well understood because water withdrawals in NY remain relatively unregulated. For instance, only systems capable of withdrawing 380 cubic meters per day of water (surface or groundwater or combination of the two) are regulated (NY DEC, 2012).

2. Methods

2.1. New York state regions

We examined eight regions across NY designated as Drought Management Regions by the New York State Department of Environmental Conservation (NY DEC) (http://www.dec.ny.gov/lands/5014.html). We also grouped the eight DEC drought regions into four main NY regions (American Council of Engineering Companies of New York: http://www.acecny.org/page/regions-13.html): Northern (drought region V), Eastern (drought regions I, II, and IV), Southern (drought regions III and VIII), and Western (drought regions VI and VII) (Fig. 1).