Sources for **"Farm Response to Changing Weather"**

A Maine Climate and Agriculture Network factsheet posted online January 2017.
https://umaine.edu/climate-ag/farm-response-changing-weather/

**1. Longer growing season and plant hardiness zone shift**

- "The average length of Maine's frost-free growing season is now 12−14 days longer than in 1930, and is expected to further increase by 2−3 days per decade."

Change in growing season based on data from:
USEPA. *Climate change indicators in the United States.*
https://www.epa.gov/climate-indicators.

Expectation of future trend from:
Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*.

- "Winter minimum temperatures that define plant hardiness zones are increasing faster than daily highs or temperatures in other seasons."

Statement based on observations of trends in data from Northeast Regional Climate Center. http://www.nrcc.cornell.edu/

**2. Early spring warmup increases frost/freeze risk**

- "Late winter/early spring temperature variability has caused early crop development before the last spring freeze date. This affected Maine apple, blueberry, and peach crops in 2012 and 2016."

Statement about increased number of growing degree days before last spring frost based on:
USDA Northeast Climate Hub**.** *Warmer Winters Affect Spring Development and Summer Pests*.
http://www.climatehubs.oce.usda.gov/content/warmer-winters-affect-spring-development-and-summer-pests

Numerous research studies and other publications have made similar statements. One local example is Laura Poppick. *Climate Change and Agriculture in Maine*. Maine Climate News. https://extension.umaine.edu/maineclimatenews/archives/summer-2011/climate-change-and-agriculture

Apple and Peach impacts based on Glen Koehler personal communication with Maine apple and peach growers. Blueberry statement based on:
David E. Yarborough. Wild Blueberry Newsletter – August 2012.
https://extension.umaine.edu/blueberries/newsletters/2012-newsletters/wild-blueberry-newsletter-august-2012/
and
David E. Yarborough. Wild Blueberry Newsletter – August 2016.
https://extension.umaine.edu/blueberries/newsletters/2016-newsletters/wild-blueberry-newsletter-august-2016/

**3. More frequent or intense heat waves**

- "Daily high and overnight temperatures are increasing. Extreme caution is advised for outside work when the heat index exceeds 90°F. "

Daily temperature statement based on data from Climate Reanalyzer, University of Maine. http://cci-reanalyzer.org/

Heat index caution statement based on:
National Weather Service. *National Weather Service Heat index chart.* https://www.weather.gov/media/unr/heatindex.pdf

Apple and pepper impact statement based on:
J. Racsko & L. E. Schrader (2012): *Sunburn of Apple Fruit: Historical Background, Recent Advances and Future Perspectives,* Critical Reviews in Plant Sciences, 31:6, 455-504 http://dx.doi.org/10.1080/07352689.2012.696453

- "High temperatures can damage crops such as apples and peppers, and can reduce productivity and health of dairy cows and other livestock."

Dairy cow and livestock impact statement based on:
eXTension. *Cooling Strategies During Heat Stress.* June 17, 2014. http://articles.extension.org/pages/63354/cooling-strategies-during-heat-stress
Various other papers on Thermal Heat Index for dairy cows as cited on the eXtension web page.

A corroborating reference for beef cows is:
J. B. Gaughan, T. L. Mader, S. M. Holt, and A. Lisle*. *A new heat load index for feedlot cattle*. J. Anim. Sci. 2008. 86:226–234 doi:10.2527/jas.2007-0305

**5. More frequent intense downpours**

- "The frequency of extreme precipitation events in Maine increased 74% between 1948 and 2011. Intense storms that used to occur an average of once per 12 months now happen once per 7 months. The maximum hourly rate of precipitation increased by about 35% between 2001 and 2013. The frequency and intensity of extreme precipitation events are expected to continue increasing in the coming decades."

Statement about frequency of extreme precipitation events based on supplement to:
Travis Madsen and Nathan Willcox. 2012. *When It Rains, It Pours Global Warming and the Increase in Extreme Precipitation from 1948 to 2011.* Environment America Research & Policy Center.

Statement about maximum hourly rate of precipitation and expectation for continued increases in extreme precipitation events based on:
Andreas F. Prein, Roy M. Rasmussen, Kyokolkeda, Changhai Liu, Martyn P. Clark and Greg J. Holland. *The future intensification of hourly precipitation extremes*. Nature Climate Change. December 5, 2016. DOI:10.1038/NCLIMATE3168

Additional corroboration for statements about more frequent or intense downpours.
Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment.*

- "Loss of fieldwork days interfered with potato and corn planting in 2015."

Statement based on personal communication with Sean McCauley, Scientific Research Technician, University of Maine.

Corroborating statements found in:
USDA Northeast Climate Hub. *June precipitation leading to fewer fieldwork days.* http://www.climatehubs.oce.usda.gov/content/seasonal-climate-trends-northeast-spring-frosts-and-soggy-junes?utm_medium=email&utm_source=govdelivery
and
Walthall, C.L., et al. 2012. *Climate Change and Agriculture in the United States: Effects and Adaptation.* USDA Technical Bulletin 1935. Washington, DC. 186 pages.

Projected increase in Maine precipitation:
Fernandez, I.J., C.V. Schmitt, S.D. Birkel, E. Stancioff, A.J. Pershing, J.T. Kelley, J.A. Runge, G.L. Jacobson, and P.A. Mayewski. 2015. *Maine's Climate Future: 2015 Update.* Orono, ME: University of Maine. 24pp.

Increase in number of 5-day wet periods:
Jeanne M. Thibeault, Anji Seth. 2014. *Changing climate extremes in the Northeast United States: observations and projections from CMIP5.* Climatic Change (2014) 127:273–287.

**6. More frequent and longer dry spells**

Image is from a NASA Scientific Visualization Studio animation (https://svs.gsfc.nasa.gov/4270) which is based on:
B. I. Cook, T. R. Ault, J. E. Smerdon. 2015. *Unprecedented 21st century drought risk in the American Southwest and Central Plains.* Sci. Adv. 1, e1400082.

The image shows decline in average summer soil moisture at surface to 30cm depth for different years under the RCP85 emission scenario. RCP85 is a high emissions scenario that most closely matches the emission trend as of January 2017.

In the animation, and in the source paper, the values on the color scale are Kernel Distribution Functions (KDF) values of -3, -2, -1, 0, +1, +2, +3. For normally distributed functions, KDF values are similar to normal distribution Z values. The model outputs for soil moisture were close to normal, so the KDF values are essentially Z values that can be translated into expected number of years between events of similar magnitude.

- "Higher average temperatures and longer heat waves lead to lower average soil moisture. Winter precipitation in Maine may increase, but little or no increase is expected in summer, and winter increases will not replace heat-driven losses."

Maine winter and summer precipitation projections based on:
USDA National Institute of Food and Agriculture. *Pine Integrated Network: Education, Mitigation, and Adaptation project (PINEMAP).* http://www.pinemap.org/.

Soil moisture statement based on Maine projections included in:
B. I. Cook, T. R. Ault, J. E. Smerdon. 2015. *Unprecedented 21st century drought risk in the American Southwest and Central Plains.* Sci. Adv. 1, e1400082.

Corroboration in:
Tara Lohan. June 14, 2016. Surprising Way Climate Change Is Impacting Water. Newsdeeply. https://www.newsdeeply.com/water/articles/2016/06/14/surprising-way-climate-change-is-impacting-water.

Statement by hydrologist that for each 1 $^{o}$C temperature rise, evapotranspiration increases 4%, leading to increased drought with no change in precipitation.

J Jeanne M. Thibeault, Anji Seth. 2014. *Changing climate extremes in the Northeast United States: observations and projections from CMIP5.* Climatic Change (2014) 127:273–287.

Shows no change or only very gradual increase in number of 5-day long dry periods in comparisons of 1951-1980 vs. 1981-2010 vs. 2041-2070 vs. 2071-2100. Combined with increased evapotranspiration losses caused by higher temperatures, even no change in dry period duration could result in more frequent need for irrigation.

Also includes statement that northeastern U.S. precipitation projections for January and July suggest that the increase in total annual precipitation is strongly influenced by winter precipitation extremes. Thus, higher annual precipitation will not necessarily ameliorate increased summer soil moisture losses.

- "Maine apple, blueberry, potato and other vegetables, forage, and hay yields were affected by drought in 2016."

Statement based on Glen Koehler personal communication with Maine apple growers and University of Maine Cooperative Extension commodity experts.

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Citations compiled by Glen Koehler and Ivan Fernandez, University of Maine. January 14, 2017.