**NASA DEVELOP National Program**



NASA Langley Research Center

*Spring 2015*

Northwest United States Agriculture II

Evaluating Suitability for Apple Cultivation Based on Accumulated Chill Units in Washington State from 2003 – 2065

 **Technical Report**

Rough Draft - Feb 19, 2015

Lydia Cuker (Project Lead)

Laura Lykens

Alyssa Walzak

Timothy Stelter

Dr. Kenton Ross, NASA DEVELOP National Program (Science Advisor)

Dr. Noel Baker, NASA Postdoctoral Program Fellow (Science Advisor)

Previous Contributors:

Lauren Makely

Idamis Del Valle-Martinez

Clarence Kimbrell

Zachariah Long

Chad Smith

Mathew Smith

# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Insert here 2-8 keywords that relate to your project

Example: Remote Sensing, Biomass Burning, Erosion, Sea Level Rise, etc.

# II. Introduction

As the leading apple producing state in the United States, Washington produces over half the nation’s apples (USDA NASS, 2012). Washington built its reputation as a major figure in the apple industry initially with Red Delicious apples (Carter, 2007). The apple industry contributes significantly to the prosperity and growth of Washington’s economy, grossing \_\_\_\_\_\_ million dollars annually (citation).  For this to be possible, the apples will need to grow in an appropriate climate and environment. Currently, eastern Washington’s climate is very suitable for apple cultivation with its warmer dry summers and cooler winters with frequent precipitation events (Chambers, 2002). The region east of the Cascade Mountains hosts the major apple production regions such as Yakima Valley, North Central (Wenatchee) district, and the Columbia Basin (Smith, 2015).

More specifically, Washington has a moderate, marine-influenced, desert climate that enables apple orchards to prosper (Smith, 2001). Less effort and expenditures are required for the growers since Washington has such dry, warm growing seasons for the apple orchards (Schotzko, n.d.). Such a climate aids in preventing apple diseases and pest issues (Schotzko, n.d.). Additionally, the snowmelt in Washington provides ample stream water, which is advantageous for the growers (Smith, 2001). Water is also plentiful for irrigation due to the Columbia River, a body of water that begins near the northeastern corner of Washington and runs through eastern Washington (Chambers, 2002). These conditions are favorable for the growth of apples.

However, coming climate change may alter these conditions in Washington, specifically chill hours and total precipitation. Both of these factors contribute to the health and success of apple crop production. Chill hours, which are hours with temperatures between 0 - 7° C, are vital for successful apple tree blossoming in the springtime. Apple trees require 500 – 1000 chill hours, depending on the apple variety, in order to thrive (Carter, 2007). Due to requirements for accumulated chill hours, rising temperatures may shift the location of ideal apple growing conditions northward. Additionally, a change in rainfall accumulation may modify demands for irrigation resources.

However, impending climate changes may alter these conditions in Washington. One of the key climatic factors affecting apples is accumulated chill hours, or the total time apple trees spend between 1.4°C and 12.4°C (Richardson et al., 1974). This time spent “chilling” is critical to allow trees to fully rest, thus ensuring a homogenous dormancy break and bloom in the spring. Without meeting chill hour requirements, the spring bloom will be staggered, leading to a heterogeneous fruiting, and ultimately shorten the lifespan of the tree. Homogenously blooming and fruiting trees are economically ideal in that they yield the most consistent crops (Citation). Apple trees require 500 – 1000 chill hours per year, depending on the apple variety, in order to thrive (Carter, 2007). Due to requirements for accumulated chill hours, rising temperatures may shift the location of ideal apple growing conditions northward.

Accumulated chill hours for temperate climates like that of east Washington can be calculated using the Utah Model developed by Richardson et al. (1974). The specific equation used in the Utah Model is an updated version of the Chill Hours Model developed by Bennett (1949) and Weinberger (1950), however it was found more functional because of the significance of adding units of weight to different temperature ranges (Luedeling, 2009). The process of assigning units to ranges was found more specific and accurate. The Utah Model was formed by combining two algorithms from the years of 1974 and 1977 to create the current equation (Rea and Eccel, 2006). Previous studies on fruits in California used the Utah Model with success primarily due to the specificity of the narrowed temperature range from 2.4°C – 9.1°C (Luedeling, 2009).

The objectives of this project were to map accumulated chill hours in Washington during three time periods: current accumulations, accumulations in 2045, and accumulations in 2065. The study period ranged from 2003 – 2013 to establish current conditions and from 2040 – 2070 to forecast future trends. In doing so, this project addressed two national applications areas of NASA’s Applied Sciences – agriculture and climate. For agriculture, this project examined where areas within Washington will be suitable for apple cultivation approaching 2100. For climate, this project showed how temperature ranges in Washington may shift approaching 2100.

The project partnered with the United States Department of Agriculture – Agriculture Research Service out of the Appalachian Fruit Research Station who then disseminated the findings to orchard owners and managers in Washington. The maps of accumulated chill hours will be used by apple orchard owners and managers to help them decide how to proceed in the industry in light of coming changes. Depending on location and how much temperatures change in coming years, it may be in the orchards’ best interest to alter cultivation practices to accommodate the current apple variety in the new conditions, switch the variety of apple(s) they grow to one(s) better suited to the new conditions, or move their orchard to another region deemed more suitable than the present location.

**(TO BE ADDED: Background on climate models used)**

# III. Methodology

*Data Acquisition*

Air temperature data were acquired from weather stations across the regions where apple orchards are most prevalent.  This was downloaded from the NOAA website for the years 2003 - 2013.  Land Surface Temperature (LST) data measured by Aqua MODIS level 3 1 km (MYD11A1 version 5) were downloaded from NASA’s Reverb Echo website for 2003 - 2013 to cover Washington (tiles h9v04 and h10v04).

*Data Processing*

In Microsoft Excel, hourly air temperature data from each weather station was compiled from January 1 to December 31 for each year in the dataset.  The average for each hour of each calendar day was calculated from all years in the dataset. The hourly averages were then entered into the Utah Model to calculate Chill Units and then summed for the 24 hour period to reach accumulated chill units for each day. Separately, the hourly air temperatures for each day of a set of representative days were plotted to determine the function by which the temperatures oscillate over a 24 hour period.  That function was then applied to the maximum and minimum temperatures from those same days, the accumulated chill units calculated based on the plotted temperature distributions, and compared to the accumulated chill units initially calculated using individual hourly data.  Once the relationship between the total 24 hour dataset accumulated chill units and the max-min function dataset accumulated chill units was established, the function was applied to the 5 day rolling average maximum and minimum air temperatures calculated from MODIS data to determine the accumulated chill units for each day.  Daily accumulated chill units were summed for the entire year (365-366 days between September 1 and August 31) to establish the current accumulated chill unit apple trees in the region experience.

*Data Analysis*

From the calculation of accumulated chill units experienced under current conditions, forecasted accumulated chill units for the region were calculated.  The projected changes in maximum and minimum air temperatures were combined with the respective corresponding MODIS data for each day and the newly calculated temperatures were entered into the Utah Model then summed for accumulated chill units for each 2045 and 2065.  The results of each of these applications were mapped with delineations for suitable apple growing areas.

**(TO BE ADDED: Methodology used with the climate models)**

# IV. Results & Discussion

Insert images, graphs, maps, charts, etc. here. Choose the most important results to highlight here. Things to discuss:

* Analysis of Results: What can you tell from your graphs, images, etc? What does this mean for your project?
* Errors & Uncertainty: What factors could you not account for, what things didn’t work out like you expected they would, etc
* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600.

# VI. Acknowledgments

Insert here. Keep to a concise paragraph or bullets of names. End with the following sentence.

This material is based upon work supported by NASA through contract NNL11AA00B and cooperative agreement NNX14AB60A.

# VII. References

Bennett, J.P., 1949. Temperature and bud rest period. California Agriculture 3 9, 12.

Carter, K (2007). Low-Chill Apples.*Center for Landscape and Urban Horticulture.*

Cesaraccio, C., Spano, D., Snyder, R. L., & Duce, P. (2004). Chilling and forcing model to

predict bud-burst of crop and forest species. *Agricultural and Forest Meteorology*, *126*(1), 1-13.

Chambers, M. (2002). Climate of Washington. Retrieved February 19, 2015, from         <http://www.wrcc.dri.edu/narratives/WASHINGTON.htm>

Jensen, W. S. (n.d.). Washington’s billion-dollar secret: The tree fruit producers who help

grow our economy [WWW page]. URL   http://www.wahort.org/images/downloads/issue-brief.pdf

Luedeling, E., Zhang, M., Luedeling, V., and Girvetz, E. H. (2009). Sensitivity of winter chill

models for fruit and nut trees to climatic changes expected in California's Central Valley. *Agriculture, Ecosystems & Environment*, *133*(1), 23-31.

Richardson, E.A., Seeley, S.D., and Walker, D.R., 1974. A model for estimating the

completion of rest for Redhaven and Elberta peach trees. Hortscience 9, 331-332.

Schotzko, R. T., & Granatstein, D. (2004). A brief look at the Washington apple industry:

Past and present. *Washington State University, School of Economic Sciences, SES*, 04-05.

Smith, T. J. (2001). Crop Profile for Apples in Washington. *Washington State University*

*Extension. Last Accessed: August*, *1*, 2013.

Smith, T. J. (2015). Overview of tree fruit production in the Pacific Northwest United

States  of America and southern British Columbia Canada [On-line serial]. URL         http://county.wsu.edu/chelan-douglas/agriculture/treefruit/Pages/

Tree\_Fruit\_Overview.aspx

USDA NASS. (2012). 286 Washington 2012 Census of Agriculture - County Data Table 10.

*Irrigation: 2012 and 2007* (Vol. 2007, pp. 286–290).

Weinberger, J.H., 1950. Chilling requirements of peach varieties. Proceedings of the

American Society of Horticultural Science 56, 122-128.

# VIII. Appendices

Insert here