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Article

Statistical forecast of GDDs and CHs for northern Mexico improved for bias correction

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Abstract

The existing information on monthly climate forecasts of agrometeorological variables, such as growing degree-days and chilling hours, is limited. This work presented the evaluation of a statistical forecast of growing degree-days and chilling hours for northern Mexico, with a focus on grape- and pecan-producing regions. The forecasting model is based on the analogous years method, using sea surface temperature anomalies through the monthly Niño-3.4 index, which is based on the ERSSTv5 database. In addition, it uses monthly historical databases of growing degrees-days and chilling hours, corresponding to the periods 1925-2012 and 1950-2020, respectively. To evaluate the model, monthly retrospective forecasts of growing degree-days and chilling hours were made for a period of 12 years (2012-2023) and contrasted with observations. It was found that the model underestimated up to -100 growing degree-days for regions in the south and center of the country; in contrast, for Sonora, Chihuahua, Durango, and Coahuila, the growing degree-days were underestimated with values ranging from -20 to -60 growing degree-days. In the case of chilling hours, it was found that the model underestimated up to 60 chilling hours, mainly in Chihuahua, Durango, Zacatecas, Baja California, and the center of the country. Based on these results, a bias correction method was applied, which was based on subtracting the mean bias, to reduce the error in the forecast. The corrected model showed a reduction in bias, mainly in cold months. Nevertheless, persistent bias was found in the model after applying bias correction.

Keywords:

analogous years, bias correction, growing degree-days, chilling hours.

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Introduction

The influence of temperature on plant growth and development is fundamental. To establish an accurate relationship between temperature and the growth rate of organisms, vital parameters known as thermal constants are defined, which can be estimated within a range from the base temperature to the maximum threshold.

These thermal constants are expressed in growing degree-days (GDDs) and are used in agriculture to model the developmental phases of both plants and insects. In addition, chilling hours (CHs) are used to model the sprouting of deciduous fruit trees. Plant and insect phenology, when modeled based on thermal units, provides a more accurate measure of physiological time compared to the traditional calendar (Terence *et al*., 1984; McMaster and Wilhelm, 1997; Luedeling *et al*., 2011).

GDDs allow quantifying heat accumulation over a specific period, being a widely used measurement in agricultural models. This tool is key to optimizing activities such as irrigation scheduling, planning phytosanitary treatments, determining the optimal time of harvest, and estimating the maturity date of crops (McMaster and Wilhelm, 1997). On the other hand, CHs represent the accumulated physiological time in which a fruit tree is at temperatures below a certain threshold, generally 7.2 °C, during the winter months.

During this period, the tree enters a resting state with minimal physiological activity, meaning it does not actively grow or flower. This winter rest is crucial for the sprouting, development, and productivity of the tree in the following growing season (Luedeling *et al*., 2011; Campoy *et al*., 2011; Liu and Sherif, 2019). CHs are particularly important in the production of temperate fruits, such as apples, grapes, pears, peaches, cherries and plums.

They refer to the number of hours in which the temperature remains below a specific threshold during the winter, which is essential to ensure good development in the following season (Luedeling, 2012). Temperature patterns can vary from year to year, which affects the accumulation of GDDs and CHs and therefore directly influences crop growth and development. A recent study by Corrales-Suastegui *et al*. (2022) suggests that, by the end of the century, temperatures could rise by up to ~3.5 °C under a high-emissions scenario.

This increase would lead to an increase in GDDs and, as a consequence, a possible decrease in the accumulation of CHs. In addition, dry summers and wet autumns are projected in the states of Sonora, Chihuahua, Durango and Coahuila, which are one of the main pecan- and table grape-producing regions in Mexico. In this region, according to SIAP data, approximately 72 000 t of pecans were exported in 2022, generating a value of around 640 million dollars, while grape production reached 300 000 t.

For these reasons, having monthly and seasonal weather forecasts of GDDs and CHs is a very useful tool. With this information, producers in the agricultural sector could adapt their practices, which could include the selection of more heat-resistant crop varieties, as well as the definition of more effective criteria for irrigation scheduling in efficient pressurized systems, as suggested by previous studies (Flores-Gallardo *et al*., 2012).

This publication aims to present the technology developed by INIFAP, called monthly forecast of growing degree-days and chilling hours for pecan- and grape-producing regions (ProNOVIDclim). This technology is adaptable to different regions of the country and crops, thus contributing to improving agricultural management.

Materials and methods

Study area

The leading pecan-producing regions are located in northern Mexico in the states of Chihuahua, Coahuila, Sonora and Durango (Figure 1), which represent 12.62, 7.73, 9.15 and 6.29% of the country's territory, respectively (INEGI, 2020). On the other hand, Coahuila, Durango, and Sonora are grape-producing states, with Sonora being the largest producer of table grapes in the country (SIAP, 2022).

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Figure 1. a) Mexico (in black line), topography (m) and study area (highlighted in thick black line), the arrow indicates north and b) Chih, Coah, Son, and Dgo refer to the states of Chihuahua, Coahuila, Sonora and Durango, respectively.

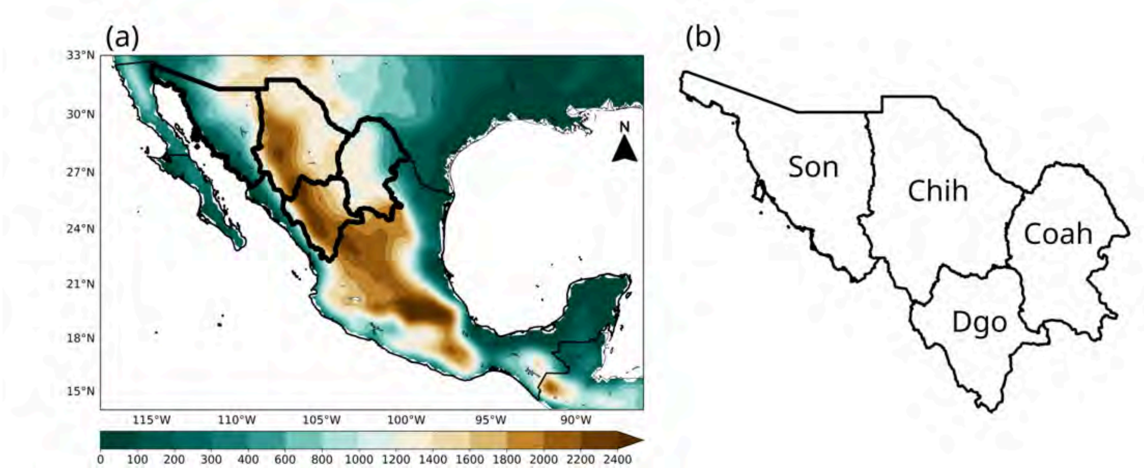

Table 1 presents annual data on precipitation (Prec), maximum (Tmax), minimum (Tmin), and average (Tmed) temperature for these states based on CONAGUA data, available at (https://historico.datos.gob.mx/busca/dataset):

Table 1. Climatology 1991-2020 of annual precipitation, maximum, minimum and average temperature for the states that make up the pecan- and grape-producing region.

	Prec (mm)	Tmax (°C)	Tmin (°C)	Tave (°C)
Coahuila	400.5	28.8	13.3	21.1
Chihuahua	454.3	27	9.5	18.2
Durango	449.8	26.8	8.9	17.9
Sonora	420.4	31.4	13.6	22.5

Data

The simulations were run with daily data on maximum temperature (Tmax) and minimum temperature (Tmin) from the Livneh gridded observation database with 1/16° (~6 km) spatial resolution, which completely covers Mexico, the United States of America, and southern Canada for the period 1925-2013 (Livneh *et al*., 2015, ftp://192.12.137.7/pub/dcp/archive/OBS/livneh2014.1-16deg/) and has been used in previous simulation studies in Mexico to analyze degree-days (Corrales-Suastegui *et al*., 2021); likewise, the simulations used hourly temperature data from the ERA5 Land reanalysis (hereinafter ERA5) of the European Centre for Medium-Range Weather Forecasts (ECMWF) at a horizontal resolution of ~11 km (Muñoz-Sabater *et al*., 2021).

The evaluation of the forecast model was carried out with hourly data from ERA5 and daily Tmax and Tmin data from the gridded observation database of the CPC Global Temperature with spatial resolution of 0.5°, which are available from January 1, 1979, to the present and are provided by the Noaa/Oar/Esrl Psl, Boulder, CO, USA, from its website https://psl.noaa.gov/, date of access: 01/may/2024.

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Growing degree-days

To calculate the GDDs, the simple sine method developed by Baskerville and Emin (1969) was implemented. This method fits a sine curve to the maximum and minimum temperatures for a day. A lower and an upper temperature threshold, 10 and 30 °C, respectively, are used in the calculation to obtain the area under the curve. This method considers six different cases to calculate the GDDs according to the daily behavior of temperatures. For a complete description of this method, see: http://ipm.ucanr.edu/WEATHER/ddss-tbl.html.

Chilling hours

The CHs were calculated according to Chandler (1942) chilling hours model, which is the most common method for calculating winter cold (Luedeling and Brown, 2011; Chhetri *et al*., 2018). The model considers that temperatures between 0 and 7.2 °C have a chilling effect, and every hour at temperatures between these thresholds contributes to a CH (Luedeling, 2012). The above could be expressed as follows:

$$nch_k=\sum_{i=1}^{24} ch_i^k, ch_i^k=\begin{cases} 1, 0< T_i^k < 7.2 \\ 0, \text{other case} \end{cases}$$

1). Where nch_k are the accumulated CHs on day k; i= 1, 2, 3, ..., 24 is the hour on day k; ch_i^k and Ti_i^k are the CHs and temperature, respectively, at hour i during day k. Monthly CHs were calculated from equation 1.

Forecasting model

The GDD and CH forecast is made using analogous years (AYs), that is, it identifies past years that are similar to the current conditions of the El Niño Southern Oscillation (ENSO) phenomenon; to this end, the root mean square error was used as a metric. In this study, the AYs were obtained from INIFAP's PronEst technology (Corrales-Suastegui *et al*., 2014). Historical GDDs were calculated from the Livneh database for the period 1925-2012. The database of historical CHs was obtained from ERA5 for the period 1950-2020.

Forecast model computing program

The central core of ProNOVIDclim is the computer program (hereinafter program) for the implementation of the forecast model, which was developed in the GNU/Linux operating system using Bash programming, the Climate Data Operators (CDO) tool, and the Python 3 programming language, which are freely accessible. Figure 2 shows a fragment of the source code of the program, whose development is copyrighted, RPDA: 03-2024-120915472700-01.

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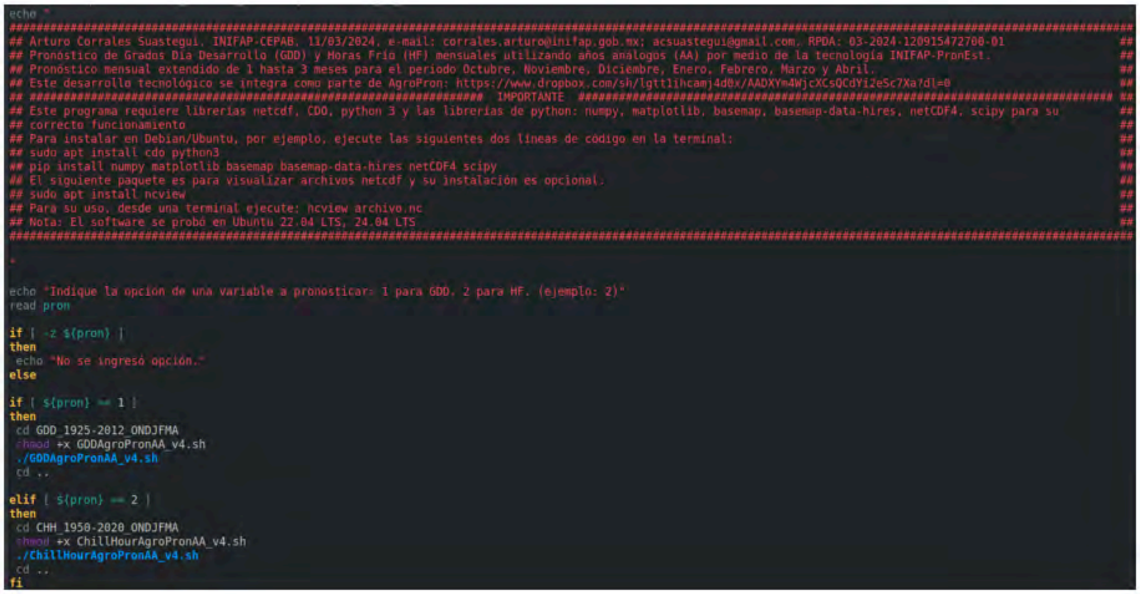
Figure 2. Fragment of the source code of the ProNOVIDclim program.



```
echo "
##########################################################################################################
## Arturo Corrales Suastegui, INIFAP-CEPAB, 11/03/2024, e-mail: corrales.arturo@inifap.gob.mx; acsuastegui@gmail.com, RPDA: 03-2024-120915472700-01  ##
## Pronóstico de Grados Día Desarrollo (GDD) y Horas Frío (HF) mensuales utilizando años análogos (AA) por medio de la tecnología INIFAP-PronEst.  ##
## Pronóstico mensual extendido de 1 hasta 3 meses para el periodo Octubre, Noviembre, Diciembre, Enero, Febrero, Marzo y Abril.  ##
## Este desarrollo tecnológico se integra como parte de AgroPron: https://www.dropbox.com/sh/lgttlihcamj4d0x/AADXYm4WjcXCsQCdYi2eSc7Xa?dl=0  ##
## ################################################################## IMPORTANTE ################################################################## ##
## Este programa requiere librerías netcdf, CDO, python 3 y las librerías de python: numpy, matplotlib, basemap, basemap-data-hires, netCDF4, scipy para su  ##
## correcto funcionamiento  ##
## Para instalar en Debian/Ubuntu, por ejemplo, ejecute las siguientes dos líneas de código en la terminal:  ##
## sudo apt install cdo python3  ##
## pip install numpy matplotlib basemap basemap-data-hires netCDF4 scipy  ##
## El siguiente paquete es para visualizar archivos netcdf y su instalación es opcional.  ##
## sudo apt install ncview  ##
## Para su uso, desde una terminal ejecute: ncview archivo.nc  ##
## Nota: El software se probó en Ubuntu 22.04 LTS, 24.04 LTS  ##
##########################################################################################################

"

echo "Indique la opción de una variable a pronosticar: 1 para GDD, 2 para HF. (ejemplo: 2)"
read pron

if [ -z ${pron} ]
then
 echo "No se ingresó opción."
else

if [ ${pron} == 1 ]
then
 cd GDD_1925-2012_ONDJFMA
 chmod +x GDDAgroPronAA_v4.sh
 ./GDDAgroPronAA_v4.sh
 cd ..

elif [ ${pron} == 2 ]
then
 cd CHH_1950-2020_ONDJFMA
 chmod +x ChillHourAgroPronAA_v4.sh
 ./ChillHourAgroPronAA_v4.sh
 cd ..
fi
```

By way of illustration, the forecast for the period November-January 2023-2024 was calculated. When the program starts, information about the technology is displayed and instructions are provided for the installation of the required libraries, if necessary. In addition, the user must enter the data corresponding to the period and the variable to be forecasted. Once this information is entered, the forecast calculation process runs automatically. After the calculation, the system will notify the user of the completion of the process.

The forecast results are stored in a folder automatically generated during program execution. The folder name follows the structure 'forecast start year' followed by the forecasted months (year-m1m2m3); in the example above, the folder will be designated as '2023-111201'. This folder contains the outputs of the model, such as maps of i) forecasts, ii) anomalies and iii) climatologies of the forecasted months in PNG format and as data files in netCDF format. These files can be viewed and processed in geographic information systems, such as QGIS.

Results and discussion

The seasonal forecast can provide potentially useful information on cold sufficiency for each crop. The lack of winter cold prevents crops, such as some fruit trees, vines, and nuts, from having an early and complete sprouting, which is necessary for them to reach their maximum yield; likewise, it also reduces their quality. An early forecast of the winter cold in the coming months can help producers manage the lack of cold to minimize these negative impacts (Jha and Pathak, 2024).

To evaluate the model, monthly retrospective forecasts of GDDs and CHs were made for a period of 12 years (2012-2023) during the 'cold year', which begins in October of year k and ends in April of year k+1. In this way, for example, the 'cold year' that corresponds to 2012 will be from October 2012 to April 2013, and so on for the other years, until ending with the 'cold year' 2023 (October 2023-April 2024).

Figure 3 shows the average of 12 cold years during 2012-2013 for GDDs. Observations from CPC (Figure 3a) show maximum GDD values in the Yucatan Peninsula and southern states of Mexico, while for states in the pecan- and grape-producing region, values of 100< GDDs< 400 were found for Sonora, 200< GDDs< 300 for Coahuila, and 100< GDDs< 300 for Durango and Chihuahua, which is consistent with Corrales-Suastegui *et al*. (2022).

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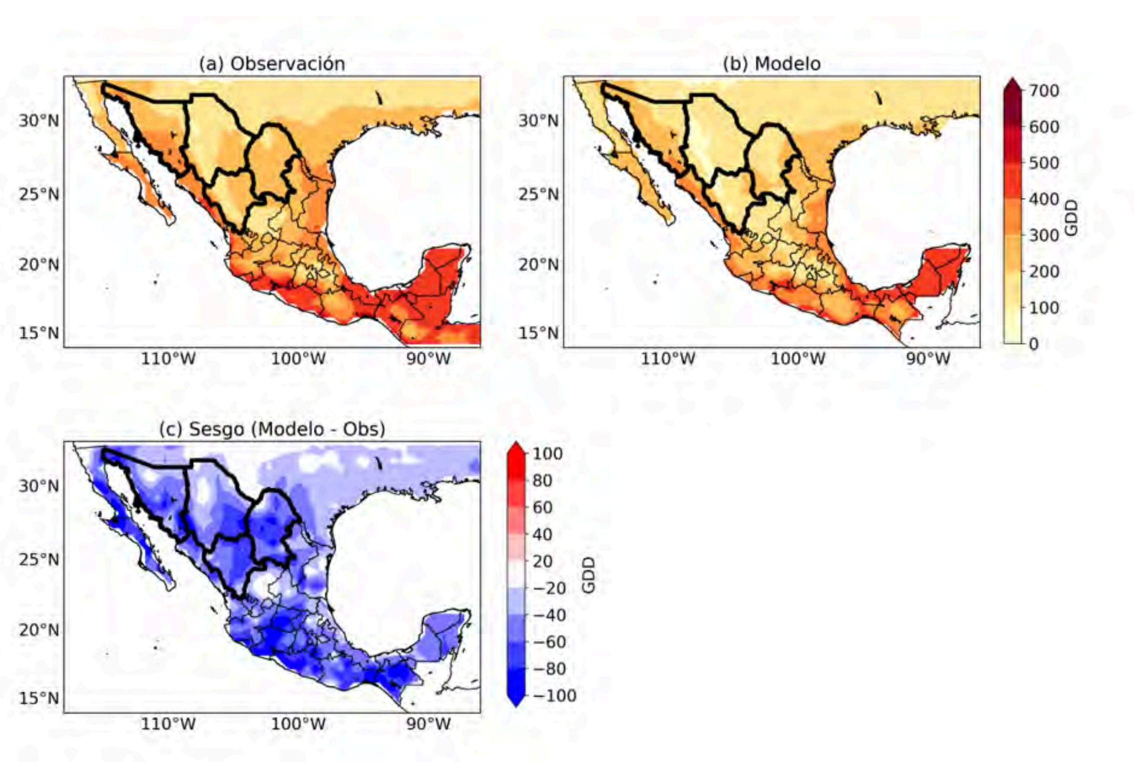
Figure 3. a) average of 12 'cold years' (2012-2023) of monthly GDDs according to CPC; b) average of 12 'cold years' of GDDs based on the model and c) difference (model-observation) in GDDs.



On the other hand, the model (Figure 3b), reproduces this spatial pattern, with GDD maximums in the Yucatan Peninsula and southern states of Mexico and values of 100< GDDs< 300 for Sonora, Chihuahua, Coahuila and Durango. However, the model showed a cold bias (Figure 3c), underestimating up to -100 GDDs for southern and central regions of the country; in contrast, for Sonora, Chihuahua, Durango and Coahuila, GDDs were underestimated with values ranging from -20 to -60 GDDs.

Figure 4 shows the average of 12 cold years during 2012-2013 for CHs. The average of CHs from ERA5 (Figure 4a) shows maximum CH values >200 in highlands of Durango and Chihuahua, as well as in regions of central Mexico, whereas for northern Sonora and areas of Chihuahua, Coahuila, and Durango, CHs were found in a range of 75 to 175. On the other hand, the model (Figure 4b) reproduces this spatial pattern, with CH maximums in the highlands of Durango, Chihuahua, and regions of central Mexico, and values of 75< CHs< 200 in northern Sonora and areas of Chihuahua, Coahuila and Durango.

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Figure 4. a) average of 12 'cold years' (2012-2023) of monthly CHs according to ERA5; b) average of 12 'cold years' of CHs based on the model and c) bias [sesgo (model-obs)] in CHs.

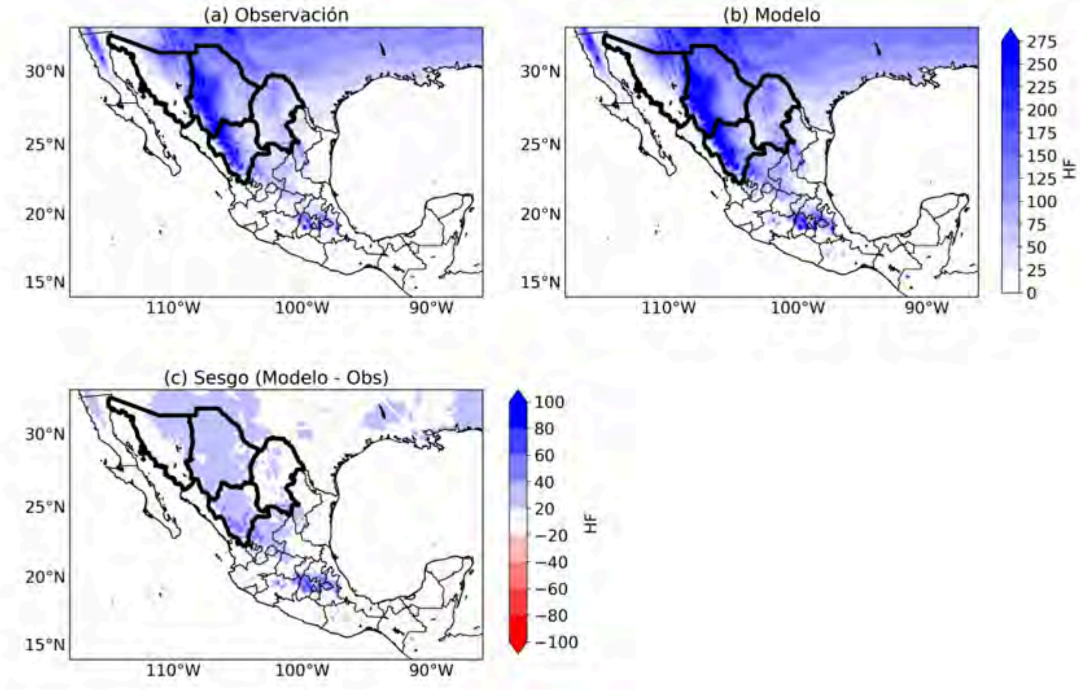

Figure 4c shows that the model overestimated CHs in the range of 20 to 40 CHs, mainly in Durango, Chihuahua, and northern Sonora, which indicates that the model presented a cold bias in CHs, which is consistent with what was found for GDDs (Figure 3c).

Once the bias of the model was calculated (Figure 3 and 4), the 'cold years' corresponding to the period 2012-2022 were selected and used to estimate the corresponding year-on-year average for each month forecasted and observed; likewise, the difference between the model and the observation was determined and used to obtain the average monthly error for GDDs and CHs. This allowed the application of a reasonably simple bias correction technique; for example, if the forecast is calculated for February, March, and April 2024, a corrected forecast (ModelC) can be estimated by subtracting the average monthly error corresponding to the forecasted month.

A similar technique has been used to remove bias in short simulations using a mesoscale model (Stensrud and Skindlov, 1996). Bias correction is important to improve both the quality and value of the forecast (Anghileri *et al*., 2019). The above is shown in Figure 5 for February-April 2024. Figure 5 a-c represents the observed GDDs for February, March and April, respectively. Figure 5 d-f presents the uncorrected model bias (sesgo) corresponding to February, March and April, respectively.

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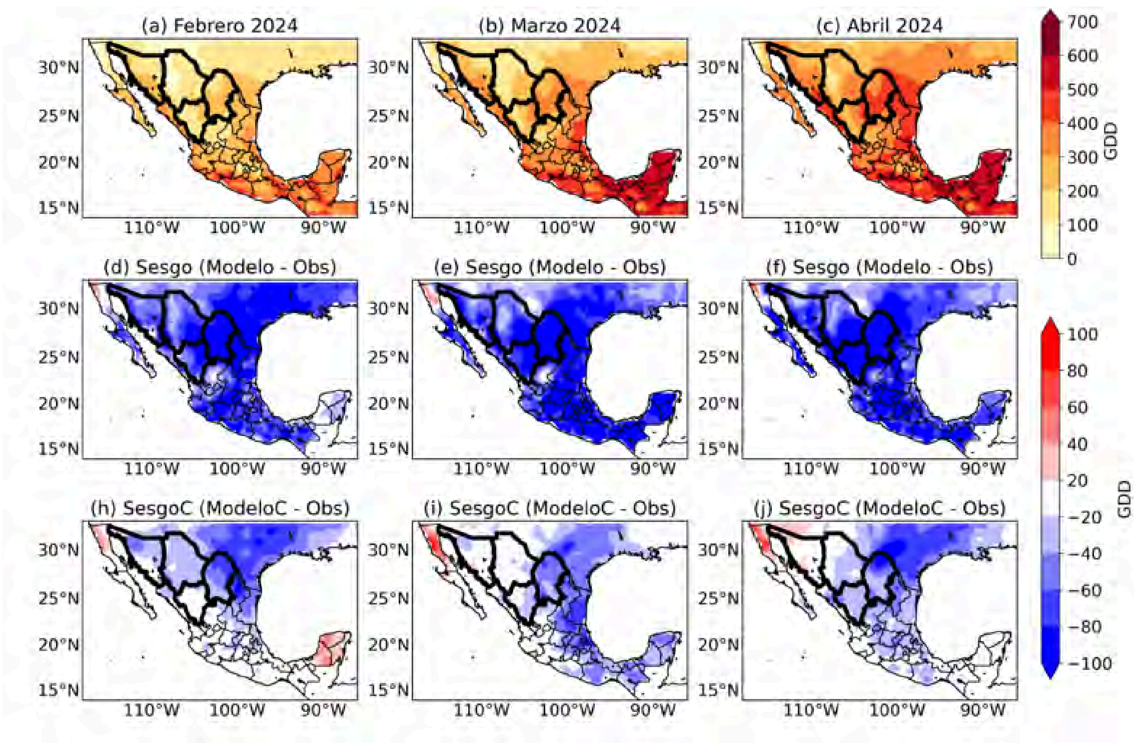
Figure 5. Monthly GDDs observed for a) February, b) March and c) April 2024. Bias [sesgo (model-obs)] for d) February, e) March and f) April. (h-j) similar to (d-f) but for the corrected model bias [sesgoc (modelc-obs)].



The corrected model bias (sesgoc) is shown in Figure 5h-j for the same period. The bias is shown in Figure 5d-f, which presents values ranging from -40 to -80 GDDs in Sonora and Chihuahua and up to -100 GDDs in Durango and Coahuila. Nevertheless, when applying the bias correction (Figure 5h-j), a considerable reduction in the model error (sesgoc) was found, where there is a predomination of bias values of 20 to -20 GDDs and in the range of -20 to -40 GDDs, except for the northern area of Coahuila in February (Figure 5 h) and March (Figure 5j), where values of -6 -80 GDDs were reached; this could be because the CPC database is warmer than those of Livneh or ERA5, as shown by previous studies (Corrales-Suastegui *et al*., 2011).

Similarly, for CHs, Figure 6 shows the observed CHs for the period of February-April 2024 (Figure 6a-c), the bias (sesgo) (Figure 6d-f), and the corrected model bias (sesgo C) (Figure 6h-j). The uncorrected model shows the greatest bias during February (Figure 6d), with values ranging from 80 to 100 CHs in Durango, Coahuila and Chihuahua; in contrast, in regions of Sonora, values of up to 100 CHs were found. On the other hand, in March and April, the bias values are between 20 and 60 CHs in Durango and Chihuahua, except for northern Sonora, where they presented negative values of up to -60 CHs (Figure 6e, f).

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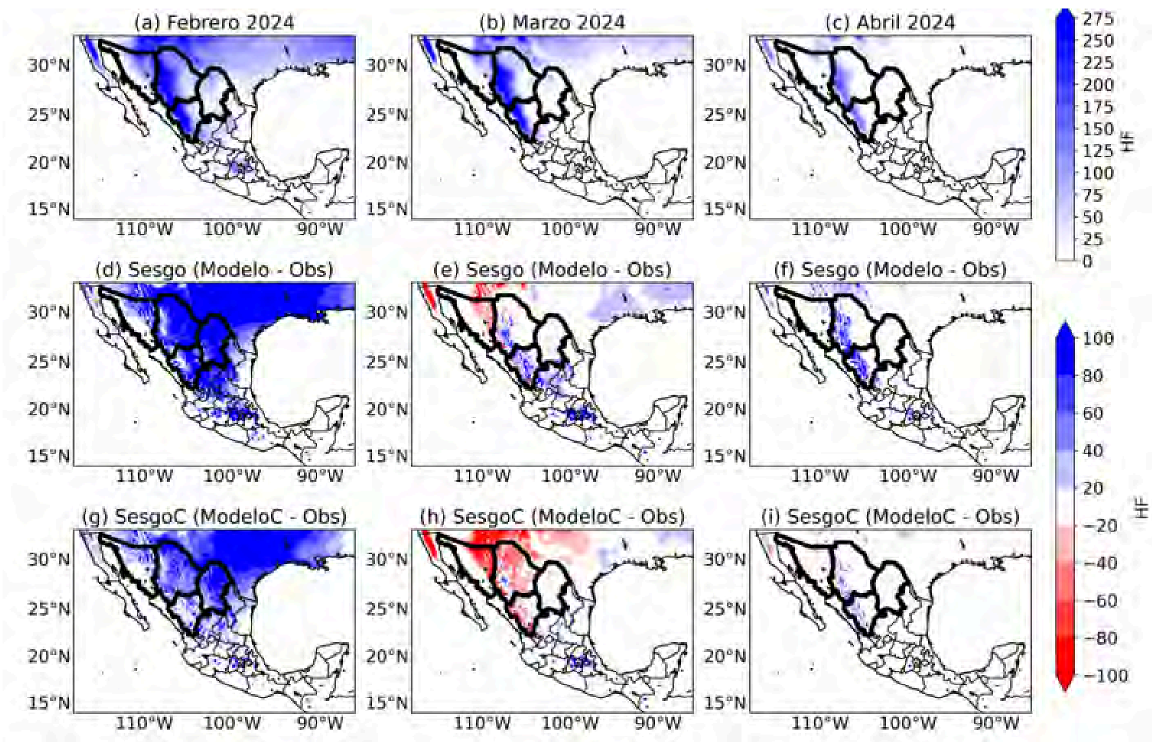
Figure 6. Monthly CHs observed for a) February, b) March, c) April 2024. Bias [sesgo (model-obs)] for d) February, e) March, f) April; (h-j) similar to and (d-f) but for the bias from the corrected model (sesgo C, modelo C-obs).



When applying the bias correction (Figure 6 h-j), a reduction in the error of the model was found, where for February (Figure 6h), bias values of 20 to 60 CHs predominate in Durango, Chihuahua and Coahuila; only the northern region of Coahuila presented bias values still similar to the uncorrected model version (Figure 6d). In the case of March (Figure 6h), the bias decreased in Durango, while for Chihuahua and Sonora, the bias took negative values from -20 to -60 CHs and there was bias in regions that did not present bias in the uncorrected version (Figure 6e). In contrast, during April (Figure 6i), bias decreased considerably (~50%) with values below 40 CHs.

This suggests that, for the colder months, bias correction may significantly improve the CH forecast, which also applies for April; however, during the transition from winter to spring during March, applying bias correction may not present an improvement in the CH forecast. Previous studies have reported persistent biases in models after applying the bias correction, which could be explained by the highly variable climate of some regions (Lorenz *et al*., 2021).

Conclusions

This work assessed a monthly statistical forecast for GDDs and CHs extended to three months for Mexico, with emphasis on pecan- and grape-producing regions. The model reproduced the spatial patterns of the predicted GDD and CH variables according to the evaluation period. Nonetheless, the forecast showed a negative bias in GDDs and a positive bias in CHs. From the average error of twelve years, a simple bias correction technique was applied.

The corrected model showed better forecasting ability by considerably reducing bias, mainly in cold months and in the pecan- and grape-producing region. Nevertheless, a persistent bias was found in the model after applying the bias correction, which could be explained by the highly variable climate of some regions of the study area.

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As a work in progress, ERA5 is being integrated as a GDD database, and the historical period will be extended to 2024 for both variables, which will be reflected in an enhanced version of the computing program. This paper highlights the need to generate and periodically evaluate, for this geographical and agro-industrial sector, a seasonal forecast of GDDs and CHs. This made it possible to provide the producers of these crops with tools for decision-making related to pecan trees and vines in the region.

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Bibliography

1 Anghileri, D.; Monhart, S.; Zhou, C.; Bogner, K.; Castelletti, A.; Burlando, P. and Zappa, M. 2019. The value of subseasonal hydrometeorological forecasts to hydropower operations: how much does preprocessing matter? Water Resour. Res. 55(12):10159-10178. https://doi.org/10.1029/2019WR025280.

2 Baskerville, G. L. and Emin, P. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50(3):514-517.

3 Campoy, J. A.; Ruiz, D. and Egea, J. 2011. Dormancy in temperate fruit trees in a global warming context: a review. Scientia Horticulturae. 130(2):357-372. https://doi.org/10.1016/j.scienta.2011.07.011

4 Chandler, W. H. 1942. Deciduous orchards. Lea and Febiger, Philadelphia. 438 p.

5 Chhetri, A.; Ramjan, M. D. and Dolley, N. 2018. Various models of calculating of chill units in fruits crops. Indian Farmer. 5(04):439-442.

6 Corrales-Suastegui, A.; Martínez-Diaz, G.; Ruiz-Álvarez, O.; González- González, M. A. and Pavía, E. G. 2022. Temperature and precipitation towards the ed of the 21st Century in pecan producing areas of Mexico. Advanced Modelling and Innovations in Water Resources Engineering. 235-254 pp. Singapore: Springer. https://doi.org/10.1007/978-981-16-4629-4-18.

7 Corrales-Suastegui, A.; Ruiz-Alvarez, O.; Torres-Alavez, J. A. and Pavia, E. G. 2021. analysis of cooling and heating degree days over Mexico in present and future climate. Atmosphere. 12(9):1131. https://doi.org/10.3390/atmos12091131.

8 Corrales-Suastegui, A.; González-Jasso, L. A.; Narváez-Mendoza. M. P.; González González, M. A.; Ruíz-Álvarez, O. y Maciel-Pérez, L. H. 2014. PronEst: aplicación informática para generar pronósticos estacionales de lluvias y heladas de uno a tres meses. INIFAP-CIRNOC-CEPAB. Folleto técnico núm. 62. 21 p.

9 Flores-Gallardo, H.; Ojeda, W.; Flores, H.; Mejía-Sáenz, E. e Ibarra, E. 2012. Grados día y la programación integral del riego en el cultivo de papa. Terra Latinoamericana. 30(1):59-67.

10 INEGI. 2020. http://cuentame.inegi.org.mx/monografias/default.aspx?tema=me.

11 Jha, P. K. and Pathak, T. B. 2024. Seasonal climate forecasts show skill in predicting winter chill for specialty crops in California. Commun Earth Environ. 5:485. https://doi.org/10.1038/s43247-024-01623-0.

12 Liu, J. and Sherif, S. M. 2019. Combating spring frost with ethylene. Frontiers in Plant Science. 10:1408. https://doi.org/10.3389/fpls.2019.01408.

13 Livneh, B.; Bohn, T. J. and Pierce, D. W. 2015. A spatially comprehensive, hydrometeorological dataset for Mexico, the US. and Southern Canada 1950-2013. Sci. Data. 2:150042. https://doi.org/10.1038/sdata.2015.42.

DOI: https://doi.org/10.29312/remexca.v16i30.4048

14 Lorenz, C.; Portele, T. C.; Laux, P. and Kunstmann, H. 2021. Bias corrected and spatially disaggregated seasonal forecasts: a long-term reference forecast product for the water sector in semi-arid regions. Earth System Science Data. 13(6):2701-2722.

15 Luedeling, E. 2012. Climate change impacts on winter chill for temperate fruit and nut production: a review. Scientia Horticulturae. 144:218-229.

16 Luedeling, E. and Brown, P. H. 2011. A global analysis of the comparability of winter chill models for fruit and nut trees. International Journal of Biometeorology. 55:411-421. 10.1007/s00484-010-0352-y.

17 Luedeling, E., Girvetz, E. H., Semenov, M. A. and Brown, P. H. 2011. Climate change affects winter chill for temperate fruit and nut trees. PLoS One. 6(5):e20155. https://doi.org/10.1371/journal.pone.0020155.

18 McMaster, G. S. and Wilhelm, W. W. 1997. Growing degree-days: one equation, two interpretations. Agricultural and Forest Meteorology. 87(4):291-300.

19 Muñoz-Sabater, J.; Dutra, E.; Agustí-Panareda, A.; Albergel, C.; Arduini, G.; Balsamo, G.; Boussetta, S.; Choulga, M.; Harrigan, S.; Hersbach, H.; Martens, B.; Miralles, D. G.; Piles, M.; Rodriguez-Fernández, N. J.; Zsoter, E.; Buontempo, C. and Thépaut, J. N. 2021. ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. Earth System Science Data . 13(9):4349-4383.

20 SIAP. 2022. Servicio de Información Agroalimentaria y Pesquera. 7-9 pp. https://www.gob.mx/cms/uploads/attachment/file/771603/Producci-n-Uva-en-M-xico.pdf.

21 Stensrud, D. J. and Skindlov, J. A. 1996. Gridpoint predictions of high temperature from a mesoscale model. Weather and Forecasting. 11(1):103-110. https://doi.org/10.1175/1520-0434(1996)011<0103: gpohtf>2.0.

22 Terence, L. W.; Wu, H. I. Sharpe, P. J. H.; Scholfield, R. M. and Coulson, R. N. 1984. Modeling insect development rates: a literature review and application of a biophysical model. Forum Annals of the Entomological Society of America. 77(2):208-225.

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