Modification of the Solar Radiation Model in Soil Moisture Calculations

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Dear Dr. Fan;

Please accept the enclosed report entitled "Modification of the Solar Radiation Model in Soil Moisture Calculations". This report is a summary of one project I had the opportunity to work on while employed with Agriculture and Agri-Food Canada this summer. This topic is representative of the work I accomplished over the summer work term and showcases an ability to integrate my research and computer programming skills into a business environment. This was my first work term, and an excellent introduction to professional programming, as well as the co-op program.

Within Agriculture and Agri-Food Canada, I worked on a team known as NAIS, the National Agroclimate Information Service. This department is responsible for monitoring and documenting the weather climate across Canada. In particular my role was doing software development for the Drought Watch Website (http://www.agr.gc.ca/pfra/drought/index_e.htm), which provides soil moisture levels across Canada to assist farmers throughout the crop growing season. I was responsible for making several improvements and additions to several different applications to increase the accuracy and efficiency of the tools utilised on a daily basis.

The enclosed report is an entirely original report, created solely by myself based on the research and development I was involved in. My supervisor, Richard Warren, helped provide me with some of the materials used to verify and explain the mathematical equations that are covered in the report.

Sincerely,

Scott Myers,
Agro-Climate Student Technician *(Your Position Title at Co-op Employer)*

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Executive Summary

The Government of Canada offers tools for farmers to help them anticipate and adjust their crop seeding and harvesting schedule. One of these tools is the Drought Watch Website, which shows estimates of soil moisture levels across Canada. The soil moisture is calculated using a mathematical model used to compute a Palmer Drought Index (PDI) value which indicates how wet or dry the soil is compared to the normal over the last 30 years. This mathematical model involves multiple other models to estimate climate conditions to provide more accurate values than just the original model offered. This report is comparing two different implementations of one such supplemental model, particularly the one involved in calculating solar radiation.

The current method is a smooth approximation based on the day of the year. The new proposed model shows variance by estimating cloud cover, vapour pressure, and geographic location. By running sample data through a program that uses the new proposed model and comparing to the same sample data run through the current computer model, it was found that the new model was much more accurate when compared to actual observed values. The new model was implemented into the computer model and found to be on par with what was produced from the pre-existing program used in the research testing.

Overall the adaptation of the new model is recommended for use, but requires further sample data for comparison before being applied. Since all sample data so far has been in Saskatchewan, additional research should be done to ensure that the constants applied work well across Canada, or if further work will need to be done to expand the range beyond the prairies.

1. Introduction

Farming plays a huge role in Canadian society; economically and socially. Those that farm provide food and grain for others and depend on a successful crop to maintain their liveliness. Unfortunately, farming is largely dependant on the climate, soil and weather conditions, to determine how successful a crop will turn out. In order to help farmers get the most out of their crop, tools have been developed to try to track and anticipate climate conditions for crop growth. The Government of Canada tries to assist farmers by offering tools to allow them so see current conditions compared to previous/normal conditions so they may adjust their seeding and harvest schedule. By reading data from nearly 50,000 stations across the country, and analysing the weather conditions with a computer model, users can see if and approximately how much they should adjust their schedule from previous growing season. This information is shared online and via request from Agriculture and Agri-food Canada, such as the drought watch website (http://www.agr.gc.ca/pfra/drought/index_e.htm).

The maps provided indicate the soil moisture level across Canada. This value is computed using a mathematical model known as the Palmer Drought Index (PDI). This model uses the temperature and precipitation values over the last 30 years to calculate how much water is in the soil, taking in account snow and rain, evaporation, snow melt and runoff, geographic location, among other factors. Agriculture and Agri-Food Canada use a computer model based on this mathematical model. In addition to the original model, other models have been included to make the results more accurate. While some values are only estimated in the original PDI model, the computer model incorporates additional mathematical models to more accurately calculate these values. Examples of such values include the computation of soil temperature, crop moisture requirements, frozen ice layer, solar radiation and other variables that influence the PDI result, but are not directly accounted for in the model.

This report will be looking at one such incorporated model – used to calculate solar radiation. The current computer model uses a method based entirely on the day of the year, which does not account for snow, varying sun exposure due to cloud cover, or the difference of precipitation from the daily normal. A new proposed method was suggested, to increase the accuracy of the soil moisture values. This new method would take in account the other variables listed above, but it was unclear how much of a difference the new model would have. Using sample data from one Saskatoon weather station for the 2009 year, research was conducted to determine how significance of a difference the new solar radiation values would cause, and if it would ultimately be worthwhile to implement the new method.

2. Solar Radiation Calculations

2.1 Explanation of Terms

When working with Solar Radiation, certain variables and values will be commonplace. Below is an overview of the more common elements that are used in both the current and new proposed solar radiation calculation methods.

Daylength is the estimated length of time during a day when the solar radiation form the sun hits the measured station location.

Day of Year is the Julian day of the year which is currently of interest. This is used along with the geographic location to adjust the daylength, as the sun gives more exposure during the summer months.

Solar Constant is the constant amount of radiation given out by the sun. It is roughly 1367 Watts/m^2, but actually varies throughout out the year as the Earth's distance from the sun varies.

Solar Declination refers to the angle that the sun's rays hit the earth. This again varies throughout the year as the earth's location in relation to the sun changes.

2.2 Current Calculation

The current model uses solar radiation to approximate the evapotranspiration for a given time period. The current method calculates maximum daily clear sky radiation based on the day of the year and latitude of the location. This provides a nice smooth curve as solar radiation increases in the summer due to longer days. When looking at the actual observed data, it can be seen that the actual radiation is not a smooth curve but rather scattered up and down (fig 1).

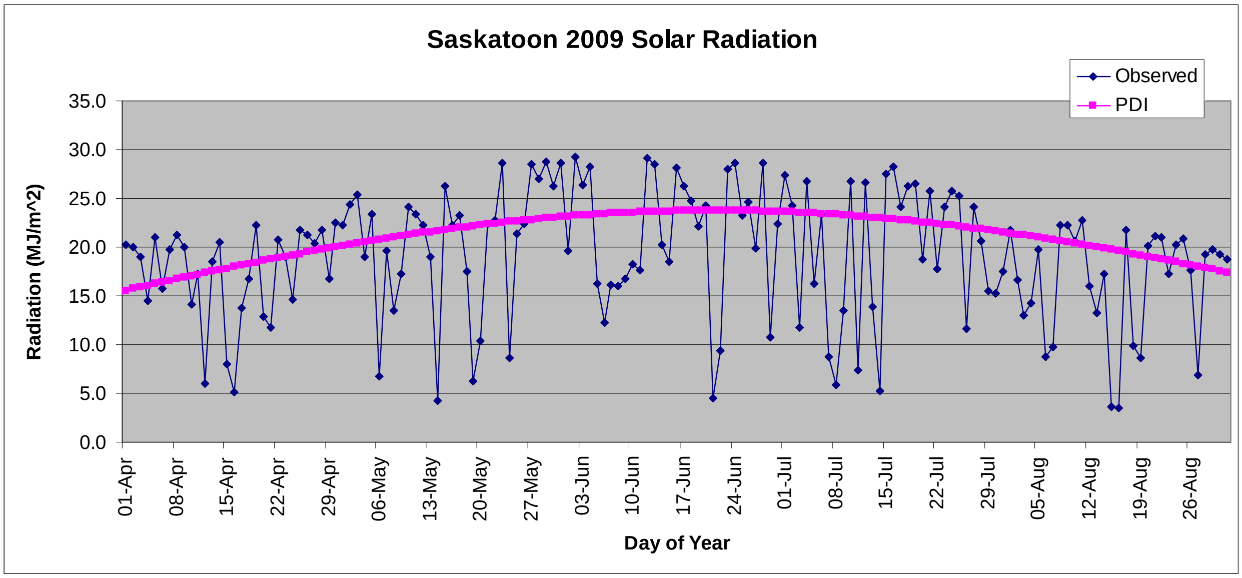

fig 1. Comparison of calculated Solar radiation values compared with observed values for the crop season of 2009.

The current method is only based on the latitude of the location and the day of the year. All other values are estimated off of the current day of the year, such as declination and daylength. From this a maximum clear sky radiation (total transmittance) value is determined and used in evapotranspiration calculations.

2.3 Proposed Calculation

The new proposed method for calculating the solar radiation is based on a mathematical model that would try to account for the high and low points. The varying values are caused by a number of things: cloud cover, location position, vapour pressure, and precipitation and snow conditions among others. Most significant of this is cloud cover. While the original calculation had no accounting for cloud variance, this allows the new proposed model to vary up and down from the seasonal norm. By taking the difference between the daily maximum temperature and the daily minimum temperature you get the diurnal temperature range for a given day. By averaging this across a roaming 30-day period, an approximate variance of the total transmittance can be calculated through the formula $T = 1.0 - 0.9 \exp(-B \times dtr^{1.5})$

Where T is the cloud corrected total transmittance.

B is a radiation constant based on the diurnal temperature range.

dtr is the diurnal temperature range.

Location position has an impact on the amount of radiation recorded as well. Elevation and latitude are taken into account in both models, used to calculate how much of the radiation actually makes it to the observation point. The new model also takes into account the slope of the observation point, as well as visual horizons in the east and west. These values can be used to calculate the day length, or how long the location is exposed to the sun. This is done by using the declination and latitude of a location to determine the hour angle (in radians) of sunset.

Cos(angle at sunset) = - sin(latitude)*sin(declination)/(cos(latitude)* cos(declination))

Day length (seconds) = 2 * angle at sunset * 13750.9871

13750.9871 is a constant for the number of seconds per radian of hour angle.

Using the minimum temperature of a given day, the vapour pressure can be calculated and used to correct the daily maximum transmittance. There is a drop of 0.000061 per Pa of pressure. In order to calculate the vapour pressure accurately, the dewpoint must be known or calculated for the location. The new proposed model uses a simple assumption that the night time minimum temperature approximately equals the dewpoint temperature. So for calculation purposes, the two are interchangeable. Vapour pressure can then be computed as such

pva = 610.7 * exp(17.38 * dewpoint/(239 + dewpoint))

This is then applied to the total transmittance calculated

transmittance = transmittance + (-0.000061 * pva)

Current level of fallen snow and daily rain/snowfall also impact the final result of solar radiation. A correction factor is added to the calculated solar radiation if there is a snow cover on the ground. This calculation was based on a bias noted in experimentation with this model in Austria in 2000.

correction = 1.32 + (0.096)(SWE)

Where SWE is the Snow Water Equivalent, a conversion of how much snowfall stays at a certain location. For the Canadian version of the model, a ratio of 0.7 would be used to reflect snow blowing from a certain location.

3. Research

3.1 Base Model Implementation

Beyond the mathematics, a program written in C was acquired that used this new proposed radiation method. This program was designed to calculate the difference between the moisture at two different locations, given the location and elevation of each point relative to one another. Although that purpose would not be useful to the PDI model, the solar radiation model explained above was still a significant resource. By modifying the source code of this program, and using the same temperature and precipitation values from the observed Saskatoon 2009 radiation data file used to compare the observed radiation values, it is possible to use this program to use the solar radiation model to calculate solar radiation values.

Since the Saskatoon location is a known station, the latitude and elevation information is easily acquired. The program also requires slope and direction values to determine how long a location is exposed to the sun in a given day. Since these are not known for each station location, several tests were run to see the impact of the slope and direction, and the difference was negligible for low slope values, such as those seen on the prairies. Because of the low impact, values were approximated to give a similar result to the observed solar radiation values.

The purposes of modifying the code to run these tests was to see what the models output values would look like, and if the difference was significant enough to warrant modifying the existing PDI model to incorporate. It is also worth noting that due to the small impact the slope and direction of a location seem to have on solar radiation, these values are set at approximate values for continued testing, though further testing is required once sample data beyond Saskatoon can be obtained.

3.2 Observed Value Comparison

Once calibrated as described above, the external program generated values for the sample data given. As was the purpose of the model, the values varied up and down to approximate the various factors that impact the solar radiation. The calculated values produce a normalized root mean squared deviation of 11%, as compared to the current model the PDI program uses, which produces a value of 18%. This means the new model has consistently less variance than the current model, as shown in Figure 2.

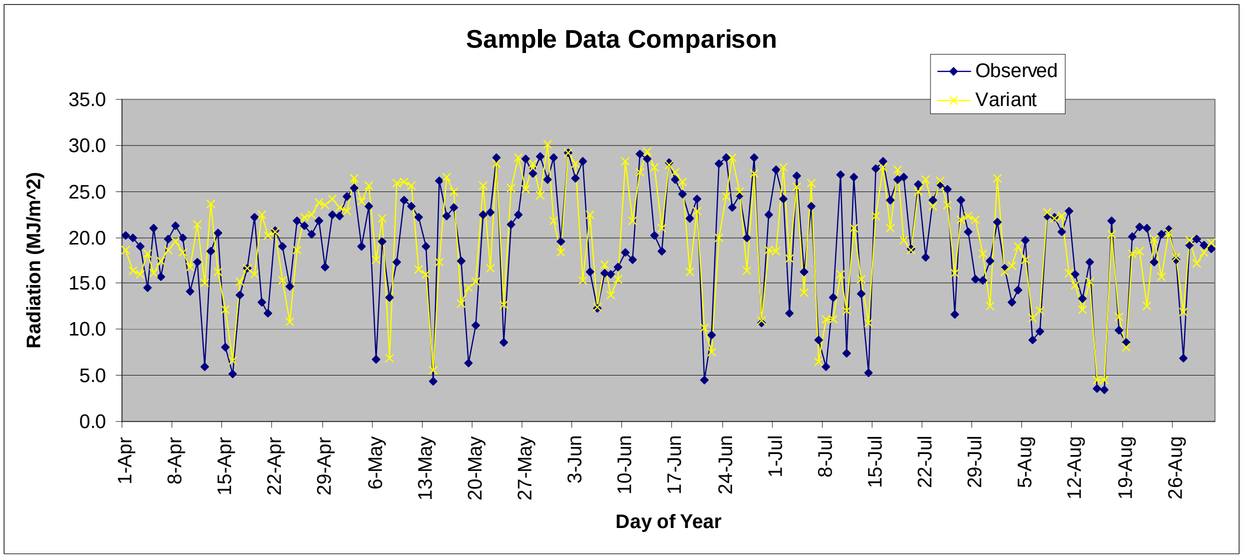

fig 2. Comparison of calculated varying solar radiation values using new calculation model compared with observed values.

Although not entirely accurate, the model does vary with the actual observed values, which was the intent of adopting the new model.

3.3 Current Method Comparison

The new model accurately mimics the observed behaviour, but how does it compare to the current method? Figure 3 is a comparison of the new calculated values compared to those calculated in the current PDI model. The variance resemblances the difference between the observed values and the PDI calculated values and warrants a further investigation. With enough research to support further work, the model will now be translated into the current PDI model for further testing with the existing program code.

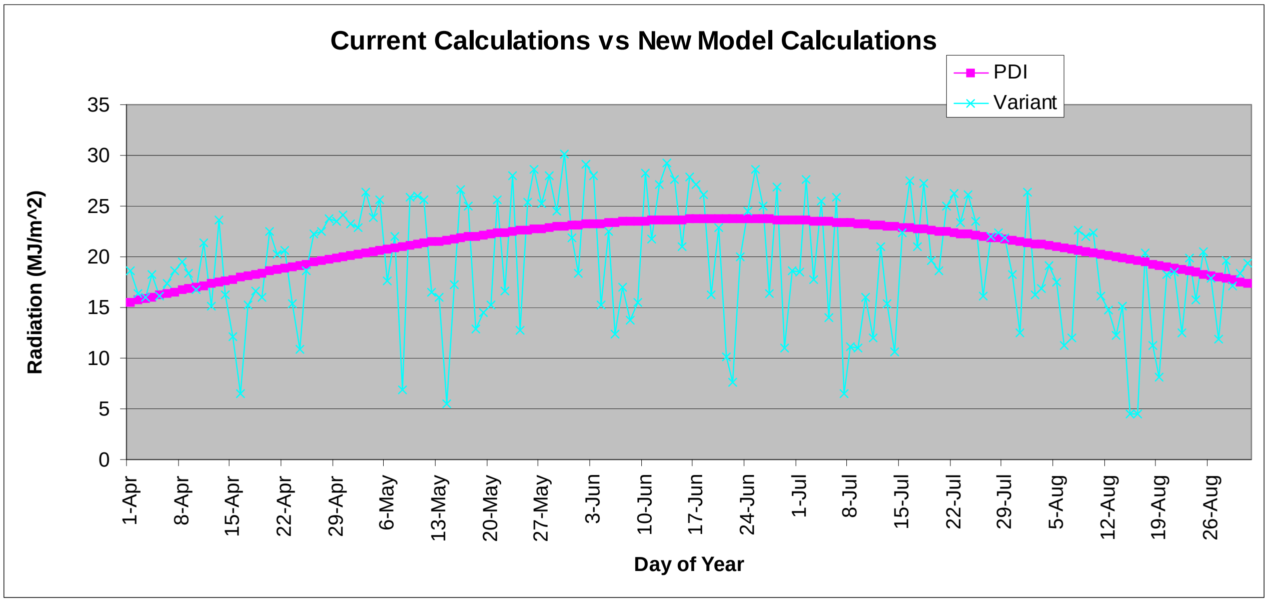

fig 3. Current and new predicted calculation values for solar radiation, using the sample data from Saskatoon, 2009 across the crop growing season.

4. Implementation

4.1 Developer Switch

The new method is still in the testing stage, and will not currently be replacing the existing calculation model. In order to accommodate both methods, and switch has been implemented to use one or the other method. Since the switch would apply to an entire run through all data stations, a binary switch was added to the PDI object, rather than to each station object as it is created and called. The solar radiation calculation function within the station class had to be modified to support the addition parameter for this binary switch. This is implemented at the beginning of the function, separate from the main code in case the switch is to be removed.

Depending on if the switch is active, either the original getSolRad function will be called, or the new calcSolRad function outlined in section 4.3 will be called. This switch is only implemented in the VB.net code, not on the user interface. Although the switch is intended as a developer's tool and should be removed once the new calculation functions can replace the existing, it could be built into a user interface should it be required for testing.

4.2 Changes to Existing Methods

As the new calculations are intended to supplement the current calculations at this time, not much existing code was changed. Aside from the changes required to make the switch described in 4.1 working, changes were only required in the station object. Several new data members were required to provide all the complete information. An elevation variable was added to store the stations elevation along with the longitude and latitude. Currently this information is not read in when creating the station files as that would require work outside of the PDI and Station classes, which is to be addressed at a later time.

Two arrays of length 366 have been added to store the diurnal temperature range (dtr). It was originally considered to make the arrays as two dimensional arrays like the daily climate values (precipitation and temperatures), but since the dtr changes based on previous values, it was decided to only store the current years dtr values. The second array is for a smoothed dtr, which averages out the value for each day from a rolling 30 day window. In addition to these is a Boolean array with a value for each year of data stored in the object. This is simply used to check if a year's dtr values have already been smoothed, so as to not repeat the process for every day of the year.

The New function for station objects was modified to initialize the smoothed array similar to the climate arrays, and the SetInfo function had the elevation added to it when it reads in the Latitude and Longitude. An optional parameter allows the elevation value to be passed, as the eventual plan is, or default to a standard elevation for Canada.

The getPE function, which calculates the potential evapotranspiration, was modified to utilise the new functions and data members when the Boolean switch indicates the new method is to be used. It calculates the dtr values for the year if needed, and calls the dtr smoothing function if it has not been completed for the current year. It also calls the new CalcSolRad function, which contains the new solar radiation calculation model.

4.3 Additional Calculation Methods

Two new functions were added to the station class: smoothDTR and calcSolRad. The smoothDTR function is used to smooth the dtr values stored in the dtr array, and output the new values into the smoothed_dtr array. The function loops through the previous 30 days and averages out the value to give the smoothed dtr value for a given day. Both arrays are passed by reference and the current year is passed to the function as an integer. The function returns a Boolean value corresponding to the success of the smoothing process.

The calcSolRad function contains all of the new calculations and the new constants and variables used for the equations. It returns a double representing the solar radiation value, and is passed the date as a vb.net Date data type, as well as the current snowpack as a double. The snowpack value is computed daily for the station within the PDI class. Constant values were taken from the model code used for research and values for elevation, angle and direction of location were approximated based on the tests with that program.

The solar radiation value is calculated by combining 3 different values: the direct radiation (srad1), the diffuse radiation (srad2), and the snow correction (sc). Srad1 is based on cloud corrected total transmittance, and vapour pressure. Srad2 is based on those aspects, as well as the albedo of snow (if present), and calculated horizons based on the site's geographic location. The snow correction is based on the equation given in section 2.3.

5. Results

5.1 Current Versus Proposed Method

As one would expect, the new model implemented in the PDI program is similar to the tests in the research program. The daily solar radiation values produced were similar to those observed for the test location. Figure 4 shows a comparison of the new PDI calculated values compared to the original values calculated using the previous model. The green trend line shows the polynomial fit of the new values.

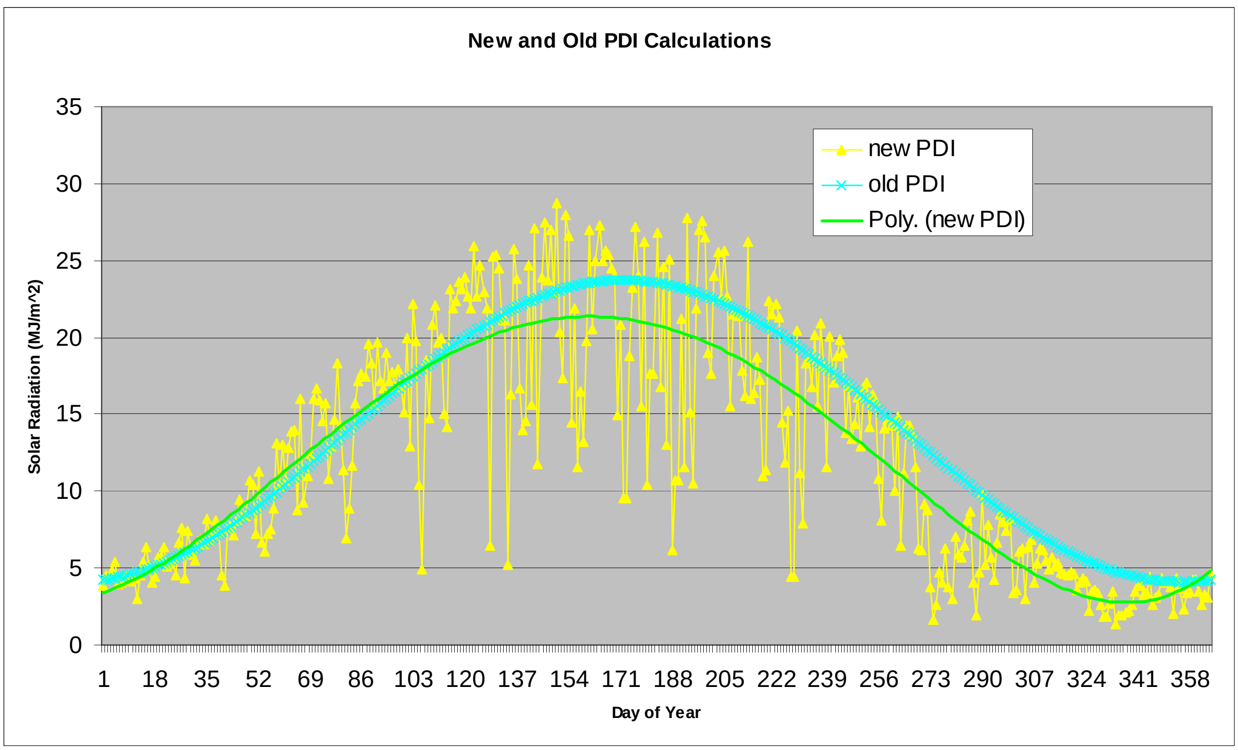

fig 4. Comparison of new and previous calculated values, showcasing the variance in the new models computed values.

While the original PDI calculations showed a variance of 18%, the new PDI program only has a variance from the observed values of 4%. This increase in accuracy, in addition to the dynamic change between consecutive days indicates the new model is an improvement over the previous, static values.

5.2 Proposed Versus Base Model

Although both programs are based on the same mathematical model, both produce different values. Figure 5 shows a comparison between observed values as reported by the Saskatoon test data, and calculated values from the model program used as research, and calculated values from the newly implemented model in the PDI program.

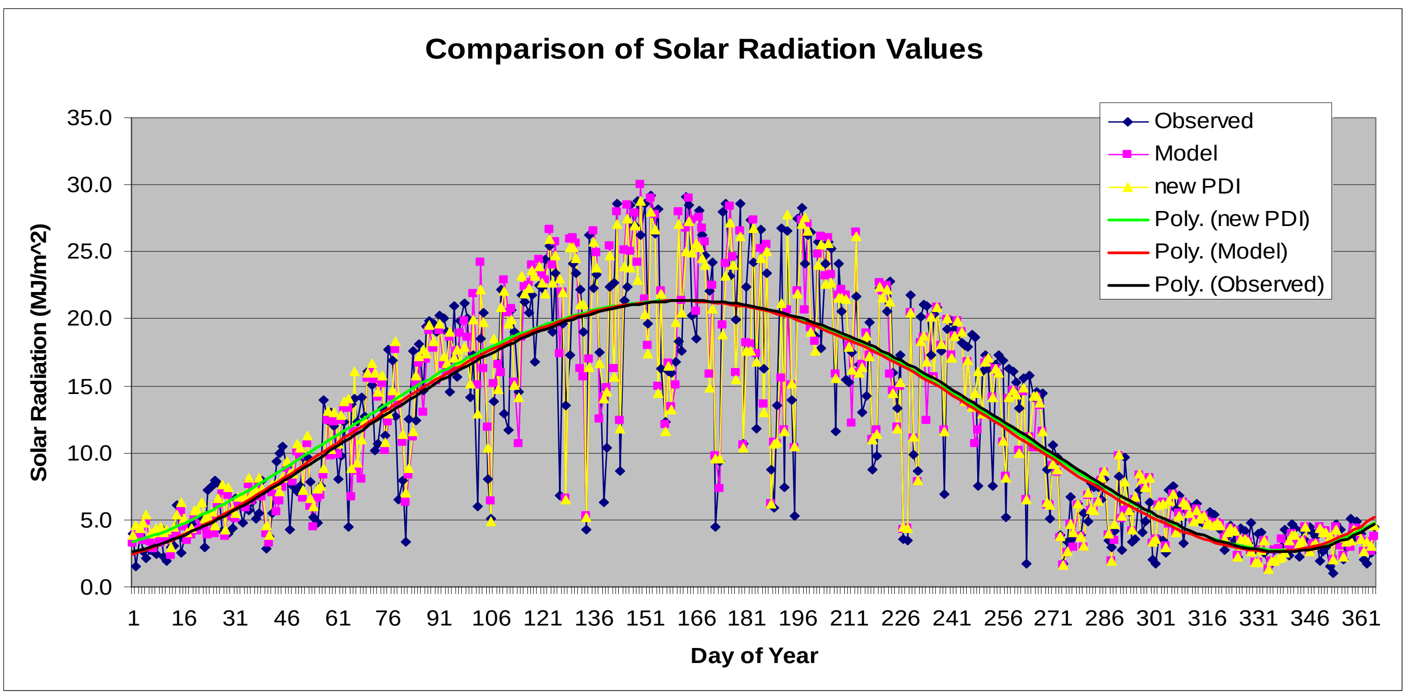

fig 5. Observed values plotted against the calculated values from the research model program, and the new PDI calculations. Polynomial trend lines are shown for each set of values to indicate overall similarity.

The research model had a variance of 11% as listed previously. This was using approximated values for location information in order to determine the validity in implementing the model. In figure 5 above, more accurate values had been used to correspond to those used in the testing of the PDI implementation. With the new values, the research model was able to calculate more accurately, producing a variance percentage of only 6%. Even with this improvement, the new PDI implementation has a variance of only 4%.

5.3 Explanation of Differences

At first it may seem odd that both models do not produce the exact same results given the same input, but there are a few notable differences between the executions that are worth mentioning. The research model program was designed to only be run for one year's worth of data. Because of this, some values must be estimated at execution to find base values. Since the PDI program is computing across 30 years of data, it can carry over the values from one year to the next. This is particularly noticeable in the snow cover layer. Since the PDI model computes daily snow cover, that value is passed directly into the solar radiation calculations. In contrast, the model program approximated the snow layer using a simplified melting model running through the whole year.

Another difference is the dewpoint temperature. As previously stated, the night time minimum temperature is used as an approximation for the dewpoint temperature. The model program also allows for the dewpoint temperature to be input in the data file, should it be known. When it is not known, the program calculates the solar radiation using the estimated values, then estimates the dewpoint temperatures again based on the radiation values, and then calculates the radiation values again based on the new estimates for dewpoints. This is not currently done in the PDI implementation. At this point in time the runtime is large enough and the values computed are accurate enough to not warrant the added process.

5.4 Expansion of Model Implementation

The new model implemented in the PDI program certainly improves upon the values calculated for solar radiation, however there are still more opportunities to improve even further. The first obvious method to improve the calculations is to use different values for the elevation, slope angle, and facing direction of each station location. Elevation information is known, but requires feeding the data through the previous program which prepares the data files for the PDI program. Since the elevation value has not produced a noticeable difference in the output values, this has so far seemed unnecessary. Slope angle and facing direction, however, are not known for each station. These have been approximated based on the initial tests with the Saskatoon data. Requests have been made for observed climate and radiation values from other locations across the country, and once tests can be run on those data sets, it may be possible to better approximate location angle and directions for various parts of Canada.

Another potential improvement is to incorporate a dewpoint estimation similar to that seen in the research model program. Once solar radiation is calculated once for a day, the solar radiation is used to approximate the dewpoint temperature. The new temperature is more accurate than the one based on the minimum observed temperature, and can then be used to refine the solar radiation values. Because of the way the PDI class is currently set up, running these extra calculations would inflate running time of the program, but if the class were restructured to call the appropriate functions for an entire year instead of each day, this would help increase the accuracy of the radiation values.

6. Conclusion

Based on the comparison of the various calculation models compared to the observed values obtained for Saskatoon 2009, the new implementation in the PDI program appears to most accurately represent the actual observed radiation values. Although further testing needs to be done with more sample data sets, it seems clear that the new model is an obvious improvement over the previous method. Even without further enhancements, the new method produces much more accurate results (4% variance compared to 18%) for the sample data. It is recommended that the new model be used going forward once tests can be completed on data from other locations and years to verify that similar improvements to the calculations hold across the country.

The solar radiation values themselves are only a part of the puzzle. These values are ultimately used to calculate the soil moisture, and from that, the drought index of the various stations across Canada. Although not covered in this report, the difference of soil moisture calculations based on the solar radiation model used should be tested before a full implementation. Based on the data set used for testing, an increase of approximately 3-4 mm in soil moisture was observed. This may not seem like a large difference, but so far the test sampling has been small, and the actual value difference isn't what is important – the fact that the values are more accurate is.

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