A Comparison of Vapor Pressure Estimates from MTCLIMv3 and CLIMSIM

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Abstract. Plant productivity is strongly dependent upon moisture. Ecosystem models estimate the moisture content in the air from measurements of vapor pressure. Realistic vapor pressure values allow these models to more accurately estimate plant productivity. Observational measurements of vapor pressure are relatively scarce, and a reliable means of estimating vapor pressure is needed. CLIMSIM and its later version, MTCLIMv3, are climate simulators that estimate daily vapor pressure. CLIMSIM calculates vapor pressure by assuming that the dewpoint is reached every night and that it is equal to the night-time minimum temperature, a more widely available parameter. Unfortunately, this method overestimates the vapor pressure in arid and semi-arid regions. MTCLIMv3 estimates vapor pressure by scaling down minimum-temperature derived calculations by a ratio of daily potential evapotranspiration to annual precipitation. This study compared the vapor pressure estimates from CLIMSIM and an improved version, MTCLIMv3. The input data needed for the climate simulators, daily maximum and minimum temperature and daily precipitation, were obtained from a WGEN weather generator. CLIMSIM and MTCLIMv3 simulated vapor pressure for six locations in the United States: five in arid and semi-arid regions in the West and one in a relatively wetter region in the East. The success of the most recent version, MTCLIMv3, was determined by its ability to match the average monthly vapor pressures in the Danny Marks data set, which were derived from a climatology and assumed to be accurate. MTCLIMv3 out-performed CLIMSIM in all five of the rid and semi-arid regions. However, for certain months, MTCLIMv3 did no better than CLIMSIM at two dry sites. Why MTCLIMv3 fails to improve vapor pressure estimates all year for some dry climates and only some months for other dry climates needs to be investigated further.

INTRODUCTION.
Vegetation and ecological processes such as photosynthesis, respiration, and decomposition are affected by changes in climate. Several previous studies have compared how vegetation distribution and ecosystem physiology models respond to climate (Melillo et al. 1993, Monserud, Tchebakova and Leemans 1993, Nielson 1993, Ojima et al. 1993, Running and Nemani 1991), however, they did not use common input data. Since both the models and the input data differed, it is not clear whether the different results are
due to the model or the data set. This makes an intercomparison of the previously studied models impossible.

The Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) seeks to compare how 6 different vegetation and ecosystem models react to climate changes. Two of these models require daily inputs of variables while the other four require monthly inputs. Phase I of VEMAP created a common data set that could be used by all six models. It contains both monthly and daily data for the same locations and time periods for all variables.

Vegetation and ecosystem models require a coherent set of input variables that realistically represent both spatial and temporal variation of plant requirements, such as nutrients, sunlight, warmth and moisture. Models include variables such as minimum and maximum temperature, solar radiation, precipitation, and vapor pressure to simulate the needs of plants. Vapor pressure is a measurement of the amount of moisture in the air, a critical factor in plant productivity. Therefore it is an essential variable needed in the VEMAP data set.

Although there are many stations that record climatological data such as temperature and precipitation, it is more difficult to find a high station density of vapor pressure measurements. Of the sparse data that is available, it is even rarer to find the vapor pressure data for the location and over the time interval needed by the VEMAP models. Therefore, the vapor pressure values included in the VEMAP data set were simulated using a climate simulator program.

VEMAP Phase I used the CLIMSIM (Running, Nemani and Hungerford 1987) climate simulator to derive vapor pressure. CLIMSIM assumes that the night-time minimum temperature equals the dew point temperature. This dew point is used to calculate the vapor pressure. This assumption works well in environments that receive a fair amount of precipitation, however, it is not valid for arid and semi-arid environments like those found in the southwestern United States. In arid regions, the minimum temperature is typically higher than the dew point. Since CLIMSIM overestimates the dew point, the vapor pressure derived from the dew point is also overestimated.

The vapor pressures used by VEMAP are initially derived using CLIMSIM. The final vapor pressures included in the
data set, however, correct for the CLIMSIM overestimates in dry locations by downscaling the values so that the monthly average values resemble the monthly average values assembled in the Danny Marks data set (1990). The Danny Marks values were estimated from extrapolated dew point measurements, and these values are assumed to be accurate.

Relying on the Danny Marks data set to adjust overestimated CLIMSIM results is not very feasible for VEMAP Phase II. The Danny Marks monthly vapor pressures represent a climatology, or averages calculated from dew points that were measured within a relatively short time period. This period may not be representative of vapor pressures in general. Therefore, another reliable method of estimating vapor pressure is needed.

The newest version of CLIMSIM is able to estimate vapor pressure more accurately in dry environments than the original CLIMSIM. CLIMSIM is a simplified version of a more complex climate simulator called MTCLIM. The difference between the two programs is that MTCLIM can extrapolate variables to locations at higher elevations, whereas CLIMSIM makes extrapolations to flat regions. Like CLIMSIM, the older version of MTCLIM estimated vapor pressure by assuming that the dew point equals the night-time minimum temperature. MTCLIMv3 (Kimbell, Running and Nemani 1996) is the latest version of MTCLIM. It adjusts inflated vapor pressures in dry places using a ratio of potential evapotranspiration (PET) to annual precipitation. This ratio indicates the amount of moisture needed in the air (PET) to the amount of moisture actually available (precipitation).

I compared the monthly average vapor pressure estimates from MTCLIMv3 and CLIMSIM. These estimates were also compared to the monthly average vapor pressures found in both the VEMAP and Danny Marks data sets. The goal of my comparison is to determine whether MTCLIMv3 is able to scale down the vapor pressures that are underestimated by the CLIMSIM method so that they more closely resemble the estimates in the data sets of Danny Marks.

BACKGROUND.
The six models being studied in VEMAP include three biogeography models and three biogeochemistry models. The biogeography models include BIOM2 (Prentice et al. 1992,
Haxeltine and Prentice, in prep.), DOLY (Woodward et al. 1994), and MAPSS (Nielson 1994). The biogeochemistry models include BIOM-BGC/GESSys (Running and Hunt 1993), CENTURY (Parton et al. 1987, 1994), and TEM (Mellilo et al. 1993, McGuire et al. 1993). Among the input variables required by the models are minimum and maximum surface air temperature, precipitation, total incident solar radiation, humidity in the form of vapor pressure and mean daylight relative humidity, and surface wind speed. Daily inputs of the variables are needed by DOLY and BIOM-BGC. The remaining four models need monthly inputs. Both daily and monthly versions of the input variables are presented in the VEMAP database (Rosenbloom and Kittel 1995).

Both the vapor pressures in the VEMAP database and the values from MTCLIMv3 have been adjusted by a ratio. The CLIMSIM vapor pressures in the VEMAP database were adjusted by a ratio so that their monthly averages fit the monthly averages of Danny Marks. The MTCLIMv3 adjusts vapor pressures based upon a ratio of daily PET to annual precipitation. The MTCLIMv3 ratio and the ratio used in the VEMAP database are given in the Methods section of this paper.

The original CLIMSIM vapor pressures are based on the assumption that the dew point is reached every night and that this dew point equals the night-time minimum temperature, which is shown in Figure 1a. Figure 1b illustrates why this assumption works well for relatively wet regions but not for dry regions. In wet environments, the air is full of moisture. As the temperature falls, this moisture begins to condense. When the minimum temperature at night is reached, the moisture has condensed to form dew. Therefore the dew point is approximately equal to the minimum temperature in wet regions. In dry regions, there is very little moisture in the air. When the minimum temperature at night is reached, there is not enough moisture in the air to initiate condensation. The temperature would have to fall below the minimum temperature if dew was to form in dry regions. Since CLIMSIM uses minimum temperature to estimate vapor pressure, and the minimum temperature it uses is high than the actual dew point in dry regions, the vapor pressure calculated from the minimum temperature is also too high. CLIMSIM's newest version, MTCLIMv3 corrects for these overestimations.
Both the MTCLIMv3 and CLIMSIM simulators require the input of daily maximum and minimum temperature and daily precipitation. These values are obtained from a modified version of the WGEN weather generator. Weather generators produce simulated climatological data that behaves much like real data by analyzing long term records of real data for their statistical properties. The weather generator incorporates these properties into it's simulations. The WGEN-derived temperature and precipitation are put into MTCLIMv3 and CLIMSIM, and then MTCLIMv3 and CLIMSIM estimate vapor pressures.

METHODS.

We compared the monthly average vapor pressures at six locations: Langley Air Force Base, VA, Salt Lake City, UT, Las Vegas, NV, Missoula, MT, Merced, CA, and Tucson, AZ. Five of the six sites are located in the western United States, which is the driest section of the country. We compared the monthly average vapor pressures that were derived from four sources: the Danny Marks data set, the original CLIMSIM, the adjusted CLIMSIM values included in the VEMAP Phase I data set, and MTCLIMv3, which is the improved version of CLIMSIM. Monthly rather than daily vapor pressures were used because monthly data has less variability, allowing patterns in the data to be more easily distinguished.

The original CLIMSIM estimates the vapor pressure by assuming that the dewpoint equals the night-time minimum temperature. The vapor pressures in the VEMAP data set take vapor pressures from the original CLIMSIM. However, the CLIMSIM values have been adjusted by a ratio to match the monthly average vapor pressures in the Danny Marks data set.

\[
\text{ratio} = \frac{\text{Danny Marks's monthly average vapor pressure (mb)}}{\text{CLIMSIM average vapor pressure (mb)}}
\]

If the ratio was less than 1.0, then VEMAP Phase I assumed that the CLIMSIM-derived vapor pressures were too high. The daily CLIMSIM estimates were scaled down by the value of the ratio. Otherwise, if the ratio was greater than 1.0, VEMAP Phase I did not change CLIMSIM's daily vapor pressures. These daily estimates were then used to compute the monthly averages.
MTCLIMv3 uses a different ratio to judge the dryness of a region and as a correction factor for downscaling minimum-temperature derived vapor pressures. This ratio is based upon mean daily PET to annual precipitation. If the ratio of daily PET to annual precipitation is greater than 2.25, it is used in the recalculation of the daily minimum-temperature derived vapor pressure. If the ratio is less than 2.25, the minimum temperature-derived vapor pressures are not changed. We used the daily vapor pressure estimates to compute the monthly averages.

\[
\text{ratio} = \left\{ \frac{(\text{PET} / \rho) \times T}{P} \right\}
\]

where
\[
\rho = \text{density of water (kg m}^{-3}) \]
\[
T = \text{day length (s)} \]
\[
P = \text{annual precipitation (m)}
\]

Daily PET is a complex quantity derived from average daily net all-wave radiant energy flux \((R)\), daily average surface conductive energy flux \((G)\), the rate of change of saturation vapor pressure with temperature \((\Delta)\), the latent heat of vaporization \((\lambda)\), and the density of water \((\rho)\). Several simplifying assumptions were made by MTCLIMv3 in the calculation of PET. \(R\) was assumed to be approximately equal to net solar radiation, and the daily average solar radiation is further assumed to equal 80% of the solar irradiance. \(G\) is estimated to be 10% of the daily net solar radiation. Furthermore, \(\Delta\), \(\lambda\), and \(\rho\) are estimated using mean daily air temperature in a procedure developed by Running and Coughlan (1988). The Priestly and Taylor (1972) method of calculating PET used by MTCLIMv3 is shown below.

\[
\text{daily PET} = \left\{ \alpha \cdot \frac{\Delta}{(\Delta + \gamma)} \right\} \times (R - G) / \lambda
\]

where
\[
\alpha = \text{Priestly-Taylor coefficient;}
\]
\[
\alpha = 1.26;
\]
\[
\Delta(Pa/K) = \text{rate of change of saturation vapor pressure}
\]
with temperature

\[ \gamma (\text{Pa/K}) = \text{psychrometer parameter;} \]
\[ = \text{specific heat of air (J/kg K) * air pressure (Pa) / (\lambda * ratio of molecular weights of water & air);} \]
\[ = 0.66; \]

\[ \lambda (\text{J/kg}) = \text{latent heat of vaporization;} \]

\[ R (\text{W/m}^2) = \text{daily net solar radiation;} \]
\[ = \text{solar irradiance (W/m}^2) * (1.0 - \text{solar albedo}); \]

\[ G (\text{W/m}^2) = \text{daily conductive energy flux;} \]
\[ = 10\% \text{ of } R; \]

solar albedo = 0.2

RESULTS.

Figures 2 through 7 are the results for the six studied locations. There are four plots in each figure. Plot A illustrates the daily maximum temperature (degrees C), Plot B, the daily minimum temperature (degrees C), Plot C, the daily precipitation (cm), and Plot D, the monthly average vapor pressure (mb).

Each plot covers a time period of one year. The vapor pressure plots consist of four time series: the time series marked by the upside down triangle represents the data from the MTCLIMv3 simulator; the time series with the square is the adjusted CLIMSIM data; the time series with the diamond is for the Danny Marks data, and the time series with the dark-colored triangle shows the original CLIMSIM data.

We expected certain characteristics to be seen in the vapor pressure data. For instance, the average vapor pressure should increase from month 1 until about month 7, and after this begin to decrease until the end of the year. We also expected CLIMSIM to overestimate the vapor pressures relative to the Danny Marks data for the 6 sites in the western United States. This is because CLIMSIM is less accurate at simulating vapor pressures in dry regions than in wetter regions for the eastern U.S. For all sites, the MTCLIMv3 values should be able to apply the ratio of daily PET to annual precipitation so that its results are closer.
to the Danny Marks data than the CLIMSIM results. The adjusted CLIMSIM should match the Danny Marks data. As expected, CLIMSIM overestimated the vapor pressures in all of the five arid and semi-arid regions, but MTCLIMv3 produced values closer to the Danny Marks data. However, for certain months, MTCLIMv3 did no better than CLIMSIM at 2 dry sites.

Figure 2 illustrates the results for Langley Air Force Base, VA. The MTCLIMv3, the CLIMSIM, and the adjusted CLIMSIM values all coincide with the Danny Marks data. The vapor pressure plots for Langley Air Force Base are good because it lies in a wetter climate, where the minimum temperature-derived vapor pressure calculated by CLIMSIM is a good approximation. Also, the ratios used by MTCLIMv3 and adjusted CLIMSIM, which are meant to adjust overestimated minimum temperature-derived vapor pressures, did not have to adjust their values significantly, if at all.

The vapor pressure plots for Missoula, MT are in Figure 3. Plot 3c, the precipitation plot, indicates that this is a semi-arid region. The Danny Marks data shows that the vapor pressures are likely to range between 200 and 800 mb. The CLIMSIM, adjusted CLIMSIM, and the MTCLIMv3 all fall below the average vapor pressures indicated by the Danny Marks. The difference between the Danny Marks and the other results are relatively insignificant at the beginning and end of the year but differ by about 200 mb between months 5 and 10.

The results for the Salt Lake City, UT site appears in Figure 4. Salt Lake City, like Missoula, MT, has semi-arid climate. The CLIMSIM values are rather high relative to the Danny Marks data, especially in months 5 through 9, where they differ by almost 300 mb. The data from the adjusted CLIMSIM and the MTCLIMv3 matches the Danny Marks results.

Figure 5 shows the plots for Merced, CA a very dry region. The CLIMSIM data is higher than Danny Marks data the entire year, but differs most drastically during the months 5 and 10, when the two are separated by 400 mb or more. The adjusted CLIMSIM matches the Danny Marks results, but the MTCLIMv3 does not. In months 1 through 5 and months 11 and 12, MTCLIMv3's values are slightly higher than even the CLIMSIM overestimates. It is not until month 6 that the MTCLIMv3 results begin to more closely match those of Danny Marks. Between months 9 and 10, the MTCLIMv3 vapor pressure
values should be falling, but there is an uncharacteristic increase instead.

Figure 6 illustrates the Las Vegas, NV results. Whereas the Danny Marks data indicate that the average vapor pressure rises no higher than 500 mb, the CLIMSIM estimates extend above 2000 mb. The greatest difference between the two occurs between months 4 and 10, when CLIMSIM overestimates the Danny Marks data by 500 mb or more. The difference between the Danny Marks and MTCLIMv3 are no larger than 500 mb throughout the year. The resemblance between the Danny Marks and the adjusted CLIMSIM is perfect.

Figure 7 shows the last site studied, Tucson, AZ. Tucson has a very dry climate, except in the months 6 and 7, which is it’s monsoon season. In relation to the Danny Marks results, the adjusted CLIMSIM results are a prefect match, but the original CLIMSIM results are inflated. They differ by about 200 mb at the beginning and end of the year. In the middle of the year, between month 5 through 9, the CLIMSIM results differ by about 1000 mb. MTCLIMv3 overestimates the Danny Marks data by no more than a few hundred mb’s. At month 7, MTCLIMv3 shows an increase in vapor pressure where the Danny Marks data indicates a decrease. Then, from this month until the end of the year, the MTCLIMv3 estimates are similar to those of CLIMSIM.

To summarize, both MTCLIMv3 performed well at Langley Air Force Base, but MTCLIMv3 made significant improvements over CLIMSIM in Salt Lake City and the Las Vegas sites. The CLIMSIM values in Salt Lake City were, at most, 600 mb greater than what was estimated by Danny Marks, but MTCLIMv3 was able to get within 200 mb or less of the Danny Marks results. In Las Vegas, the CLIMSIM values were as great as 1700 mb above the Danny Marks data, whereas the MTCLIMv3 estimates were within 500 mb of the Danny Marks results.

In Tucson and Merced, difference between the Danny Marks and MTCLIMv3 was less than the difference between CLIMSIM and the Danny Marks, but not as consistently as in Las Vegas or Salt Lake City. During the first seven months of the year in Tucson, CLIMSIM values were, at most, 1300 mb higher than those of Danny Marks, but MTCLIMv3 estimates were within 300 mb or less. After month 7, though, the MTCLIMv3 estimates were just as high as CLIMSIM’s. In Merced, MTCLIMv3 estimates improved over those of CLIMSIM.
only during months 5 through 10. However, these are also the five months where CLIMSIM overestimated the vapor pressure the most, by as much as 500 mb. In all of the other months in Merced, the MTCLIMv3 estimates were the same or slightly higher than CLIMSIM’s.

CONCLUSION.

Overall, the MTCLIMv3 vapor pressure estimates came closer to the estimates of Danny Marks in arid and semi-arid environments than did CLIMSIM. Of the six locations studied, five were in arid and semi-arid regions: Missoula, Salt Lake City, Las Vegas, Merced, and Tucson. MTCLIMv3 made better estimates than CLIMSIM in all of these areas except Missoula, where both MTCLIMv3 and CLIMSIM underestimated the Danny Marks data.

This study has raised and interesting question: why does MTCLIMv3 produce good vapor pressure estimates in Salt Lake City and Las Vegas, but not as well as in Merced or Tucson, even though all four regions have dry climates? Also, why do CLIMSIM and MTCLIMv3 underestimate the vapor pressure in Missoula? Perhaps there is a flaw in the ratio used by MTCLIMv3 to downscale minimum-temperature derived vapor pressures. There is also the possibility that the Danny Marks data which we are comparing MTCLIM 3 and CLIMSIM against may not be accurate if the real data it was interpolated from are from years when the real data is uncharacteristic of long term values.

If there is an error in the MTCLIMv3 program, the most qualified persons to answer our questions would be the creators of MTCLIMv3. They have a far greater understanding of the workings and limitations of MTCLIMv3, and therefore may be able to provide insight into this problem. Future work will involve making the MTCLIMv3 creators aware of the findings from this project and allowing them to analyze the results for themselves.

Correcting the inconsistencies observed in MTCLIM 3 is crucial to future phases of VEMAP. The vegetation and ecosystem models used in VEMAP require the input of daily and monthly average vapor pressure estimates. The models use vapor pressure as a means of estimating the amount of moisture available to plants, and moisture is a crucial factor controlling plant productivity. As vapor pressure estimates become more accurate, so will the models predictions of plant productivity. Then VEMAP can better
assess how this productivity and other features of vegetation and ecosystems are altered by changes in climate.

REFERENCES


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FIGURE 1a.

FIGURE 1b.
**Figure 5**

**Plot A**
Maximum temperature (°C) over 1 year for grid pt. #2425 (Merced, CA)

**Plot B**
Minimum temperature (°C) over 1 year for grid pt. #2425 (Merced, CA)

**Plot C**
Precipitation (cm) over 1 year for grid pt. #2425 (Merced, CA)

**Plot D**
Average vapor pressure (mb) over 1 year for grid pt. #2425 (Merced, CA)
FIGURE 7

PLOT A
maximum temperature (C) over 1 year for grid pt #3824 (tucson, az)

PLOT B
minimum temperature (C) over 1 year for grid pt #3824 (tucson, az)

PLOT C
precipitation (cm) over 1 year for grid pt #3824 (tucson, az)

PLOT D
average vapor pressure (mb) over 1 year for grid pt. #3824 (tucson, az)
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