Point-by-point Responses to two Referees for # hess-2021-164

Referee 2 for # hess-2021-164

The authors have used regular fonts for the Referee's comments and blue fonts for our responses and red fonts with quotation marks to show the revised text.

This manuscript seeks to improve an empirical 10 cm bare soil temperature prediction for the Great Plains by incorporating snow cover, soil moisture, and additional previous temperature data. Data from are validated against a multi-state mesonet and show a reduction in root mean squared error. The importance of knowing soil temperature data for hydrologic and agricultural applications is quite clear, the rationale for an empirical approach very understandable, and the key parameters that increase thermal mass (increased soil moisture and cover) are rational for model improvement. The topic is of high relevance for readers of Hydrology and Earth System Sciences.

Response: Thank you for your review and insights, which improved our paper. We responded to all of your comments.

Major comments:

1. While I think this manuscript may be a useful contribution to the literature, I have two major comments that I feel need addressing. One is on the input data to the model. The model seeks to predict soil temperature, but it needs soil moisture as an input. Soil moisture seems to be at least as difficult to measure, if not more so, than soil temperature, so the practical utility of this specific model seems suspect. It would have been much more useful if a satellite-based soil moisture/snow cover product such as those available from SMAP or Sentinel (Das et al., 2019) were used as inputs. Similarly, the soil texture product used in this study is at much coarser resolution than products such as POLARIS (Chaney et al., 2016), which are available at 30m resolution. I really think this analysis would be much stronger if these products were used. At the very least, I think more explanation and discussion is needed around this.

References:

Chaney, N. W., Wood, E. F., McBratney, A. B., Hempel, J. W., Nauman, T. W., Brungard, C. W., and Odgers, N. P.: POLARIS: A 30-meter probabilistic soil series map of the contiguous United States, Geoderma, 274, 54–67, https://doi.org/10.1016/j.geoderma.2016.03.025, 2016.

Das, N. N., Entekhabi, D., Dunbar, R. S., Chaubell, M. J., Colliander, A., Yueh, S., Jagdhuber, T., Chen, F., Crow, W., O'Neill, P. E., Walker, J. P., Berg, A., Bosch, D. D., Caldwell, T., Cosh, M. H., Collins, C. H., Lopez-Baeza, E., and Thibeault, M.: The SMAP and Copernicus Sentinel 1A/B microwave active-passive high resolution surface soil moisture product, Remote Sensing of Environment, 233, 111380, https://doi.org/10.1016/j.rse.2019.111380, 2019.

Response: Thank you for your insight. We agree that soil moisture and snow cover detected by satellite would be useful if they are available. Yes, the soil moisture modeling is much more challenging than soil temperature modeling due to soil moisture transport mechanisms and its high heterogeneity. We used soil moisture estimated from a simple empirical approach based on reference evapotranspiration, precipitation, and surface water balance. Yes, strictly, this estimate is not accurate in an absolute sense but it does help for improving soil temperature modeling as a secondary input in our model. We attempted to use the SMAP Level-3, 9 km soil moisture product for 2019. We did spline-interpolation for each station from the 9 km grids. It turns out that when using the SMAP data for soil moisture the modeled soil temperature had a 1.5°C RMSE on average and 26% of stations had larger than 1.6°C RMSE. We then realized that the simple estimated soil moisture for each station performed better than the results by using SMAP. We believe part of the reason for this result was because the 9 km soil moisture resolution was too coarse for our purpose. Figure R1.3 shows the result. However, we also believe that these products (if we could assimilate SMAP and other high spatial and temporal resolution satellites together in near future) would certainly be helpful for the daily soil temperature modeling.

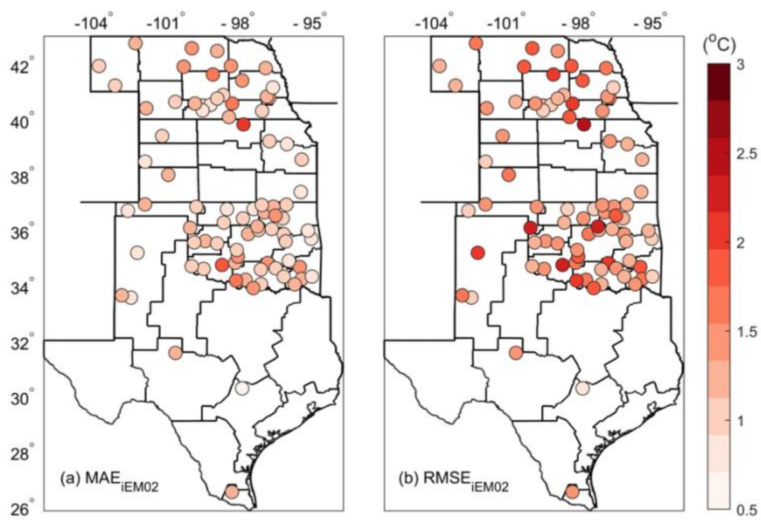


Figure R1.3: Spatial distribution of mean absolute error (MAE) and root mean square error (RMSE) for an improved empirical model (iEM02, a and b) using the SMAP soil moisture product for 2019 year as an example. The colorbar defines values of MAE (°C) and RMSE (°C).

For the second question associated with soil texture used in the study, we used the Gridded Soil Survey Geographic (gSSURGO) Database, which is an upgraded version based on the Soil Survey Geographic (SSURGO) Database. The database in gSSURGO includes 30 m resolution data that we used in our study (Soil Survey Staff, 2014). We described this in our manuscript in Lines 120-124.

In order to enhance soil moisture estimates in our future studies by integrating SMAP information, we added one sentence at the end of section 3.1 as:

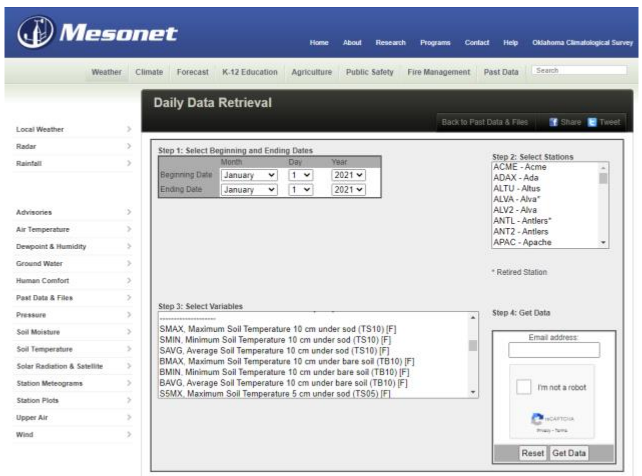
"The daily soil temperature modeling could be further improved if high-resolution (e.g., 30 m and daily) satellite-based soil moisture/snow cover products become available, for example, products based on the SMAP or Sentinel satellites (Das et al., 2019)."

2. The second issue I see is with validation. Both the NRCS SCAN and Oklahoma MESONET sites don't report soil T at 10 cm (they are reporting at 4 and 8 cm for NRCS) and 4 cm for

MESONET. Please discuss how you use these data from different depths to train and validate a model that is at 10 cm?

Responses: When we downloaded soil temperature data from Oklahoma MESONET (http://www.mesonet.org/), we used the soil temperature data at 10 cm depth although OK-MESONET does include 5 cm, 10 cm, 25 cm, and 60 cm soil temperatures. Therefore, we directly used 10-cm soil temperature to train and test our models. Similarly, the data we selected from NRCS SCAN indicated they are 4-inch soil temperatures. We re-examined these descriptions and confirmed that they are 10 cm from NRCS SCAN (https://www.wcc.nrcs.usda.gov/scan/) for Texas.

Below are two screenshots from OK-MESONET and NRCS SCAN displaying soil temperature depths.



Here is the screenshot from the NRCS SCAN website

Soil Moisture Percent -2in (pct) Mean of Hourly Values	Soil Moisture Percent -4in (pct) Mean of Hourly Values	Soil Moisture Percent -8in (pct) Mean of Hourly Values	Soil Moisture Percent -20in (pct) Mean of Hourly Values	Soil Moisture Percent -40in (pct) Mean of Hourly Values	Soil Temperature Observed -2in (degF) Mean of Hourly Values	Soil Temperature Observed -4in (degF) Mean of Hourly Values	Soil Temperature Observed -8in (degF) Mean of Hourly Values	Soil Temperature Observed -20in (degF) Mean of Hourly Values	Soil Temperature Observed -40in (degF) Mean of Hourly Values
	49.7	19.7	17.8	16.4		65	64	59	56
	47.2	25.3	17.9	16.4		61	62	60	57
		37.2	17.9	16.5		59	59	59	57
		35.7	17.8	16.5		62	61	59	57
	50.4	34.4	17.9	16.5		65	64	60	57
	46.0	33.1	17.9	16.6		65	64	60	57
	42.4	31.8	17.9	16.6		65	64	61	58

Specific comments:

1. Figs 5., 7, and 9: While RMSE is an important validation statistic, I would consider reporting other statistics such as BIAS and maybe the Nash-Sutcliffe Efficiency. RMSE really integrates both precision and accuracy while other statistics can help assess these independently.

Response: Thank you for your suggestions. We used the mean absolute error (MAE), which is the bias concept. Please see Line 202 in our original manuscript. Here we calculated Nash-Sutcliffe Efficiency (NSE) (see the Figure below) and found that we had similar or the same results as when we used RMSE.

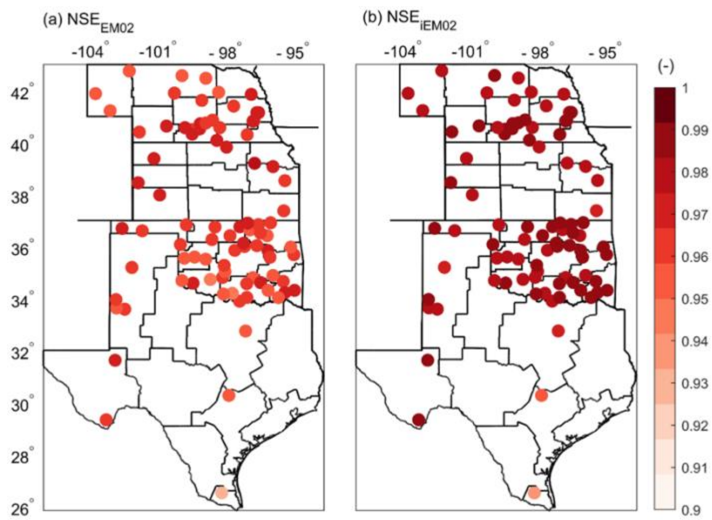


Figure R1.4: Nash-Sutcliffe Efficiency (NSE) for the empirical model (EM02, **a**) and the improved model (iEM02, **b**). The colorbar defines values of NSE (-).

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