The Influence of Soil Moisture Upon the Geothermal Climate Signal

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Abstract – **Estimates of regional climate warming over the past few hundred years are being obtained from profiles of borehole temperature versus depth. The two assumptions in recovering mean annual Surface Air Temperature (SAT) are that the relationship between the Ground Surface Temperature (GST) and the temperature-depth profile is purely conductive, and that SAT is uniquely coupled to GST. While these assumptions have been demonstrated to be approximately valid, they ignore the role of moisture transport in soil and between soil and atmosphere. In this study we examine the influence of climatic changes in precipitation upon mean annual GST with climatic SAT held constant.**

We use the most recent version of our Prairie SVAT model for a set of 80 year simulations. Our findings are 1) increasing precipitation reduces mean annual GST, 2) phasing maximum precipitation to occur during the warmest months reduces mean annual GST, and 3) increasing the variance of precipitation reduces mean annual GST. The amplitudes of the effects are small but potentially not insignificant fractions of the geothermal climate signal.

One of the long-term objectives of this investigation is to use global EOS SAT and remotely sensed soil moisture to link region-specific, geothermal climate signal histories to evolution of regional climate.

I. Introduction

Records of annual mean Surface Air Temperature (SAT) serve as indicators of past climate variability and change. These records are reconstructed from proxy data, the most quantitative of which are borehole temperature profiles. A review of the approach is found in [1] and an example is shown in Figure 1.

Two premises of inferring SAT from a borehole temperature profile, also called the geothermal climate signal, are (1) that the process linking temperature at depths of 10's and 100's of meters in soil and rock to the annual mean Ground Surface Temperature (GST) are primarily conductive, and (2) that SAT follows GST. These premises have been empirically justified [2-4]. Our near-term objective is to use our Land Surface Process (LSP) model [5-12], a sophisticated Soil-Vegetation-Atmosphere Transfer (SVAT) model, to quantitatively examine the validity of these premises*. This paper is a report on progress toward that objective. A longer-term objective is to define an EOS satellite product meaningfully continues an SAT reconstruction through the present day.

The GST reconstruction can be understood in its simplest form by considering a soil halfspace having uniform thermal properties and no moisture flux. Temperature profiles below depths of a few meters will be unaffected by diurnal and seasonal cycles so that temperature gradients will be a constant if annual land-atmosphere energy fluxes do not vary from year-to-year. The baseline gradient is positive with depth reflecting heat flow out of the Earth. If GST begins increasing, the gradient will deviate from linearity as shown in Figure 2. If GST is tightly coupled to SAT through conduction, then GST reconstructions from borehole temperature profiles will be reliable indicators of past climate.

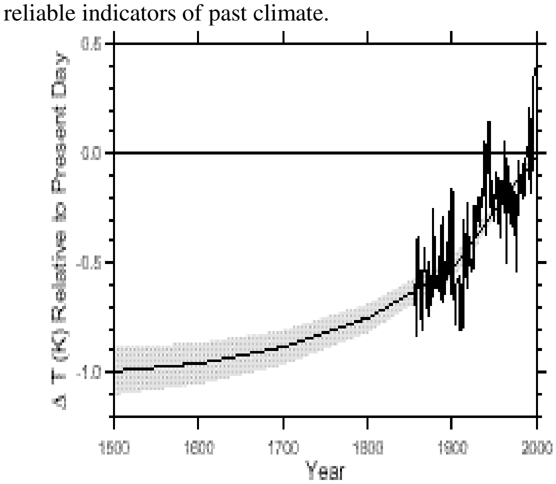

Figure 1. Reconstruction of GST from borehole temperatures [2]. Shaded area represents ± 1 standard error about the mean history. Also shown for comparison is a five-year running mean of the globally averaged instrumental record of SAT since 1860 [13].

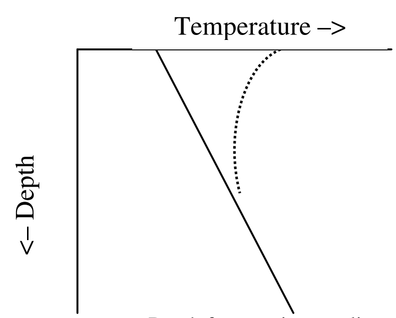

Figure 2. Temperature versus Depth for a stationary climate (solid line) and for a warming climate (dotted line).

The processes that actually link temperature in soil below the vadose zone to surface air temperature are more complex than the GST reconstruction suggests. These processes are well understood to include radiant and latent energy fluxes at the land-atmosphere interface, and moisture fluxes in the form of precipitation, infiltration, runoff, evaporation, and transpiration [14]. Furthermore, the contributions of many of these processes to GST and their linkage to SAT are distinctly non-linear. The question addressed here is to what extent variations in precipitation might be expected to influence observed GST.

II. The Experiment

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We designed 3 precipitation experiments for a hypothetical prairie grassland site near Coldwater, Kansas. The experiments were (1) To vary the precipitation by a constant factor, (2) To modify the intensity of precipitation without altering is integrated total, and (3) To vary the time-of-year of the precipitation without altering its integrated total. The site location has the advantages of rarely incurring soil freezing or insulation from snow, relevant precipitation and weather data for Coldwater are available from the U.S. National Climate Data Center, and a credible a 3-layer soil constitutive profile could be imported from the SGP'97 experiment in Oklahoma. The water table was assigned to be at 3 m.

Weather and downwelling radiation forcing at a 2 minute time interval were generated for a baseline year of 1999. Downwelling radiation was estimated using the latitude-specific algorithm described in [5], and a constant cloud cover of 20%. Relative humidity and wind velocity were held constant throughout the year at 50% and 5 m/s, respectively. Daily precipitation and surface air temperatures for 1999 were acquired for Coldwater (Figure 3).

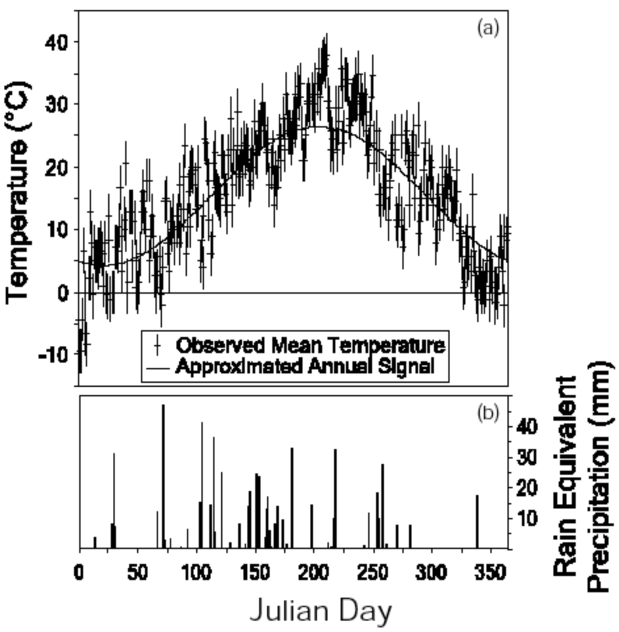

Figure 3. Daily SAT and precipitation records for Coldwater baseline.

The LSP Model

Our LSP model manages vertical energy and moisture transport in soil and vegetation of prairie grassland [12]. Calibration and extensive validation experiments occurred in South Dakota and Oklahoma [7,15]. For purposes here, the prairie LSP model was modified to increase its working depth from a few meters to 30 m in 51 layers. The experiments reported here were run with a model depth of 20 m. The lower boundary condition was modified from a constant temperature and zero moisture flux to a zero heat and moisture fluxes. Algorithms were redesigned and the model was recoded to gain the computational efficiency needed to simulate 80 years at a time step of 2 minutes over a few hours on a high-end PC running Linux. The result is an extensively annotated and compact 1500 line Fortran 90 code.

The Baseline

The model was forced with the baseline year for 80 years to assure it had reached a steady state. This equilibrium yielded a constant temperature profile below the depths the annual signal could propagate – a few meters.

Experiment 1 – Vary Precipitation by a Constant Factor

The precipitation was altered from the baseline by factors of 0.5, 0.75, 1.25, 1.5, and 2.0. Differences between baseline GST and surface soil moisture are shown in Figure 4.

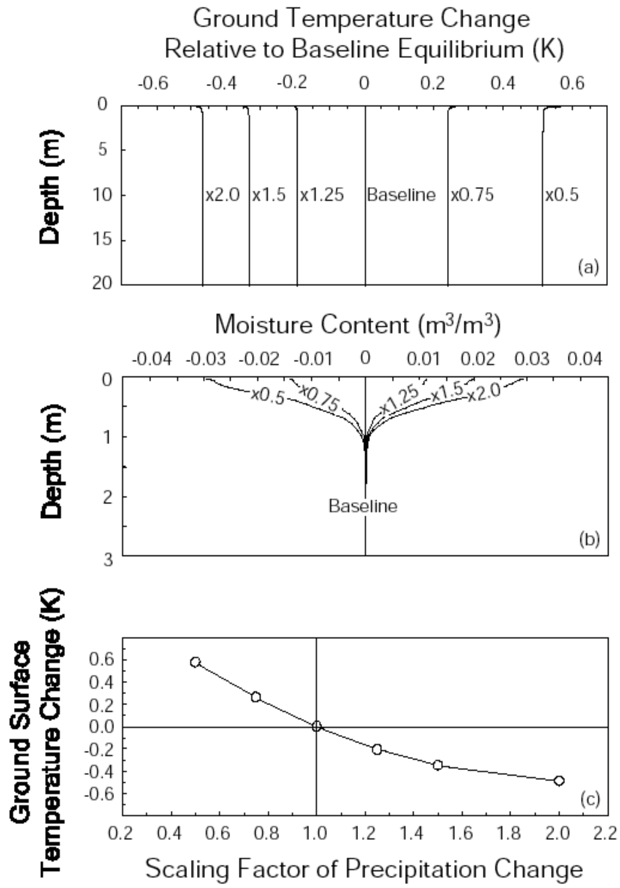

Figure 4. Response in GST and soil moisture to scaling precipitation over the range of 0.5 to 2.0: (a) temperature profile changes relative to baseline; (b) moisture profile changes relative to baseline; and (c) GST changes relative to baseline as a function of scaling factor.

Experiment 2 – Vary Intensity of Rainfall

The precipitation record was filtered either to increase intensity and reduce rate of occurrence or to decrease intensity and spread events over a longer period. In all cases, the annually integrated precipitation remained constant. The low end of the range of intensities was the average daily precipitation for the year, i.e., a constant drizzle for the year. The high end of the range of intensities was generated by gathering all of the precipitation within 7 day periods and placing their integrated total on the day that had the original maximum within the 7 day period. The degree of concentration was characterized by the Standard Deviation of the precipitation where the constant drizzle has a SD of 0 mm, the baseline has an SD of 6.2 mm, and the maximum has a SD of 8.2 mm. Results are shown in Figure 5.

Experiment 3 – Vary Timing of Rainfall

As shown in Figure 3, the precipitation was not evenly distributed throughout the year. Most precipitation occurred in spring and early summer. To examine the effect upon GST of timing of the precipitation, the baseline precipitation was shifted by 3, 6, and 9 months. Results are shown in Figure 6.

III. Conclusions

To the extent that SAT tracks GST, Figure 1 shows GST warming 1 K over the last 500 years. Our experiments suggest that much less than half the observed change could credibly result from an increase or decrease in overall precipitation (Figure 4); a redistribution of precipitation toward a constant drizzle (Figure 5); or shift of precipitation from spring and early summer to late fall and winter (Figure 6). The maximum effects found are incredible because the required changes in precipitation forcing are extreme. An expanded discussion of these observations is included in [16].

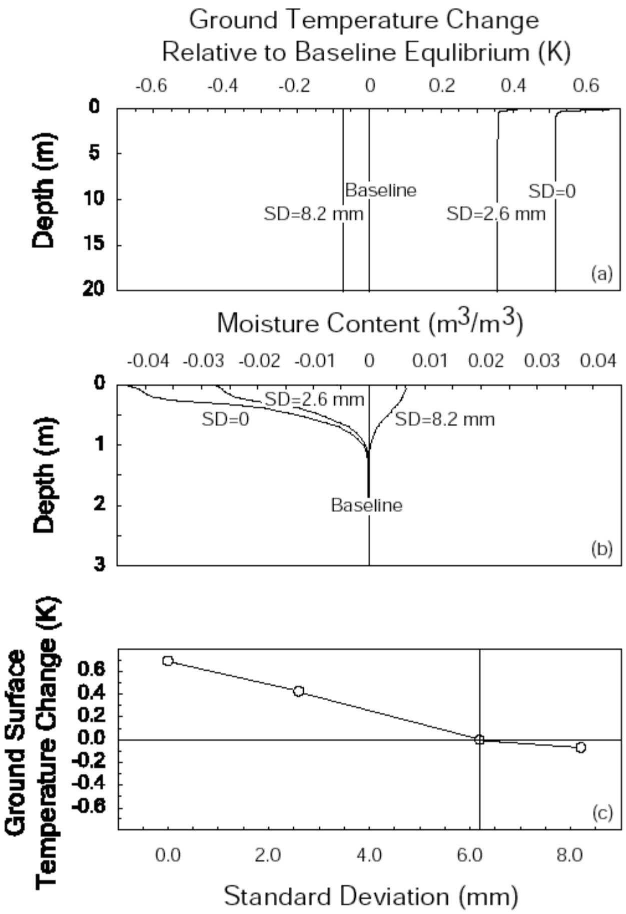

Figure 5. Response of GST and surface soil moisture to Standard Deviation of precipitation: (a) temperature changes relative to baseline; (b) soil moisture changes relative to baseline; and (c) GST changes relative to baseline as a function of SD.

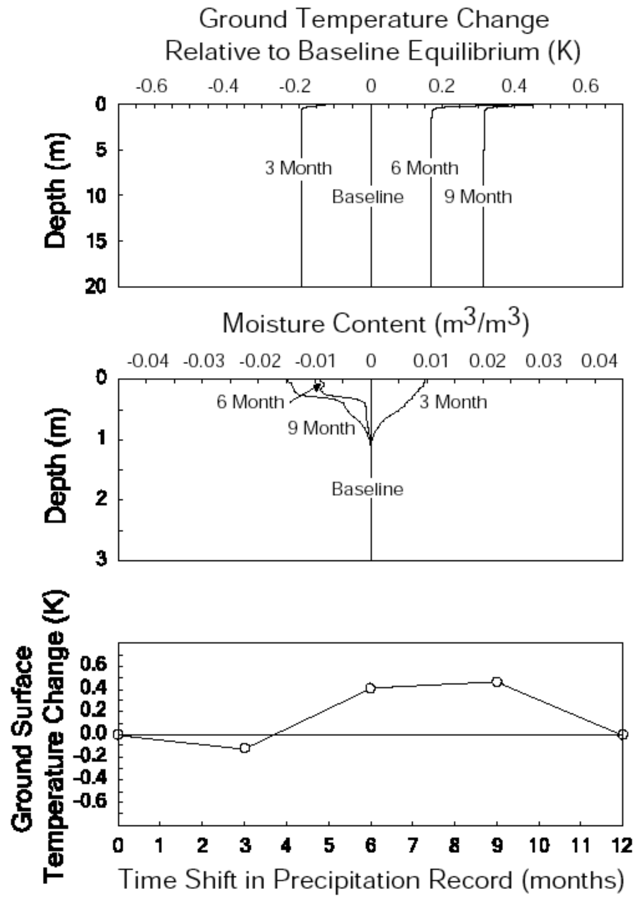

Figure 6. Response of GST and surface soil moisture to phase of annual precipitation: (a) temperature profile changes relative to baseline; (b) moisture profile changes relative to baseline; and (c) GST changes relative to baseline as a function of time shift in annual precipitation.

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