Modeling Soil Temperature Timeseries Through a Bayesian Dynamic Linear Model for Structural Breaks

Manju M. Johny

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Motivation

- Soil home to diverse array of life – Climate change could have profound implication to soil ecosystem
- Increase in mean surface temperatures over the past 50 years
- Increase in daily max and min surface temperatures over past 50 years
  - Daily min increasing *faster* than daily max
  - Diurnal surface temp (Max - Min daily temp) has been decreasing
- Scientists intersted in undersanding effect of climate change underneath the soil

Experiment

- Dr. Diane Debinski's lab simulated effects of climate change to understand impact on soil
  - Montane Meadows in Grand Teton National Park, WY
  - Early snow melt simulated through snow removal
  - Warmer temperatures (green house effect) simulated through passive heating chambers
  - Collected soil temperature at 5 cm depth

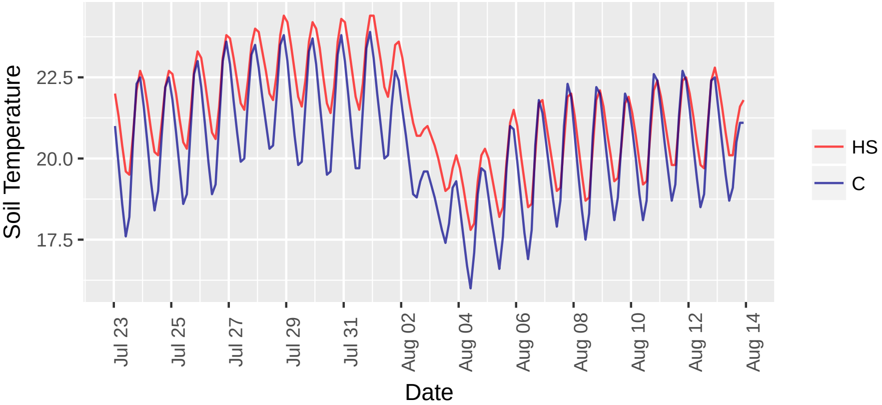
Control (C) Heating + Snow Removal (HS)

Objective

- Dissect the patterns in the control (C) and heating + snow removal (HS) soil temperatures over time
- Compare trends between C and HS
- Compare daily seasonality between C and HS
  - Amplitudes of seasonal component will help us understand effect of climate change on diurnal temp

Data: Soil Temperature

Figure 1: Time series measurements of soil temperature for two treatments



Model

- Local linear trend + seasonal factor DLM
- Difficulty: Big structural break!

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- Solution: Heavy tailed t-distribution on system evolution variances
  - t-distribution useful because it can be written as scale mixture of normals
  - allows us to use all the nice dlm algorithms (FFBS, etc)!

System Evolution Variance

- Suppose i^{th} diagonal of system evolution variance is

$$W_{it}|\lambda_i, \nu \sim T(0, \lambda_i; \nu) \tag{1}$$

  where ν is degrees of freedom, λ_i is scale parameter

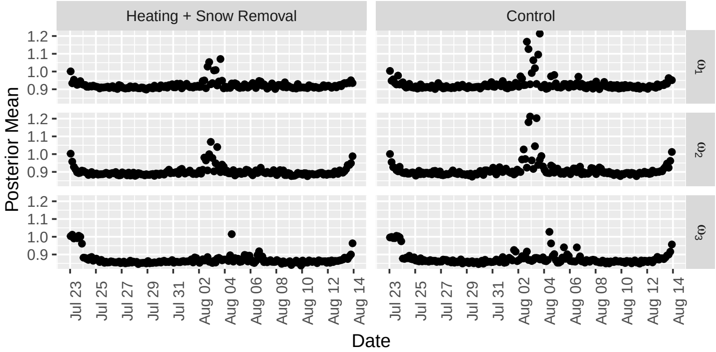
- By introducing latent variable ω_{it}, above is equivalent to

$$\begin{aligned} W_{it}|\lambda_i, \omega_{ti} &\sim N(0, \lambda_i \omega_{it}) \\ \omega_{it}|\nu &\sim IG\left(\frac{\nu}{2}, \frac{\nu}{2}\right) \end{aligned} \tag{2}$$

- In our analysis, we fix the degrees of freedom $\nu = 2$

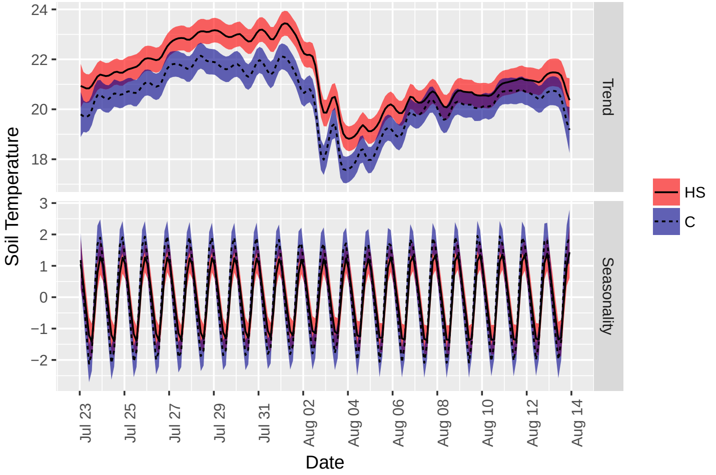
Latent Variable ω_{it}

- ω_{it} is time-variant
- large values of $\omega_{it} \rightarrow$ system evolution variance is large enough to make "jump" in the corresponding state.
- Use posterior means of ω_{it} over time to identify location of possible structural breaks



Trend and Seasonal Component Estimates

Figure 2: Smoothing Estimates with 95% Credible Bands



Conclusion & Future Work

- Structural break dealt with through t-distribution on system evolution variances
- Trend indicates higher temperatures for HS
- Amplitude of seasonal component smaller for HS
  - Visual evidence that diurnal temps may be decreasing due to simulated climate change
- Future Work:
  - Analyze for 3 month series
  - Try fixed seasonal component

References

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