Detecting inhomogeneities in the Twentieth Century Reanalysis over the central United States

AT-13

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1. Introduction

The Twentieth Century Reanalysis (20CR), which spans the 138-year period from 1871-2008, assimilates surface synoptic observations only (surface- and sea-level pressure data; monthly sea surface temperature and sea ice extent), and therefore, represents a first step towards achieving climate-quality reanalyses. It is the first and only reanalysis to span the 20th century and there is presently no alternative reanalysis source for the period 1871-1947. In this study, we address two key questions: (1) Can the 20CR be used for the assessment of changes in different hydrometeorological variables over the 20th century? and (2) What would an experimental framework for differentiating between artificial and true climate signals comprise? We answer the former through applying the latter. Our study is focused on a 15x° 15° region (30°-45°N, 105°-90°W) in the central United States where improved understanding of 20th century hydroclimatological trends and variability is a top priority to both scientific and economic stakeholders (i.e., the warming hole and breadbasket).

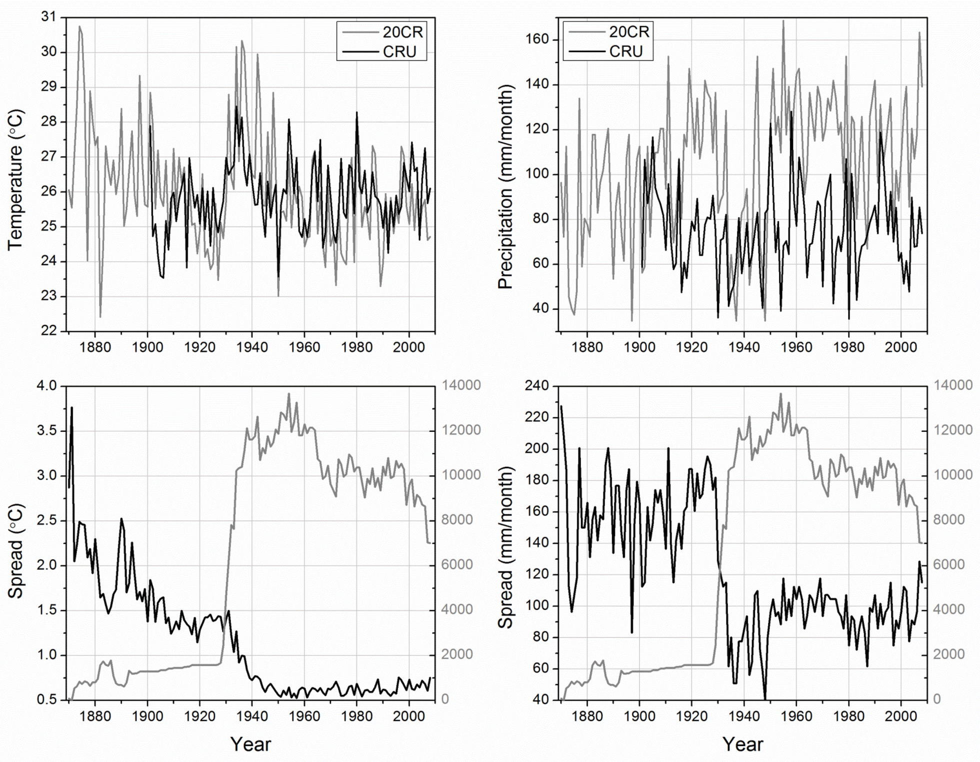


FIGURE 1. (right) Over the study region (30°-45°N, 105°-90°W), the July (top) spatially averaged T_a and P from 20CR and CRU and (bottom) 20CR ensemble spread (black line) and assimilated observation count (gray line). The ensemble spread is the time-average of the spatially-averaged 3-hourly values. The assimilated observation count is the total per July.

Major Question: Is the 20CR homogeneous and hence suitable for detecting climate-related changes?

Approach: We use three statistical methods (Pettitt and Bai-Perron tests and segmented regression) to detect abrupt shifts in multiple hydrometeorological variable mean and uncertainty fields over the central United States. For surface air temperature and precipitation, we use the Climate Research Unit (CRU) time series data set for comparison.

Key Results:

1. The 20CR is affected by inhomogeneities
2. 20th century CRU precipitation and temperature data show no statistically significant trend or change point
3. Only the most recent half century of 20CR is suitable for climate trend analysis

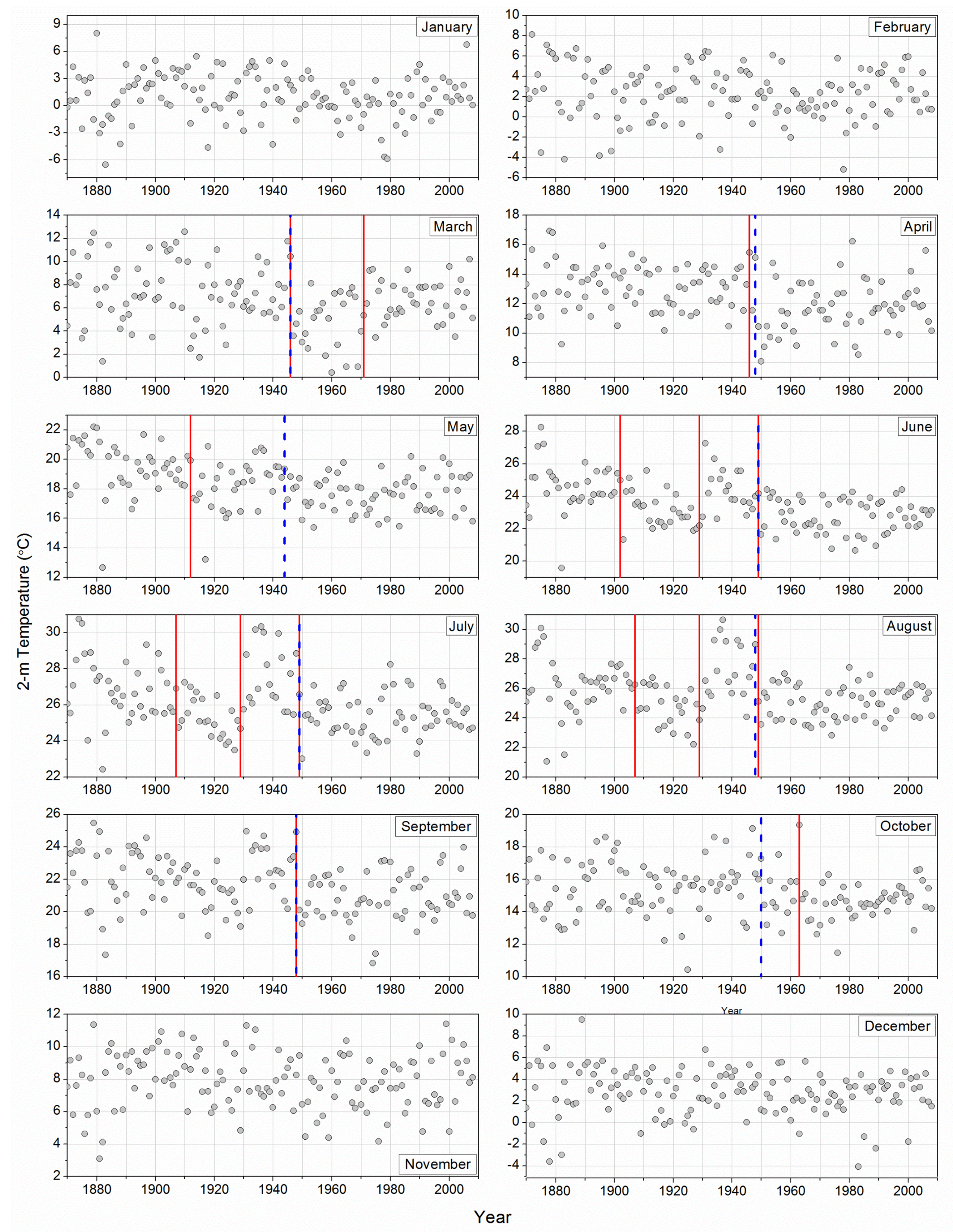


FIGURE 2. (right) Monthly time series of 2 m temperature based on the 20CR data. The red lines indicate the presence of a change-point based on the Bai-Perron test, while the blue dashed lines indicate the presence of an abrupt change in the mean based on the Pettitt test.

2. Results

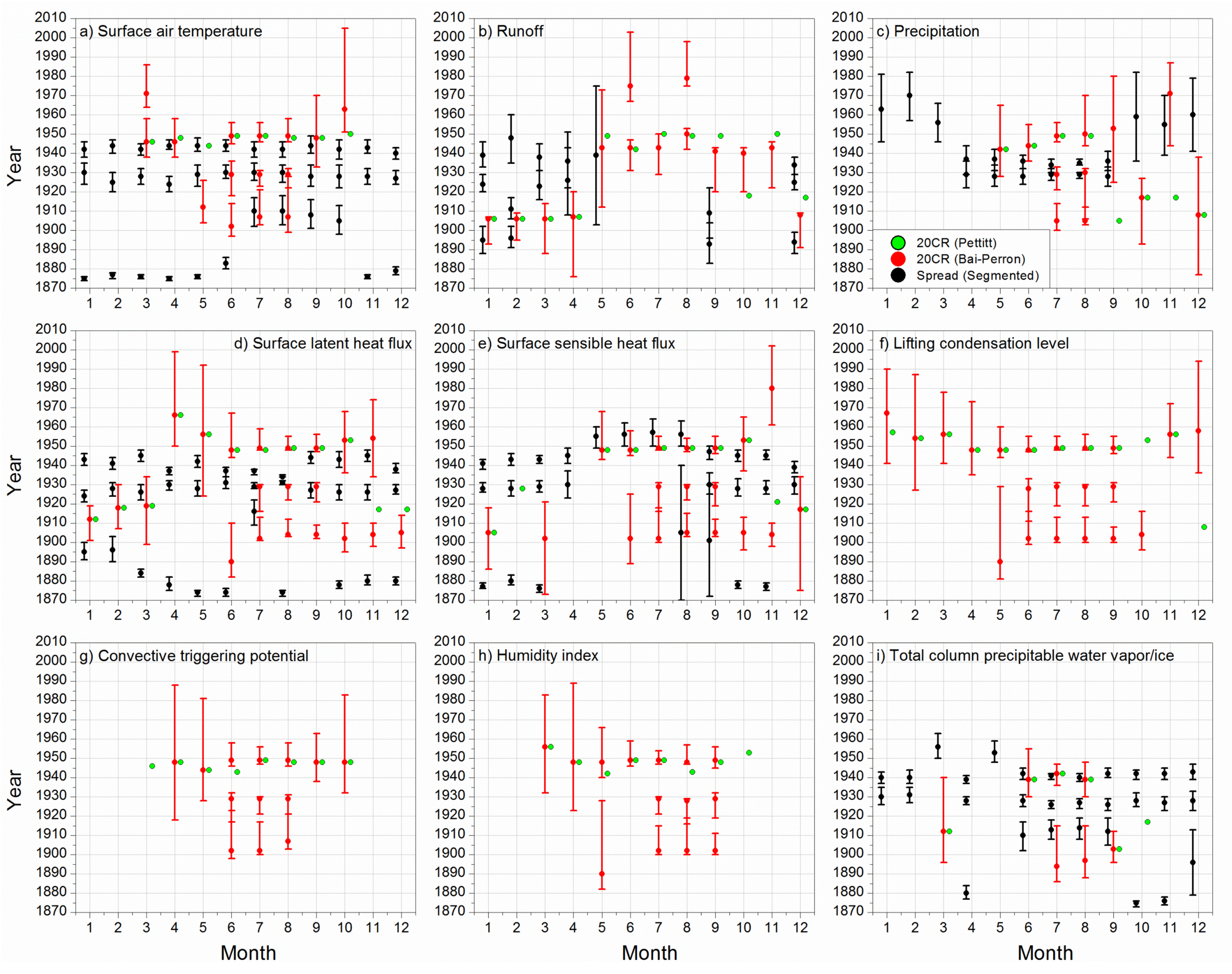


FIGURE 3. Summary of the Pettitt (green), Bai-Perron (red), and segmented regression (black) detected change-points for the following variables: (a) T_a, (b) Q, (c) P, (d) LE, (e) H, (f) LCL, (g) CTP, (h) HI , and (i) PWV. The Pettitt and Bai-Perron tests were performed on the 20CR ensemble mean fields, whereas segmented regression was performed on the uncertainty fields (i.e., ensemble spread). The whiskers extend to 95% confidence limits for Bai-Perron test and segmented regression.

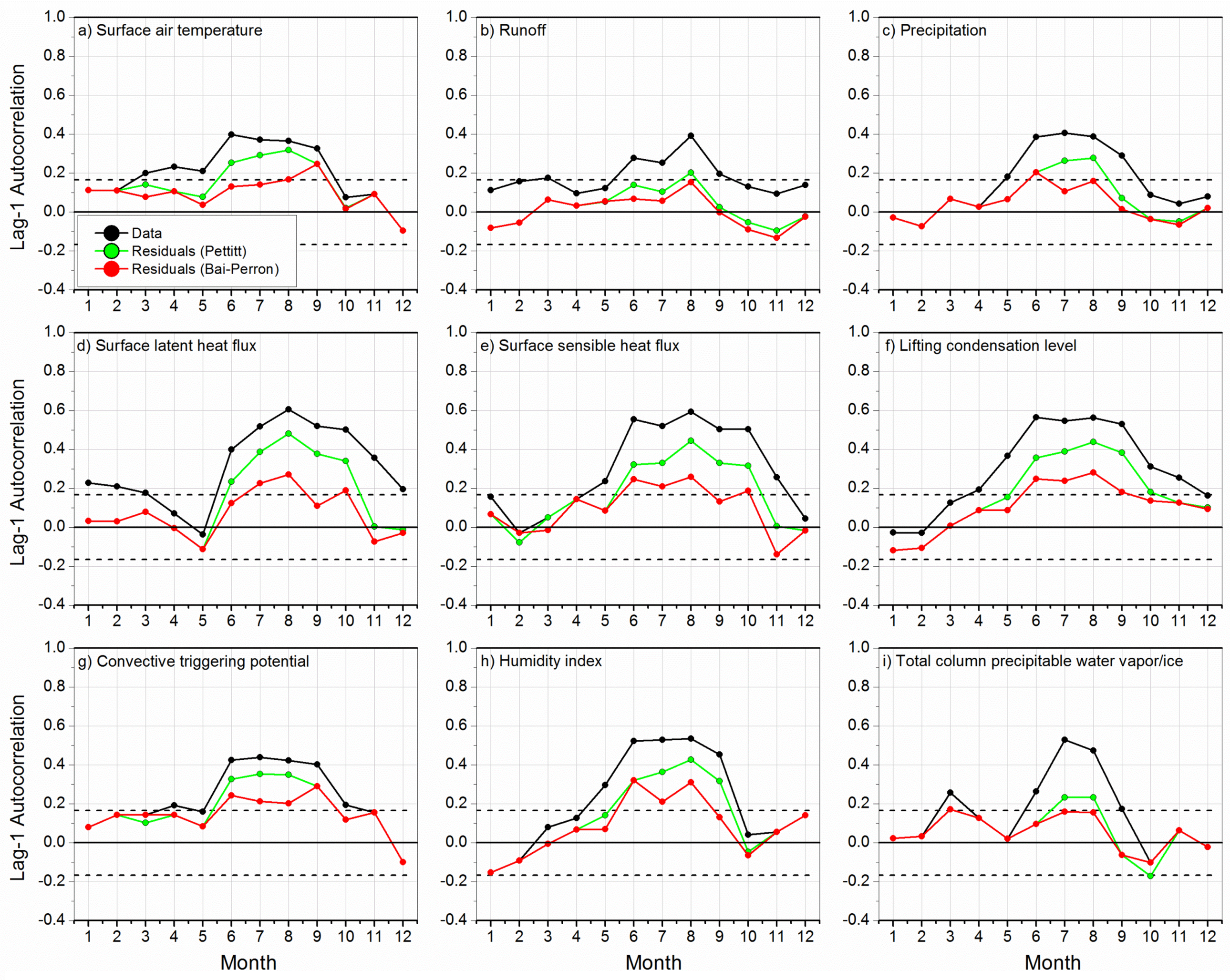


FIGURE 4. The lag-1 (year) autocorrelation values of the 20CR (a) T_a, (b) Q, (c) P, (d) LE, (e) H, (f) LCL, (g) CTP, (h) HI , and (i) PWV time series (black), as well as the time series of their residuals, after accounting for the presence of change-points detected by the Pettitt (green) and Bai-Perron (red) tests. All three values (black, blue, and red) overlap in the case that neither method detects a change-point. Blue and red values overlap in the case that the Bai-Perron test yields a single change-point that is concurred with the Pettitt test; they are different in the case that the Bai-Perron test yields multiple change-points or a single break in a year different from the Pettitt test. The dashed lines represent the 95% confidence intervals of the autocorrelation function.

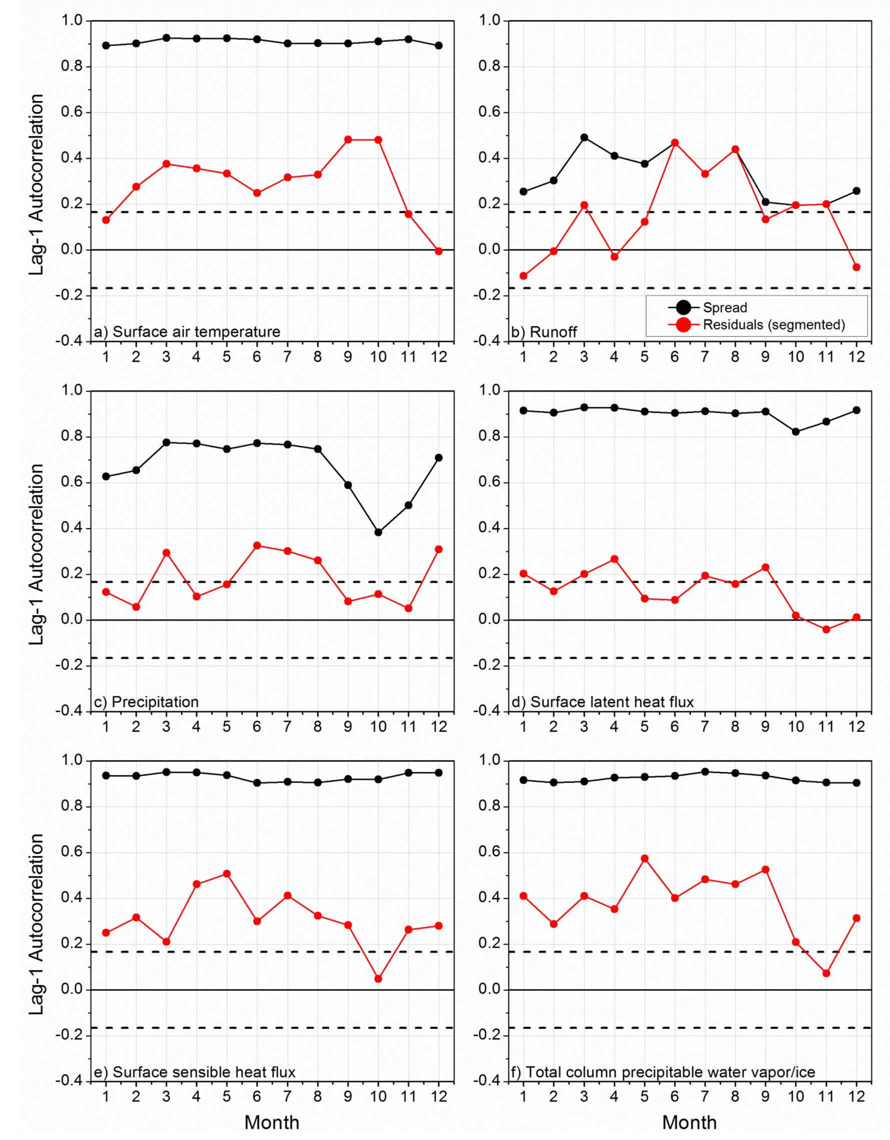


FIGURE 5. The lag-1 (year) autocorrelation values of the 20CR (a) T_a, (b) Q, (c) P, (d) LE, (e) H, and (f) PWV ensemble spread time series (black), as well as the time series of their residuals, after accounting for the presence of change-points detected through segmented regression (red). The points overlap in the case that no change-points are detected (i.e., for Q: June, July, August, October, and November, see also Fig. 3). The dashed lines represent the 95% confidence intervals of the autocorrelation function.

3.Summary and Future Work

We first performed a visual inspection of the 20CR and CRU time series (Figs. 1-2). In Fig. 1, the 20CR uncertainty estimates are shown to be inversely related to the number of assimilated observations. In the case of T_a, the uncertainty is reduced fivefold, from 3.8 to 0.7°C between 1871 and 1940. The impact of assimilated observations on the uncertainties is even more evident for the precipitation data.

The results of the three statistical change-point analyses are summarized in Fig. 3. The overwhelming consensus across variables and tests is that an abrupt shift in the 20CR occurred circa 1950. During the warm season (May-September), 91% of Pettitt change-points were detected between 1940 and 1950. Detected shifts in the cold season were less common, but generally fell within the period of 1905-1920. The Bai-Perron 95% confidence windows generally served to confirm the timing of Pettitt change-points, bracketing them in 72% of all occurrences. In the case of primary variables (T_a, Q, P, LE, H, and PWV) for which uncertainty estimates are available, the Pettitt and Bai-Perron change-points were found to correspond with segmented regression change-points 21% and 71% of the time, respectively (the Pettitt test is designed to detect a single change-point). Shared change-points between the variable and uncertainty field time series bring the physical realism of the shift into question. Notably, if an abrupt shift is detected in the uncertainty field (i.e., segmented regression) but not in the respective variable field (i.e., Pettitt and Bai-Perron tests), it does not rule out an artificial effect on the variable, but rather implies that any such effect is undetectable given the variable's natural range of variability. The fact that change-point years do not align exactly for all months and variables, we argue, is likely an artifact of spatial sampling bias, and serves only to strengthen our observation network hypothesis. We tested the CRU T_a and P datasets using the Pettitt and Bai-Perron tests and detected no significant change-points in the 1901-2008 record (not shown).

We evaluated the extent of serial correlation in the 20CR and its impact on our analysis by computing the lag-1 autocorrelation coefficients of the monthly mean data. Figure 4 shows that the degree of autocorrelation is both variable-dependent and seasonal, with peak values ranging from 0.4 to 0.6 during the warm-season. After the presence of abrupt shifts in the data is accounted for, the remaining autocorrelation is generally not statistically different from zero at the 5% level (Fig. 4). This is truer of the Bai-Perron residual time series, than of the Pettitt ones; accounting for multiple change-points results in the largest reduction of serial correlation in nearly all cases. As shown in Fig. 5, the uncertainty (i.e., ensemble spread) fields are more strongly autocorrelated, with values of 0.9 not uncommon, and with little seasonal variability.

On the basis of our findings, we recommend that users focus on the second half-century of the record (1960 to present), for which a dense network of observations exists. We accept that the role of inhomogeneities on the 20CR likely varies regionally. As a first cut, we illustrate in Fig. 6 the global patterns of Pettitt change-points for the 20CR T_a and P, CRU T_a, GPCC P, and HadISST v1.1 SST. Indeed, there is strong correspondence between the 20CR T_a and SST change years.

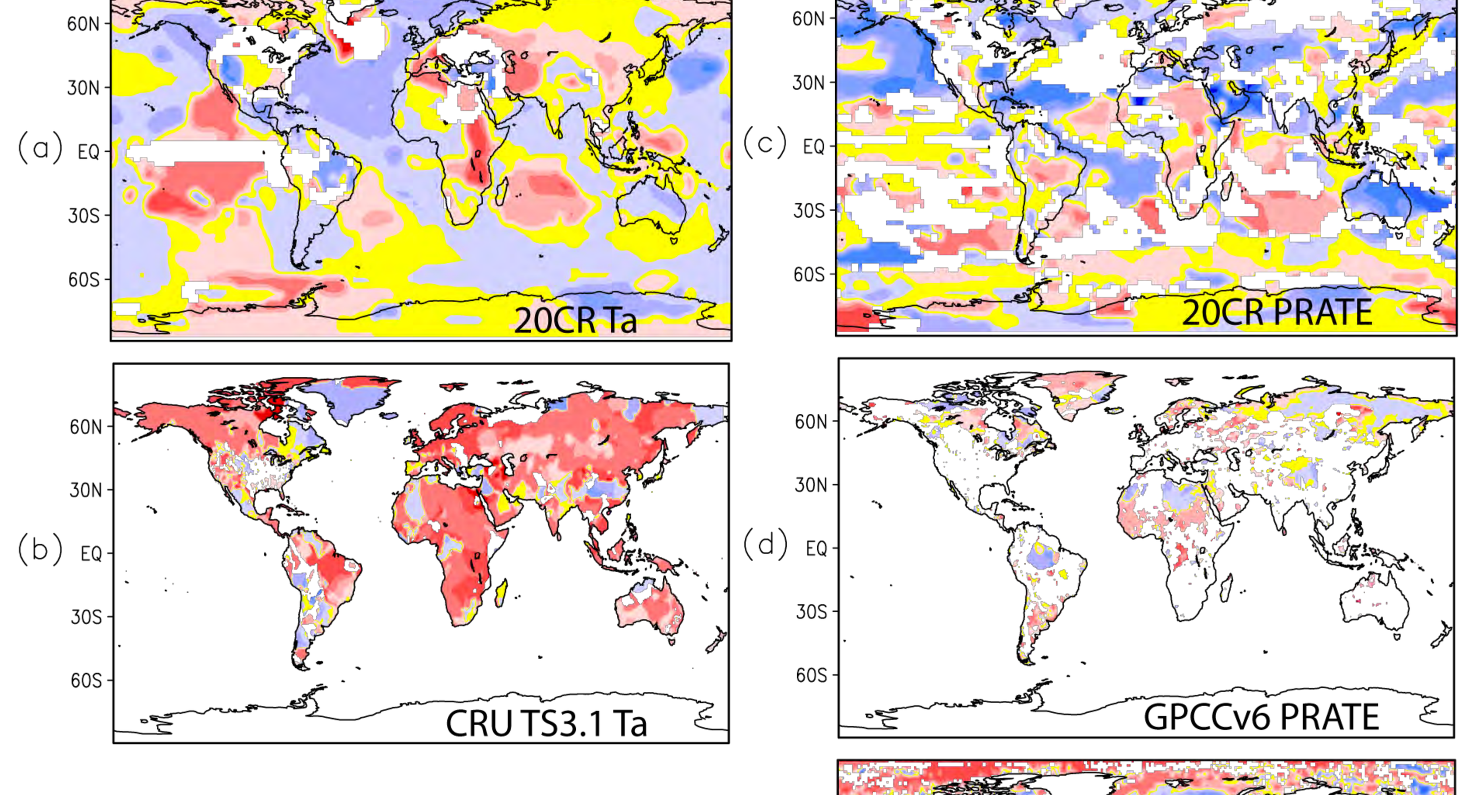
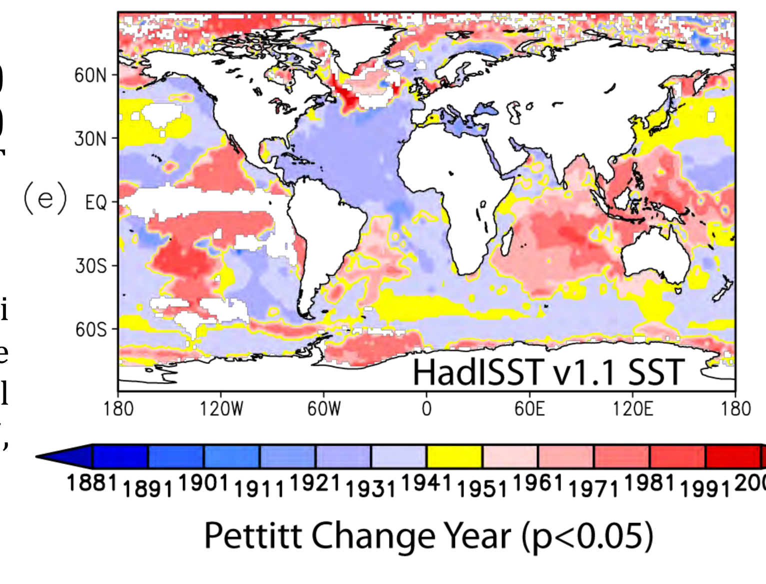


FIGURE 6. Pettitt change-points in the (a) 20CR T_a, (b) CRU TS3.1 T_a, (c) 20CR P, (d) GPCC V6 P, and (e) HadISST v1.1 SST computed from the annual means.



Reference: Ferguson, C.R. and G. Villarini (2012), Detecting inhomogeneities in the Twentieth Century Reanalysis over the central United States, *J. Geophys. Res.*, 117, D05123,doi:10.1029/2011JD016988.