# Higher-order discriminants of twentieth-century changes in Earth surface temperatures

TAPIO SCHNEIDER*
*Atmospheric and Oceanic Sciences Program, Princeton University, Princeton, New Jersey*

ISAAC M. HELD
*NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey*

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Figures I and II show the second and third discriminants of interdecadal variations in January and July temperatures. The ratio $\mathcal{R}$ of interdecadal to intradecadal variance is markedly less for the second and third discriminants than for the first discriminants. With the principal component truncation chosen (see Schneider and Held 2001, Appendix d), the variance ratios for the first three discriminants are $\mathcal{R} = (7.6,\ 2.8,\ 1.5)$ for January and $\mathcal{R} = (6.1,\ 2.2,\ 2.1)$ for July. The structure of the second and third discriminants depends more strongly than the structure of the first discriminants on analysis parameters such as choice of data groups. Features that appear in a second discriminant with the present choice of analysis parameters might appear in a third discriminant with a different choice of analysis parameters, and vice versa, suggesting that the second and third discriminants cannot be interpreted separately but must be considered jointly. Nevertheless, since the time evolution of the second and third canonical variates is coherent over decades, both for January (Fig. I b,d) and July (Fig. II b,d), the second and third discriminants represent significant interdecadal variations in surface temperatures that complement the dominant interdecadal variations represented by the first discriminant (Schneider and Held 2001, Fig. 1). The second and third discriminants add finer spatial and temporal structures to the relatively steady temperature changes indicated by the first discriminants.

The second and third discriminant for January (Fig. I) modify the interdecadal temperature variations indicated by the first discriminant most strongly over the continents of the Northern Hemisphere. The second discriminant also indicates temperature variations of the North Pacific, with warming from the 1930s until about 1955 and cooling from 1955 until about 1980. The second and third discriminant add spatial and temporal detail to the steady continental warming with an embedded region of cooling over the eastern United States indicated by the first discriminant (Schneider and Held 2001, Fig. 1 a,b).

The second and third discriminant for July (Fig. II) likewise modify the spatial and temporal structure of the interdecadal temperature variations indicated by the first discriminant (Schneider and Held 2001, Fig. 1 c,d). The second and third discriminant together indicate a similar structure of warming of the North Pacific followed by cooling as the second discriminant for January (Fig. I a,b). Like the second and third discriminants for January, the second and third discriminant for July add spatial and temporal detail to the steady continental warming with embedded regions of cooling indicated by the first discriminant (Schneider and Held 2001, Fig. 1 c,d). Most notable in the third discriminant (Fig. II c,d) is the strong warming of eastern Europe from the late 1970s onwards. This warming of eastern Europe is superimposed on the cooling of that region indicated by the first discriminant.

Figure III shows composites of the temperature variations accounted for by the first three discriminants for January and July. Displayed are temperature changes relative to the 1916–1998 mean for seven years between 1918 and 1996, the temperature changes for a given year being the sum of the first three discriminating patterns weighted by the low-pass filtered canonical variates for that year [the red lines in Schneider and Held's (2001) Fig. 1, and in Figs. I and II of this document]. The first three discriminants together account for about $80\%$ of the interdecadal January temperature variations and for about $75\%$ of the interdecadal July temperature variations.

The composites of the first three discriminants give a more detailed picture of the interdecadal temperature variations discussed by (Schneider and Held 2001). It can be seen, for example, that from the 1980s onwards, a warming trend is superimposed on the local-

**Corresponding author address:* Tapio Schneider, Courant Institute of Mathematical Sciences, New York University, 251 Mercer Street, New York, NY 10012. E-mail: tapio@cims.nyu.edu

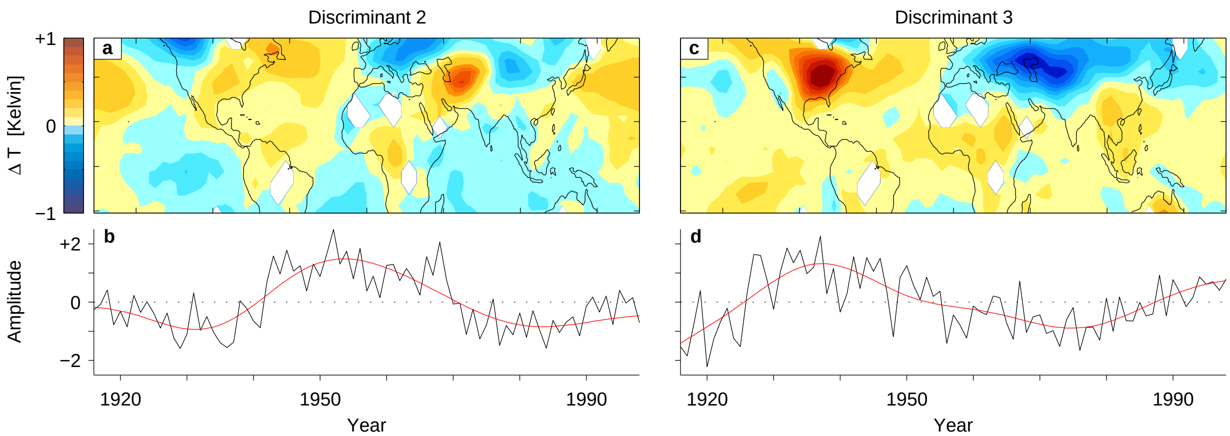


FIGURE I: Second (a, b) and third (c, d) discriminant of interdecadal variations in January temperatures. The discriminating patterns (a, c) and canonical variates (b, d) represent temperature changes relative to the 1916–1998 mean, local changes being products of the canonical variate and the local values of the associated discriminating pattern. The discriminants are normalized such that the canonical variates have unit variance. In the amplitude time series (b, d), black lines indicate unfiltered canonical variates and red lines indicate low-pass filtered canonical variates.

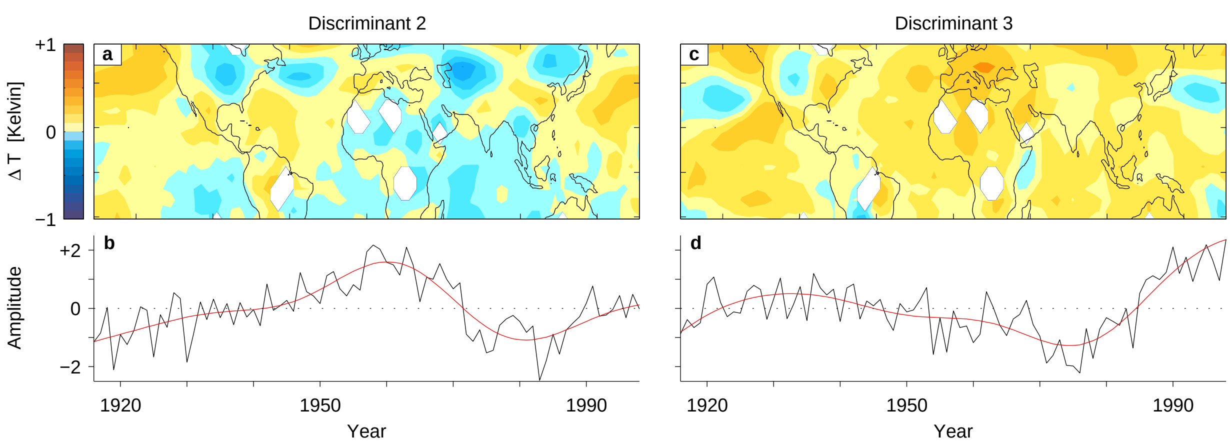


FIGURE II: Second (a, b) and third (c, d) discriminant of interdecadal variations in July temperatures. The plotting conventions are as in Fig. I.

ized continental cooling indicated by the first discriminants (Schneider and Held 2001, Fig. 1). The recent warming trend has led to a weakening of the localized cooling and, in some cooling regions of the first discriminants, even to a warming relative to the 1916–1998 mean (eastern United States in January and eastern Europe in July). That a recent warming trend is superimposed on localized cooling is consistent with the hypothesis that warming due to increased concentrations of greenhouse gases gradually dominates localized cooling due to anthropogenic aerosols.

The composites of the first three discriminants also testify to how efficiently the discriminant analysis suppresses interannual temperature variations. For example, although 1983 was a year with a strong El Niño, the composite of the first three discriminants shows, in the equatorial Pacific, only residuals of temperature changes reminiscent of an El Niño. Interannual temperature variations such as those associated with ENSO are filtered out effectively by the discriminant analysis.

## REFERENCES

Schneider, T., and I. M. Held, 2001. Discriminants of twentieth-century changes in Earth surface temperatures. *J. Climate*, **14**, 249–254.

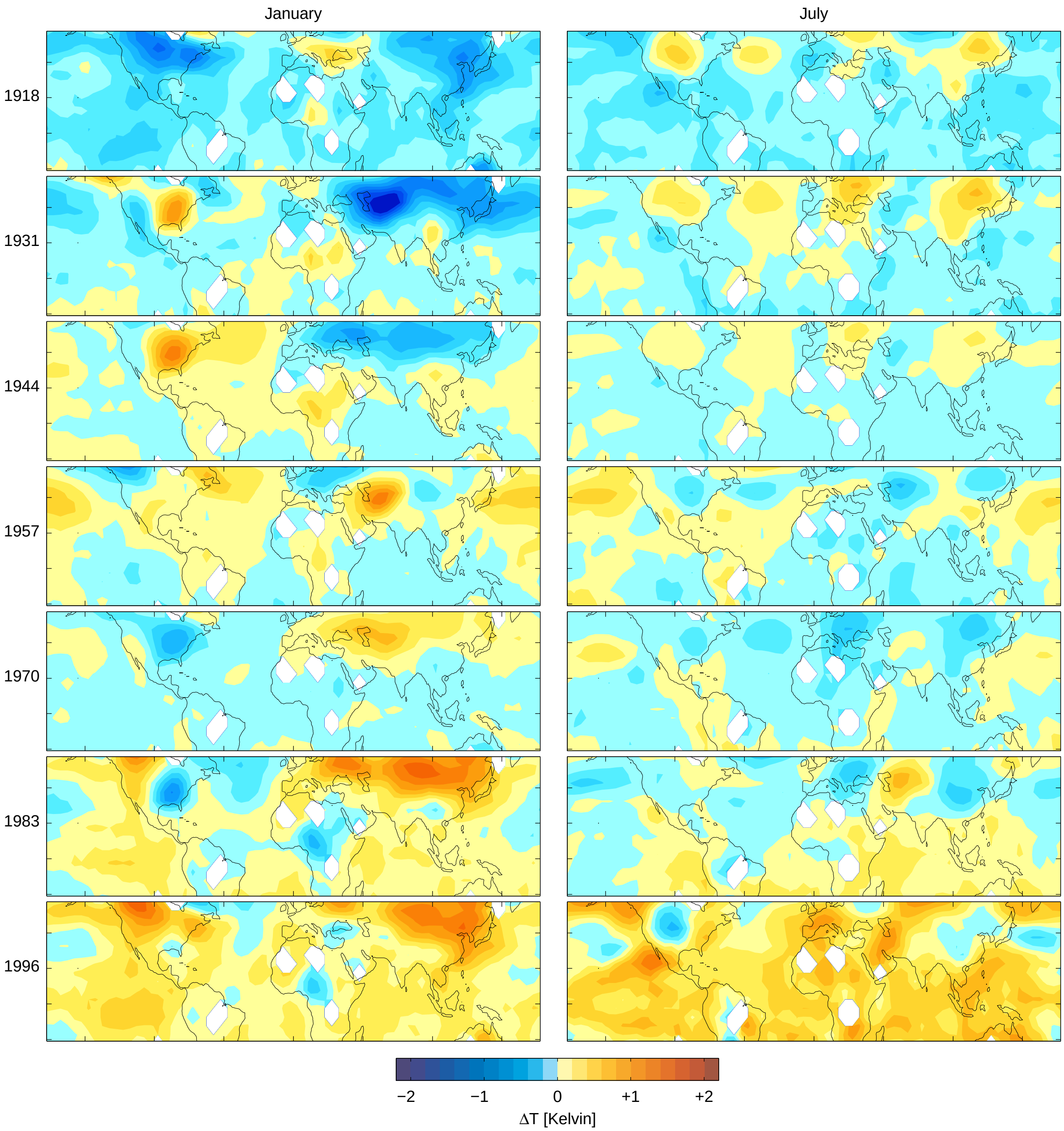


FIGURE III: Composite temperature variations accounted for by the first three discriminants for January and July. The individual frames indicate temperature changes relative to the 1916–1998 mean. The temperature change for a given year is the sum of the first three discriminating patterns weighted by the low-pass filtered canonical variates for that year.