Climate Change and Elevational Dependence at a Mid-Latitude Mountain System, Niwot Ridge, Colorado Rocky Mountains

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Mid-latitude mountain systems are critically sensitive to recent and projected climate change under an elevated greenhouse gas world. It is often taken that climatic change at high elevation sites will reflect those at lower sites – regional warming is assumed to be consistently played out in mountains, or even amplified by the snow-albedo feedback. The anticipated outcome is that the alpine will eventually be "pushed off the top of mountains." There are several reasons why this might not be the case, or at least considerably delayed – one is whether high elevation climates reasonably reflect regional lowland trends or if they are decoupled from them as a result of mountain climatic processes. Both situations (signal coherence or decoupling) appear in the record for various mountain regions around the world (Beniston & Rebentz 1996, Diaz & Bradley 1997, Kittel et al. 2000).

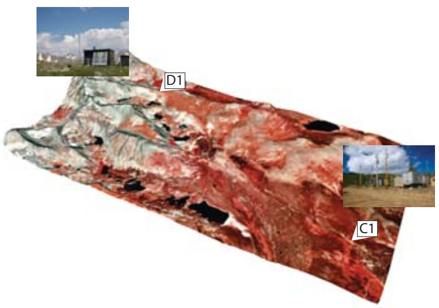

Fig. 1. Location map for the Niwot Ridge LTER and the alpine climate station D1 at an elevation of 3,749m and the subalpine forest site C1 at an elevation of 3,048m.

Objective. Is the climate of alpine areas decoupled from forested areas?

Methods. We used NWT climate station records from subalpine (C1, 3048m) and high alpine (D1, 3749m) sites (Figure 1). These records have full years for a 54-year period from 1953-2006. A daily spatial correlation process was used to fill data gaps based on observations from the other NWT stations and neighboring montane stations (Ackerman 2006; this dataset is available in the NWT LTER database: http://culter.colorado.edu/).

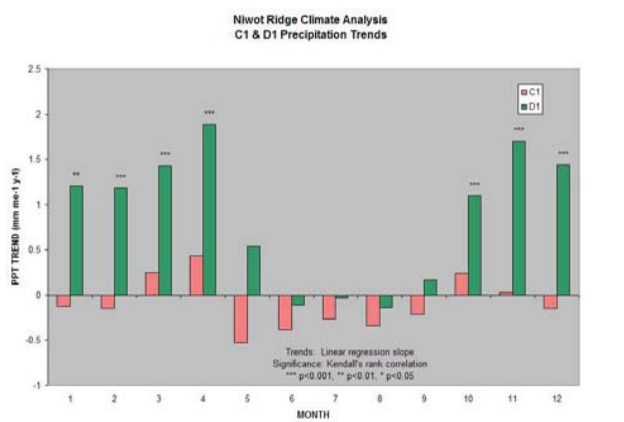

Fig 2. Long-term trends in monthly total precipitation (mm mo-1 yr-1) for Niwot Ridge subalpine forest (C1) and high alpine tundra (D1) stations for the period 1953-2006. X-axis month numbers 1-12 are January to December. Corresponding statistical significance levels are given above bars (*** p<0.001, ** p<0.01, * p<0.05); bars without symbols are not significant (p>0.05). Long-term trends were calculated using linear regression, their significance tested using Kendall's rank correlation. Note that climatic trends differed markedly between the two stations and by season (see text).

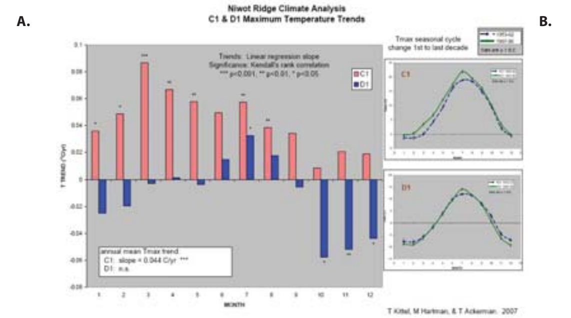

Fig. 3A. As in Fig 2, but for monthly mean maximum temperature (Tmax; ºC/yr). Annual mean maximum temperature trends are given in the box if significant.

Fig. 3B. Change in the Tmax seasonal cycle from the first decade (dashed line) to last (solid line) of the record for (top) C1 and (bottom) D1. Bars are ±1 standard error of the monthly mean.

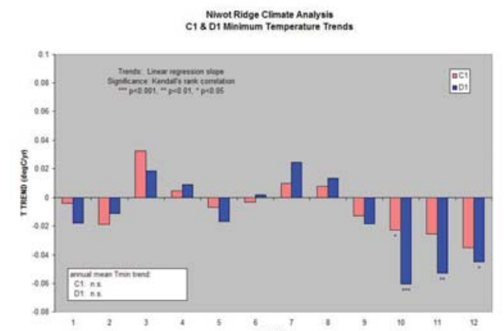

Fig. 4. As in Fig 2, but for monthly mean minimum temperature (Tmin; ºC/yr).

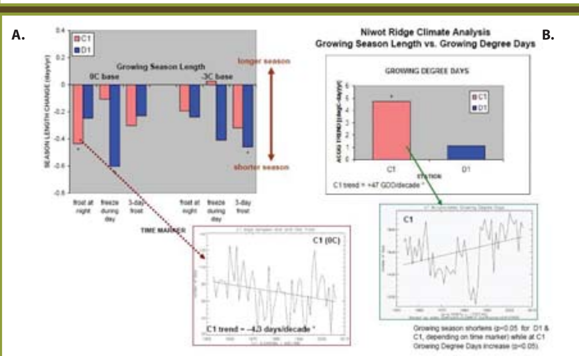

Fig. 5. As in Fig 2, but for (A) trends in growing season length (GSL; using 0º & –3ºC thresholds; days/yr) and (B) trends in accumulated growing degree days (GDD; ºC-day/yr). In (A), time markers refer to different cold temperature occurrence criteria in spring and fall: last/first frost at night (based on Tmin), last/first day with freezing daytime temperatures (based on Tmax), and last/first run of 3 days of nighttime frost (based on Tmin). 'Frost' and 'freezing' were based on 2 thresholds: T < 0 & <–3ºC, to represent 'light' and 'hard' freezing and to evaluate sensitivity of the analysis to this threshold. Example GSL and GDD timeseries with significant trends selected from (A) and (B) are given in the lower graphs.

Key findings.

- Precipitation (ppt) increased at the alpine site from October through April (trend in annual ppt=+100mm/decade), but not during any season in the subalpine (Figure 2).
- Tmax subalpine: increased through much of the year (trend in annual Tmax=+0.4ºC/decade) (Figure 3A).
- Tmax alpine: decreased in early winter (–0.4 to –0.6ºC/decade) (Figure 3A).
- These patterns resulted in altered seasonal cycles for the two sites, but in different ways: a positive offset in the subalpine (C1) and amplification in the alpine (D1) (Figure 3B).
- Tmin at both D1 and C1 show that summer onset is later and termination earlier because of decreases during spring and fall (Figure 4).
- Growing season at both sites has shortened (Figure 5A) – this reflects long-term tendencies in Tmin and decreasing frost-free days.
- An apparent contradiction is that growing degree-days (GDD) have gone up at the subalpine site (Figure 5B).
- These contrasting results at C1 are due to decreasing spring and fall Tmin's setting growing season length and greater mid-summer Tmax's determining growing degree-days. The alpine showed no corresponding GDD trend.

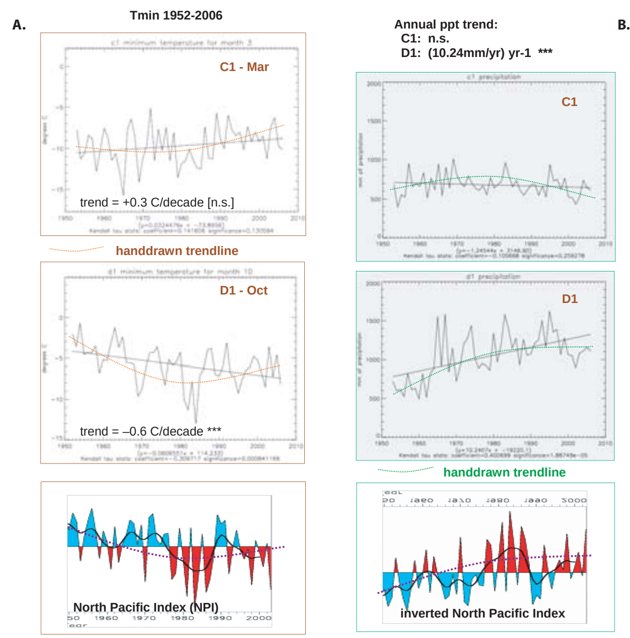

Fig. 6A. Two example monthly Tmin timeseries for C1 and D1 and timeseries of the North Pacific Index (NPI) for roughly the same period (Trenberth and Hurrell 1994). Long-term curvilinear trend is drawn suggesting mid-record shifts (see text).

Fig. 6B. As in (A) but for annual precipitation and with the NPI series inverted to reflect a similar broad curvilinear pattern as in the station series.

Discussion. An integrated view of these trends infer synoptic dynamics and surface energy processes that act differently in the high alpine near the Continental Divide vs. in the subalpine dominated by closed conifer forest. Nearly all temperature-related timeseries for both sites show a period of cooling until around 1980, followed by warming (Figure 6A). Precipitation series show corresponding periods of increasing then decreasing precipitation (Figure 6B). On the face of it, this pattern resembles that of the Pacific Decadal Oscillation (PDO), a hemispheric dynamic understood to influence climate variability in the Rockies (Kittel et al. 2000) and which switched phases in the late 1970's. Such possible correspondence is being explored in further analyses. While tentative, it suggests that alpine and subalpine climate signals may not be as decoupled as they appear, but rather that across a relatively short elevational gradient (=700m) synoptic and landscape-scale processes react differently to and differentially modify a prevailing hemispheric signal.

References

-Beniston M., and M. Rebetez. 1996. Regional behavior of minimum temperatures in Switzerland for the period 1979-1993. Theor. Appl. Climatol. 53:231-243.
-Diaz H.F., and R.S. Bradley. 1997. Temperature variations during the last century at high elevation sites. Climatic Change 36:253-279.
-Greenland, D., and T.G.F. Kittel. 2002. Temporal variability of climate at the US Long-Term Ecological Research (LTER) sites. Climate Research 19:213–231.
-Greenland, D., and M. Losleben. 2001. Climate. Pages 15-31, in: W.D. Bowman and T.R. Seastedt (eds.). Structure and Function of an Alpine Ecosystem. Niwot Ridge, Colorado. Oxford Univ. Press, New York.
-IPCC-WG1. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the FourthAssessment Report of the Intergovernmental Panel on Climate Change.
-IPCC-WG2. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report.
-Kittel, T.G.F., P.E. Thornton, J.A. Royle, and T.N. Chase. 2002. Climates of the Rocky Mountains: Historical and Future Patterns. Pp. 59-82 (Chapter 4), in: J.S. Baron (ed.). Rocky Mountain Futures: An Ecological Perspective. Island Press, Covelo, CA. 325 p.
-Pepin, N. 2000. Twentieth-century change in the climate record for the Front Range, Colorado, USA. Arctic, Antarctic, and Alpine Research 32:135-146.
-Trenberth. K.E. and J.W. Hurrell. 1994. Decadal Atmosphere-Ocean Variations in the Pacific. Climate Dynamics 9:303-319. (Updated figure from: http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np)