Southwestern U.S. Drought Maps from Pinyon Tree-Ring $\delta^{13}C$

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Tree-ring widths have long been a useful N. American drought proxy [*e.g.*, Cook *et al.*, 1999, 2004]. A potentially rich, new tree-ring proxy associated with the tree's leaf-level moisture status is stable-carbon isotope composition ($\delta^{13}C = [^{13}C/^{12}C\text{sample} \div {}^{13}C/^{12}C\text{standard} - 1] \times 1000$), which is determined by both rates of carbon assimilation and gas conductance through leaf stomata [Farquhar *et al.*, 1982]. In the U.S. Southwest where evaporation exceeds precipitation, drought may be the dominant influence on plant $\delta^{13}C$ [Warren *et al.*, 2001], so measurements of tree-ring $\delta^{13}C$ in a network of southwestern sites has allowed us to spatially map this ecophysiological indicator back to A.D. 1600.

Stomatal portals are the primary avenues of water loss and carbon gain in plants, providing CO_2 for photosynthesis, which tends to discriminate against fixation of $^{13}CO_2$ in favor of $^{12}CO_2$. In principle, under conditions of water stress the stomata close down and the reservoir of CO_2 available for continued photosynthesis is reduced, proportionally more $^{13}CO_2$ is fixed, and the $^{13}C/^{12}C$ ratio of sugars eventually incorporated into tree rings increases (*i.e.*, $\delta^{13}C$ increases), and *vice versa* during moist conditions.

In a tree-ring $\delta^{13}C$ study about two decades ago [Leavitt and Long, 1989], pinyon pine trees (*Pinus edulis* and *Pinus monophylla*) at 14 sites in six southwestern U.S. states were sampled, and 5-yr ring sequences analyzed. The isotopic chronologies show a post-1800 $\delta^{13}C$ decline, attributed to fossil-fuel and land-use change inputs of ^{13}C-depleted CO_2 to the atmosphere, and high-frequency fluctuations about the long-term trend. The chronologies were fit with spline curves to remove the long-term trends and ratios of the measured $\delta^{13}C$ value to the respective spline $\delta^{13}C$ value at each pentad were calculated ("Isotopic Index" = $\delta^{13}C_{measured}/\delta^{13}C_{spline}$). A

“Del Index” (= (isotopic index – 1) x 1000) was then computed such that positive values represent measured $\delta^{13}C$ values below the spline (lower than expected $^{13}C/^{12}C$ ratios) and negative values represent higher than expected $^{13}C/^{12}C$ ratios (moisture deficiency). Comparisons of Del Index with instrumental drought and precipitation records (Leavitt and Long, 1989) showed good correspondence, and contour drought maps of Del Index at the 14 sites for 1900-04 and 1950-54 matched well instrumental drought maps and ring-width reconstructions.

The Del Indices have since been arbitrarily re-scaled to “Drought Indices” (= Del Index ÷ 10), which puts virtually all original values into the range of -6 to +6, like the common range of the Palmer Drought Indices (http://www.drought.unl.edu/whatis/indices.htm#pdsi). Additionally, all sites were recently re-sampled to extend the isotope chronologies through the 20th Century. The $\delta^{13}C$ analysis from 1985 to 1999 was on individual rings, so Drought Indices for 3 pentads (1985-89, 1990-94 and 1995-99) have been added to the original record, as have annual Drought Indices from 1985-99 calculated using a straight-line fit to those $\delta^{13}C$ data of each site.

Now, a complete set of contour maps of isotope “Drought Indices” has been generated by gridded interpolation methods. For example, the maps for the 1900-04 and 1915-19 pentads (Fig. 1) appear to follow Southwestern moisture variation. The map for 1989 (Fig. 2) illustrates a single-year, linear contour map of a particularly dry year, as well as the error maps available for all pentads and years. These maps offer a new perspective for looking at past southwestern environment, through the lens of processes affecting stable-carbon isotopes in tree rings (likely dominated by moisture). As such, these “Drought Indices” may provide important new insight into the ecophysiological activity of trees over the past several centuries, and may be useful to better understand both the water cycle and carbon cycle in the Southwest.

These pentad $\delta^{13}C$ and isotope Drought Index data sets, maps back to 1600-04 as both linear contours and color-shaded fields, and all of the interpolated gridded (1°×1°) data tables are now available at http://www.ncdc.noaa.gov/paleo/treering/isotope/iso-drought.html, along with a more complete description of the data source and interpolation methods.

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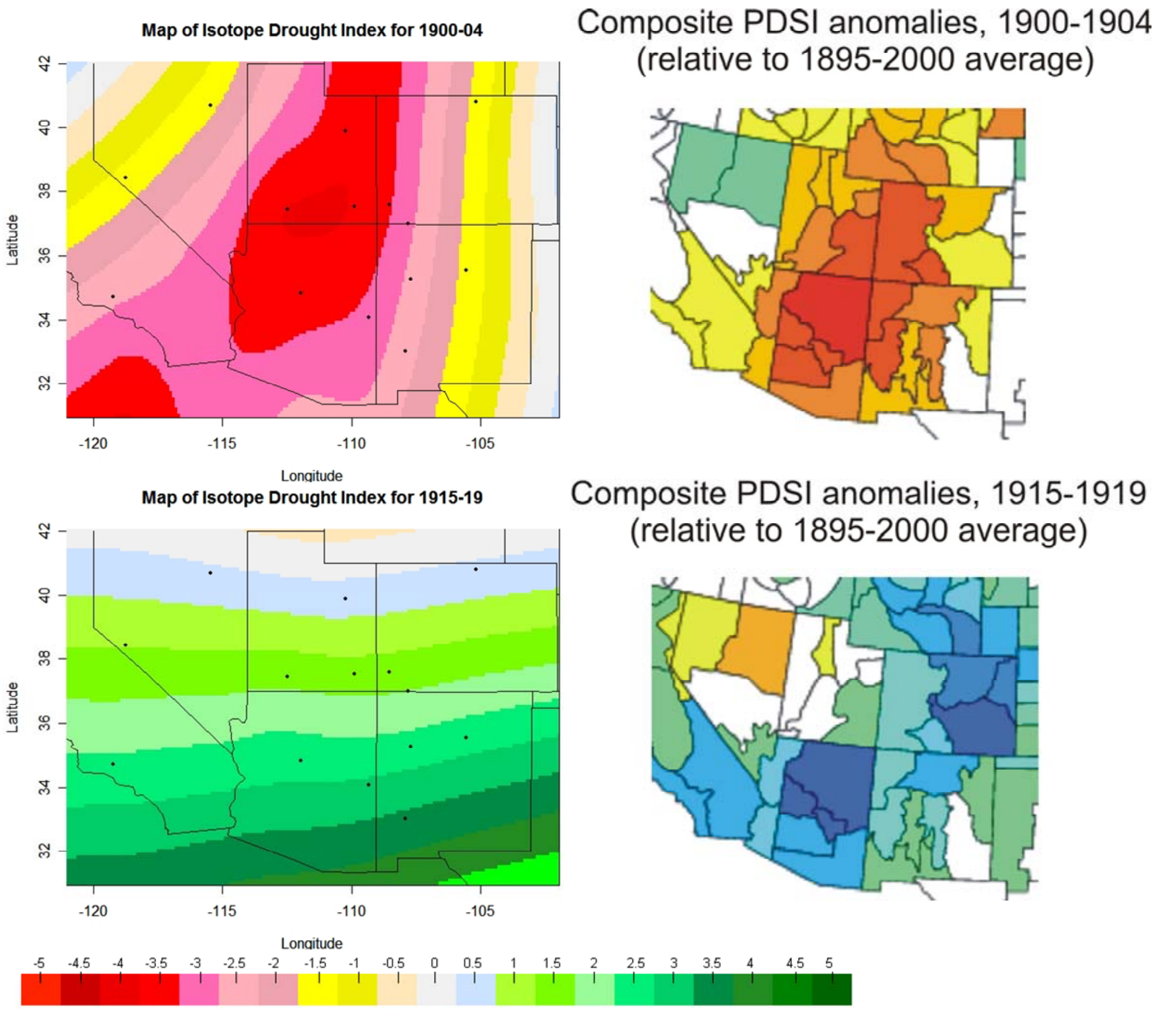

Fig. 1. Examples of pinyon pine tree-ring isotope Drought Index Maps (color contour scale at bottom), for a widespread dry pentad (1900-04, where $^{13}C/^{12}C$ ratios tended to be above the long-term trend throughout the region, i.e., negative Indices) and a moist pentad (1915-19, $^{13}C/^{12}C$ ratios tended to be below average). For comparison, the PDSI anomalies for those pentads are shown, with progressively drier areas in darker red and wetter areas in darker blue (source: http://www.cdc.noaa.gov/USclimate/USclimdivs.html)

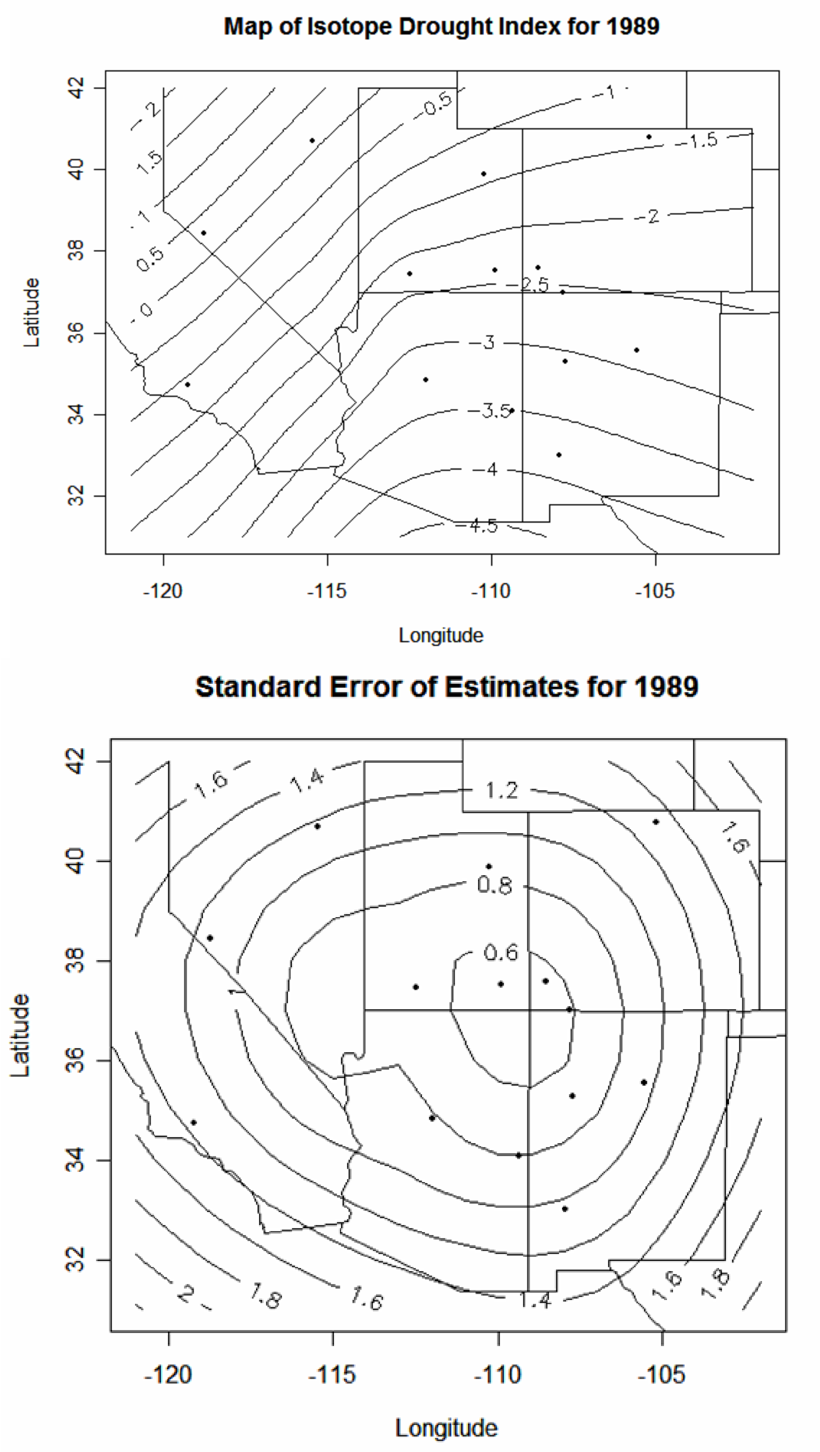

Fig. 2. From annual isotope drought maps example of widespread dry year in the Southwest (1989) (upper), and a map of the standard error of the estimate associated with each grid point (lower).