Ice Core Isotope Inversion for Determining Global Climate Indices

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The history of climate variability is not well simulated by climate models, however proxy climate records offer additional constraints for developing atmospheric analyses that to date have not been included in constructing gridded fields to represent the history of atmospheric circulation statistics. The isotopic composition of snow, captured by ice cores, is a useful proxy to consider since the physics controlling the isotopic composition is well known and can be modeled in atmospheric circulation models. Thus, we suggest model estimates of the linkage between the ice core records and the atmospheric circulation can be used in an inverse sense to estimate the atmospheric variability.

Climate models that include stable water isotopes have been run for simulation of the 1870-2003 climate by the Stable Water Isotope Intercomparison Group (SWING). An array of 35 ice cores is distributed at many latitudes and they act as long proxy records for features of global climate such as the global temperature, El Nino Southern Oscillation, Southern Annular Mode, North Pacific Index, and North Atlantic Oscillation. These indices may be constructed from the SWING models, since they are generally represented by pressure differences between stations. The ice core records may also be derived from the SWING models by determining the net isotopic deposition at each core site. Direct measurements and/or reconstructions of the climate indices have been performed for the 20th century, and thus we have both fully empirical and fully model databases of the ice cores' response to shifts in such climate features.

The inverse approach for estimating climate indices from isotope records is characterized by the forward model:

$$y = Kx + \varepsilon \qquad \text{(Rodgers, 2000)}$$

where *y* is the array of isotope records, *x* is the array of climate indices, *K* is the weighting function matrix, and ε is the error. The weighting function matrix, *K*, characterizes the sensitivity of the ice cores to the climate indices, the sensitivity of the i^{th} ice core to the j^{th} climate index is:

$$k_{ij} = \frac{\partial y_i}{\partial x_j}$$

The resulting *K* matrix is of dimensions *m* x *n*, where m is the number of ice cores and n is the number of climate indices. A *K* matrix for the relationship between the ice cores and climate indices is constructed by performing a multiple regression analysis for each ice core:

$$y_i = k_{11}x_1 + k_{12}x_2 + \ldots k_{1j}x_j + \varepsilon_i$$

where the *k*s are the multiple regression coefficients, and ε is the residual of the regression and is the estimated error.

Initial steps in developing the methodology were to use only SWING model outputs to test the ability of the inversion method to reproduce its inputs. Figure 1 shows an example of the correlation between the annual 1900-1990 climate indices predicted thru inversion of SWING model (the Melbourne University Global Climate Model- MUGCM) isotopes and the climate indices derived directly from the model output, versus the number of years used in 'training' the K matrix. We see in the figure that for training periods less than approximately 50 years, the inversion is unable to reproduce the 1900-1990 time series with strong correlations, but for 50 years or more training the correlation is approximately .5 or better for all of the indices. Similar correlations are found if the inputs are all empirical instead of model.

The utility in using the climate models is to develop a K matrix for climate regimes of the past. The first step toward that end is to model the recent, observed, climate to validate the relationships between the climate indices and the ice cores. Figure 2 shows a similar correlation to Figure 1, but for the inversion of the actual ice core isotopes using the same K matrix as above, with the output indices correlated with the actual climate indices. Other than temperature, the correlation between the indices resulting from the inversion and the actual climate indices is low. Ongoing work will be performed with longer than annual averaging, which is expected to provide stronger relationships between the model isotopes and climate indices and will also be more consistent with the empirical data.

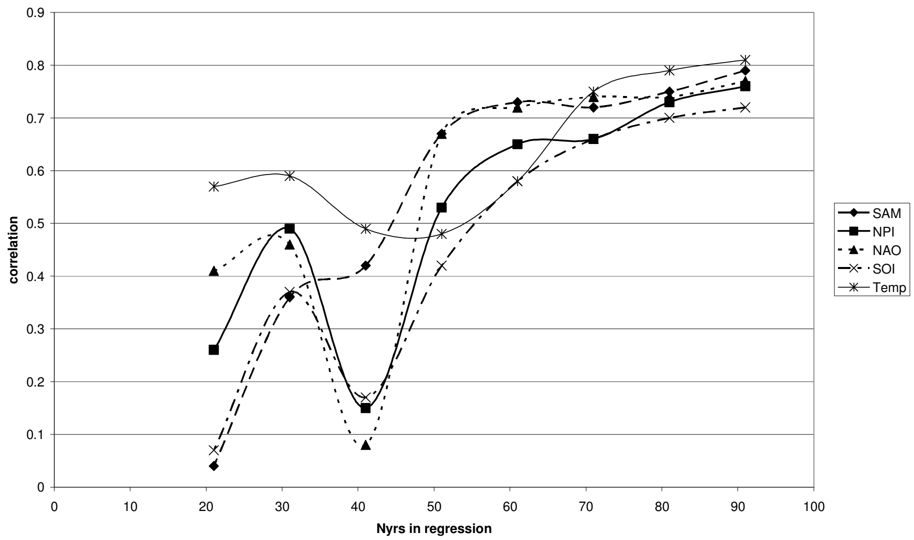

Figure 1: Correlation of the climate indices output from the inversion of the MUGCM derived ice cores' isotopes with the climate indices taken directly from the model outputs.

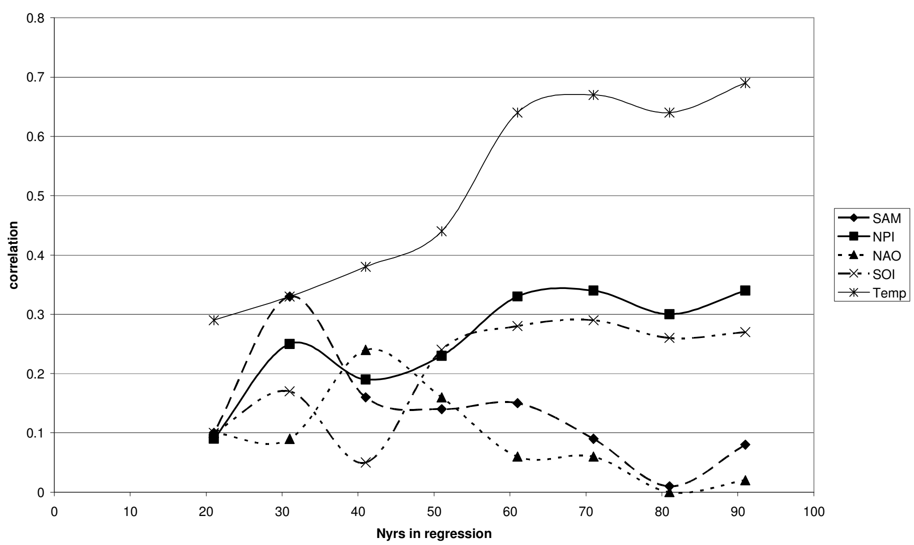

Figure 2: Correlation of the climate indices output from the inversion of the actual ice cores' isotopes with the empirical climate indices. The K matrix for the inversion is the same as in Figure 1.

Rodgers 2000. Inverse Methods for Atmospheric Sounding, Theory and Practice: World Scientific Publishing