# Using Isotopes and an Observational Based Regression Model to Assess the Hydrological Cycle in GCMs

**Nikolaus Buenning**[1], **David Noone**[1]
*[1] Cooperative Institute of Research in Environmental Sciences and the Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, CO, USA*
(Email: buenning@colorado.edu)

The isotopic composition of precipitation (herein after denoted as $\delta$, where $\delta = (R/R_{STANDARD} - 1) \times 1000$, and $R$ is the heavy to light isotope ratio, and we focus here on the oxygen-18 in precipitation, $\delta^{18}O$) is widely used for both hydrology and climate variability studies. Mapping out the spatial distribution of $\delta$ values has been done by several studies using regressions (e.g. Farquhar et al., 1993; Bowen and Wilkinson, 2002; Buenning and Noone, 2008). Isotope equipped General Circulation Models (GCMs) provide another approach in predicting the spatial distribution of $\delta$ values. In this study, regressions are performed on both the Global Network for Isotopes in Precipitation (GNIP) observational records and three GCMs to examine how well the models capture the balance of local and non-local (advective) controls. This type of analysis provides a measure of which processes give rise to model errors, and thus expands on simple model/data comparisons. In particular, the models have large errors over the high-latitudes, where predicted $\delta$ values are not depleted enough; a regression analysis provides insight into why the models perform poorly in these regions. The regression model used here is one that is similar to both Farquhar et al. (1993), Bowen and Wilkinson (2002), and described in detail by Buenning and Noone (2008):

$$\delta_a = a_1 T + a_2 T^2 + a_3 P + a_4 |\phi| + a_5 \phi^2 + a_6 \theta + a_7 \theta^2 + a_8$$

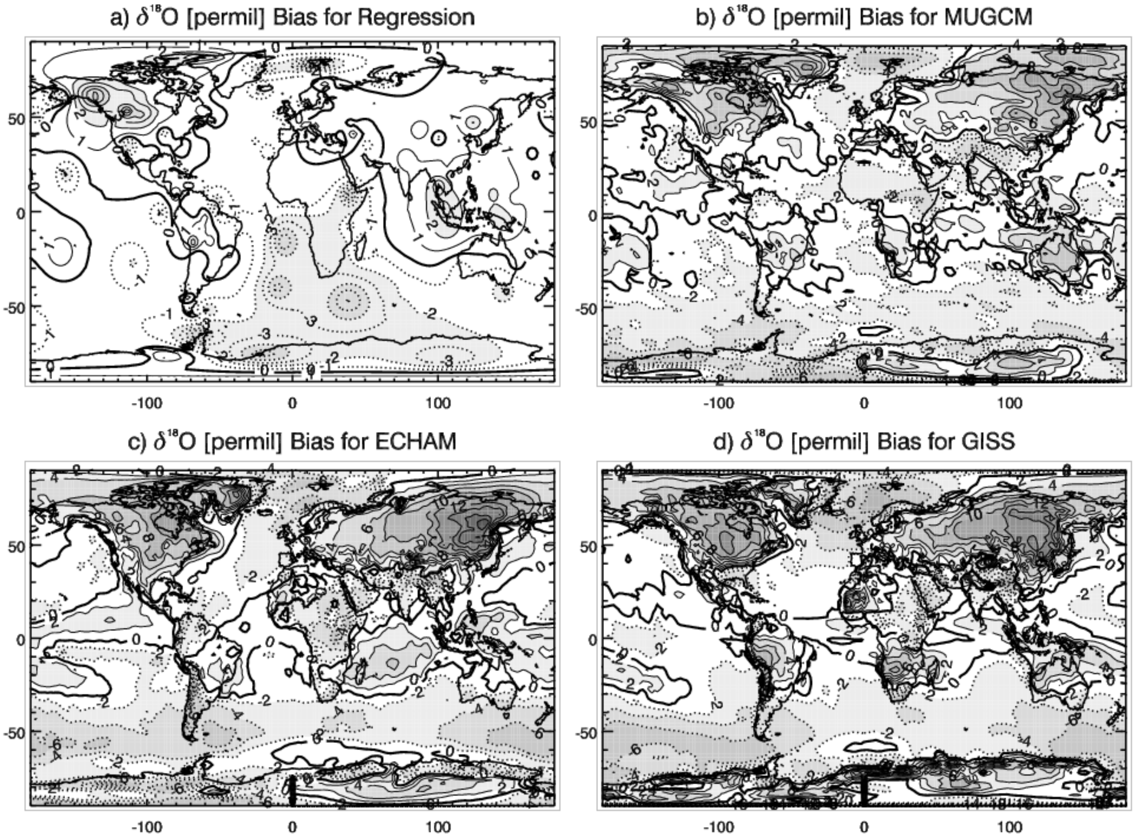
where $T$ is annual mean temperature (K), $P$ is annual mean precipitation (mm month$^{-1}$), is the latitude, $\theta$ is annual mean potential temperature (K), and $a$ values are regression coefficients used to fit the observed and simulated $\delta^{18}O$ values. The regression is performed on the GNIP station observations as well as the GCMs. The GCMs examined here are MUGCM, ECHAM, and GISS, using simulated $\delta$, $T$, $P$ and $\theta$ fields. The regression bias, associated with processes not captured by the local conditions (both observed and simulated), is defined as $\varepsilon = \delta_a - \delta_o$ where $\delta_o$ is the observed or simulated value.

Figure 1a shows the annual mean bias of the observational based regression for $\delta^{18}O$ values, mapped onto a grid using Cressman (1959) objective analysis. The regression model bias has a root mean square error of 2.26‰. However, has large biases at certain locations. For instance, the regression predicts the $\delta$ values to be too low over the Southern Oceans and the Arctic Ocean north of Scandinavia. Over most of Canada and Alaska, the model predicts $\delta$ values that are not depleted enough.

These locations are consistent with the regions where Bowen and Wilkerson (2001) found high-magnitude residual regions. Many of the problematic regions were in the mid and high latitudes, and were due to differences in vapor transport within the latitudinal zones. For example, vapor in the North Atlantic (where temperatures are high) is advected northeastward towards the Arctic Ocean where the resulting rain will be enriched in the heavy isotopes compared to other locations within a latitudinal zone. Over Canada, the opposite occurs as vapor is transported from the northwest, bringing in more depleted $\delta$ values.

Using simulated values from GCM grid cells, comparable GCM-based regression models were established, and the bias relative to the GCM simulated $\delta^{18}O$ are computed (Figures 1b-d).

Many of the biases that appeared in the observationally based regression model also show up in the GCMs; however, the magnitudes and extent are different in some regions. For example, all of the regression biases are large and positive in northern Canada; though, the GCM-based biases are higher in the eastern portion of the continent and are generally large throughout the high and mid northern latitudes. This would indicate that the GCMs inadequately simulate the non-local controls of the hydrological cycle for the northern continents. Furthermore, the observational and GCM based regressions all have negative biases in the Southern Oceans. This would suggest that the $\delta$ values are largely influenced by non-local process for this region, such as moisture advection, and the GCMs reasonably capture this non-local component of the hydrological cycle. However, the extent and magnitude of this bias is much greater than the observational-based regression (with the exception of the regions adjacent to Africa). Similarly, there is region in the Arctic Ocean, north of Scandinavia that also has large negative bias for both the observational based and GCM based regressions. Thus, the GCMs are able to capture the balance between local and non-local processes in the hydrological cycle in a bulk sense, but there are large regions within the mid to high latitudes where model improvements are needed.



a) $\delta^{18}$O [permil] Bias for Regression

b) $\delta^{18}$O [permil] Bias for MUGCM

c) $\delta^{18}$O [permil] Bias for ECHAM

d) $\delta^{18}$O [permil] Bias for GISS

**Figure 1.** Annual mean $\delta^{18}$O bias (‰) for regressions based on (a) observations (interpolated to a grid), and results from (b) MUGCM, (c) ECHAM, and (d) GISS

Bowen, G. J., and B. Wilkinson, Spatial distribution of d18O in meteoric precipitation, *Geology*, **30**, 315-318, 2002.

Buenning, N. and D. Noone., Modeling the spatial and temporal variations in the isotopic composition of precipitation with statistical and dynamical methods, 2008 (in preparation)

Cressman, G. P., An operative objective analysis system, *Mon. Weather Rev.*, **87**, 367-374, 1959.

Farquhar, G. D., J. Lloyd, J. A. Taylor, L. B. Flanagan, J. P. Syvertsen, K. T. Hubick, S. Wong, and J. R. Ehleringer,. Vegetation effects on the isotope composition of oxygen in atmospheric $CO_2$, *Nature* **363**, 439-443, 1993.