A comparison between observed and GCM simulated seasonal variations in the deuterium excess of precipitation

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Isotopes in precipitation are widely used for both hydrology and climate variability studies. The deuterium excess in precipitation is defined as $d = \delta D - 8\delta^{18}O$ where $\delta = (R/R_{STANDARD} - 1) \times 1000$, and R is the heavy to light isotope ratio ($\delta^{18}O$ for $H_2{}^{18}O$ and δD for HDO) [*Dansgaard,* 1964]. As water undergoes phases changes under equilibrium conditions, kinetic effects arise due to the different molecular weights and different diffusion rates between HDO and $H_2{}^{18}O$. The resulting kinetic effects will cause δD and $\delta^{18}O$ values to deviate from the 8:1 ratio that results from equilibrium processes. These kinetic effects are sometimes results of vapor deposition during snow formation when the environment is supersaturated over ice and other times it is a result of raindrop evaporation and subsequent exchanges with the environmental air [*Jouzel and Merlivat*, 1984; *Stewart*, 1975]. Furthermore, it has been shown that a clear relationship exists between d values and source region sea surface temperatures (positively related) and the relative humidity (negatively related) [*Craig and Gordon*, 1965; *Merlivat and Jouzel*, 1979; *Johnsen et al.*, 1989]. Though many of these studies have revealed much about the correlations and physics involved with both the spatial and temporal variations in d values, little attention has been given to the global seasonal variation in d values. The work here makes use of station observations (from Global Network for Isotopes in Precipitation, GNIP) to identify areas with large seasonal variations in d values, and compares these with simulations of d from three General Circulation Models (GCMs) (MUGCM, ECHAM, and GISS) to assess if the models are simulating the proper controls on d values in regions where seasonal amplitudes are high. A Cressman-like objective analysis [Cressman, 1959] is used to interpolate the 12 monthly means of observed d values onto a grid for comparison with GCM output.

The seasonal means of d values (Figure 1) reveal that the largest seasonal variations are over the Southwest U.S. and the Antarctic Peninsula. It is likely that these two large variations are caused by somewhat similar processes. In the Southwest U.S., there is a shift in the winds during the summer months that bring in vapour from deep within the Gulf of California and with it higher rainfall totals. This monsoonal effect could have two effects: 1) vapour that is derived from tropical regions will have a higher source water relative humidity, and 2) the increase in rain will likely cause more precipitation re-evaporation. Both of these will lead to lower d values during the summer months and lead to the large observed seasonal variation. Over the Antarctica Peninsula, there is also a seasonal shift in the moisture transport paths as the Antarctic High becomes less intense during the December-February months. This large seasonal variation in d values could also be linked to the seasonality of sea-ice conditions and supersaturation within clouds.

The GCMs are unable to correctly simulate the magnitude of these two large seasonal variations (Figures 1c and 1d). In the Southwest U.S., the GCMs are completely unable to capture the low d values during the Northern Hemisphere summer months. This could be a result of improper simulations of the North American Monsoon, either from incorrect shifts in wind direction and source water regions or lack of rainfall re-evaporation during intense rainfall events. The GCMs also do not capture the large seasonal variation seen near the Antarctica Peninsula, which could be due to improper seasonal wind shifts and cloud conditions. The models do simulate a large seasonal variation over a broad region of the subtropics that encompasses Northeast Africa, the Middle East, and northern India, and likely tied to improper timing or improper strength of the monsoon.

These findings have revealed that in certain regions some components of the hydrological cycle are improperly simulated with GCMs. The regions of most concern are regions where there are large seasonal wind shifts (monsoonal regions), which is likely a consequence of the dependence of *d* values on source water regions.

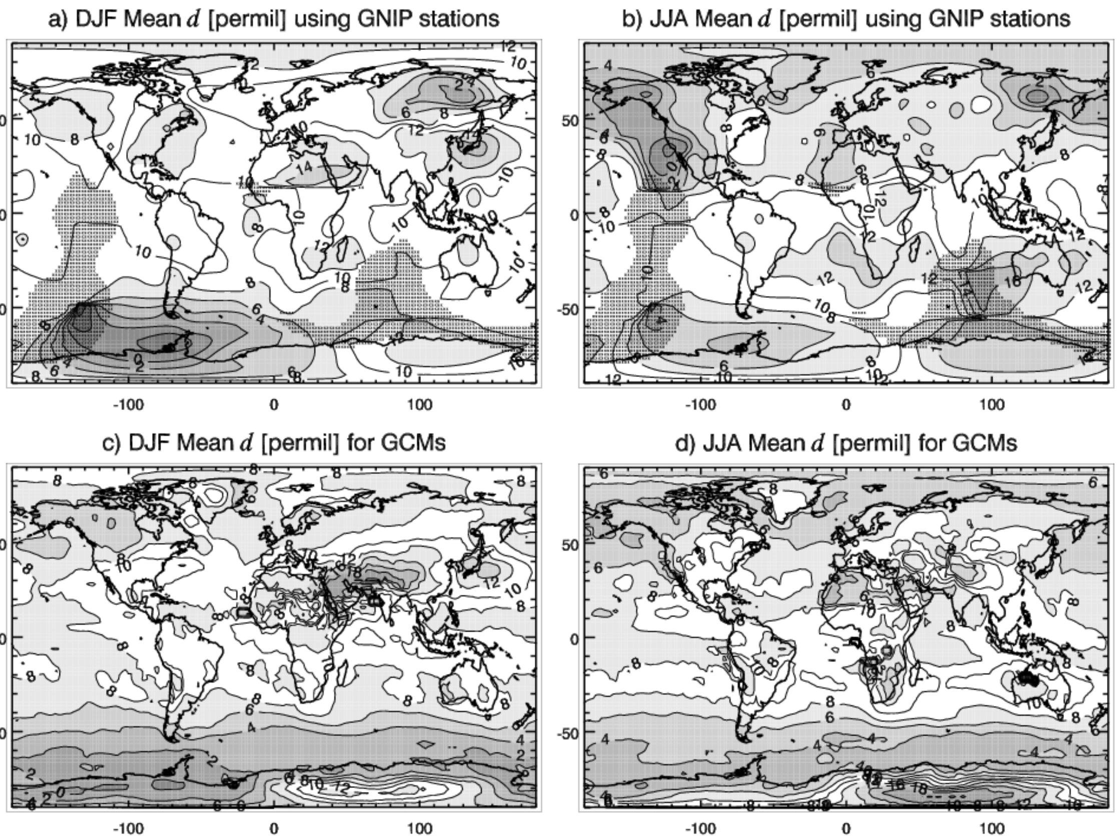

Figure 1. Seasonal means in *d* values (‰) for the (a-b) interpolated observations and (c-d) GCM mean. In a and b, stippling is added in areas with few stations.

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