Temporal variability in the isotopic composition of meteoric water in Christchurch, New Zealand; Can we create reliable isoscapes?

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Abstract

Stable isotopes are being used world wide in order to understand hydrologic, biologic, and climatic changes due to natural and human processes. Using stable isotopes as a tool can give detailed accounts of the past and origin of certain processes. While the earth is undergoing abrupt changes in atmospheric temperatures, demand for information on hydrologic processes is increasing. Unfortunately, there is limited data available to predict isotopic processes in the hydrological system. A current study in New Zealand is constructing a computational model that is attempting to predict isoscapes through a computational model. In this study, this model will be compared against past-observed data in order to prove or disprove the reliance of the GNS isoscape model.

Introduction

Stable isotope analysis can be used globally in order to understand the historical lifespan of any natural system containing nitrogen, carbon, oxygen, and hydrogen. For this study the process of focus is the hydrologic system, but stable isotopes can be used in biologic and anthropologic investigations as well. The value of isoscapes has increased because it allows opportunities to use isotopic variability as a source of information on the connectivity, variability, and sensitivity to change of climatalogical, hydrological, and biogeochemical processes (Isoscapes 2011). On a global scale, the understanding of the hydrologic system is relatively low because of the dynamic shifts in hydrology. Analysis of these elements allows for investigations into the atmospheric conditions occurring during the origination of a particular molecule. The focus of discussion here is the hydrologic system. This system is a very complicated and is hard to map as an isoscape because of the continuous fluctuations in the water cycle. Bowen, attempted to construct an isoscape for oxygen-18 in precipitation, but found much difficulty when mapping the oxygen isotopes due to high variability of precipitation

(2003). An example of this isoscape is shown in figure 1.

GNS, New Zealand's leading science/isotope research agency has developed a computational model that attempts to map New Zealand's hydrologic isoscape based on oxygen and hydrogen compositions. Stable isotopes such as oxygen and hydrogen are well known for the abundance of information that can provide about the past and also modern climatic processes. This information provides opportunities to exploit spatiotemporal variability in isotopes as a source of information on the sensitivity of climatic, biologic, and hydrologic changes (Isoscapes 2011). Creation of computational models creates controversy due to the inconclusiveness of the maps, the extreme level of difficulty producing these maps and also, the models have not been rigorously tested against observational data sets and used outside of the climate modeling community (Bowen 2010).

Background

In order to do a complete and accurate analysis of water isotopes, the basics of water isotopes must be understood. In Gat's (1996) synthesis to the hydrologic system, he notes that the isotopic composition of precipitation will become increasingly important in the interpretation of past climates but further studies of stable isotopes and application to the hydrologic system need to be investigated. Throughout the past few decades, more accounts on water isotopes have been produced to conclude a few factors are necessary for complete understanding of the variability of water isotopes. In general, the paleoclimate of a given area can be understood by tracing the hydrological cycle through the isotopic signatures provided by the water molecules (SAHRA 2005). Hydrogen and oxygen ratios are analyzed based on their isotopic fractionation formed through different phase changes during an event (Schmidt, 2006), therefore different ratios will mean different areas of origination. That being said, humid environments have high deuterium (more d-excess) values, while arid environments are low in deuterium (less d-excess). Figures 2 and 3 provide a visual explanation of this information along with examples of regions and where they lie in the plot. Additionally figures 2 and 3 display the global meteoric water line and exemplify seasonal changes along this line. *Because d18O and d2H values have a strong positive correlation with temperature, their measurements in ice cores are valuable indicators of climate variability. Values can be used to date snow and determine average snow accumulation rates.*

Geologic Setting

On a local scale, Christchurch sits in the Canterbury plains with the Southern Alps to the West and the Pacific Ocean to the East. Christchurch, therefore, experiences rain shadow effects on a frequent basis due to the high altitude Southern Alps (See figure 4a, and 4b). Since Christchurch only receives about 600-800 mm of rainfall per year, so they rely on surface and ground water to replenish human and agricultural uses but are rather limited when it comes to water sources being replenished.

In an area that is already lacking in water recharge from precipitation, global climate change will begin to increase evaporation rates higher than what they are now. The Canterbury plains are located geographically in an area where evaporation rates exceed precipitation rates (Blackstock 2010); therefore further research into climate and water sources is needed to understand the changing weather patterns in Christchurch.

The importance of studying meteoric water has become very popular over the years, and studies have become refined, but also more complex. Sourcing and understanding the processes that occurred during origin can give us good clues into past climate structures (SAHRA 2005).

Methods

Several methods were used in order to calculate the data sets. First and foremost, observed data sets were used from two different sources of research. Both forms of information used isotopic analyses when obtained the isotopic compositions of the daily and monthly data, therefore the data is 100 percent reliable. The daily and hourly isotopic compositions were used from Blackstock 2010 in order to compare the calculated isotopic compositions from the GNS computational model. The data used for the monthly averages was used from Taylor 1990. These data sets were then compared against calculated data from the GNS isotopic composition model for precipitation events. The Virtual Climate Station Network (VCSN) provided the rain data used to calculate isotopic compositions using the GNS computational model. Wind data was also obtained for these models for the years of 1984-1986 from The National Climate Database (CliFlo). All data was used from the same latitude and longitude coordinates of -43.525 and 172.575 respectively. During original data collection approximately 70% of the precipitation was collected (Blackstock, 2010), although a few discrepancies were found during this data check. These inconsistencies are displayed in Chart 1.

Several aspects of precipitation were looked at during this experiment. In no particular order, the isotopic compositions of oxygen-18, hydrogen-2 and d-excess were calculated using the GNS model. These calculations include 18 daily calculations, during 24 hour periods of time (from Blackstock, 2010), as well as monthly calculated data for the years of 1984-1986. The daily and monthly calculations were then used to plot the GNS model against the observed data as well as along the Global Mean Water Line.

Results

Attempts to model isoscapes based on computation have been proven unreliable during this experiment. On a larger scale, monthly data was used in order to compare the modeled data against observed and analyzed data. In figures 5 through 7, the GNS modeled data is plotted against observed monthly data (Taylor, 1990). Figure 5 presents the δ^{18}Oxygen data, which shows no significance based on the r-squared value of 0.32, 0.31, 0.12 for 1984, 1985, and 1986 respectively. Figure 6 also displays no significance through all three years (R^2= 0.23, 0.21, 0.03, respectively). Figure 7, also with no significance, represents d-excess values over the three years. Figure 8 is the two sets of data, observed and modeled, plotted against the GMWL over a three-year period. The trends shown are plotting along the same line trending with each other.

The GNS isotope model was used in order to calculate monthly data. In figures 9-12, values produced by the GNS model were plotted against values from observed and analyzed daily/hourly models (Blackstock, 2010). Figure 9 displays the computed GNS model plotted against observed data in regards to Oxygen-18 isotopes. The data produced shows no significance with an R-squared value of 0.07. In figure 10 the same plot was used in order to display Hydrogen-2 isotopes. This data was also insignificant with an r-squared value of 0.17. Values shown in the plot in regards to d-excess in figure 11 also show no significance with an r-squared value of 0.02. In figure 12 the projected hydrogen-2/oxygen-18 values were used to plot along the GMWL along with the observed data. The plots show little correlation along this line.

Discussion

Mapping and understanding the water cycle is a lengthy and complex task that requires a number of analyses for higher reliability. Because of the variability of precipitation patterns, hydrogen-2 and oxygen-18 values are relatively difficult to map into isoscapes and have only been mapped by atmospheric circulation models (Bowen, 2010). Unfortunately, GNS's attempt to create a computational model that can calculate isotopic compositions is showing low reliability rates based on the values found in the results.

The monthly data was used to observe the model over a larger amount of time versus daily isotopic models. The calculated isotopic composition was plotted against observed data in order to display whether there was a correlation between the two values. These calculations were used for hydrogen-2, oxygen-18 and d-excess and there was no significance found in any of the isotopic compositions at any point over the three years evaluated (figures 4, 5, and 6). In figure 7, it can be assumed that there is a correlation based on r-squared values and general observations but due to the large amount of values used to produce the figure, it has a percentage of presumed error.

The daily data followed the format from above; plotting the GNS modeled data against the observed data. There was, again, no significance found in any of the plots in figures 8, 9, and 10. In figure 11 the ratio of hydrogen-2 and oxygen-18 were plotted along the GMWL. A noticeable difference is seen in the variation of the two different data sets. The observed data is displaying isotopes of warmer, low-latitude/altitude and coastal regions while the GNS modeled isotope data is showing a cooler, high-latitude/altitude, and inland region.

Due to the insignificance of the data, it is conclusive to say that the computational model produced needs to be refined and tested against real isotopic compositions.

Conclusion

Although a computational model would advance research in the field of isotopes and precipitation, the data produced through calculations show insignificant trends for this model to be considered reliable in creating isoscapes for New Zealand. It has been dually that prediction models for isotopic compositions may never be developed because of the low accuracy level (Bowen, 2010), Bowen also notes that isotopic predictions are highly generalized because they reflect climatological systems versus meteorological systems (2010). Regardless of the outcome of this model, the science and understanding of meteoric water is becoming increasingly popular especially with global climate change, which allows for more interest and support from a larger community. Future research is definitely required in order to create a model that can be reliable on large and small-scale events.

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Appendix

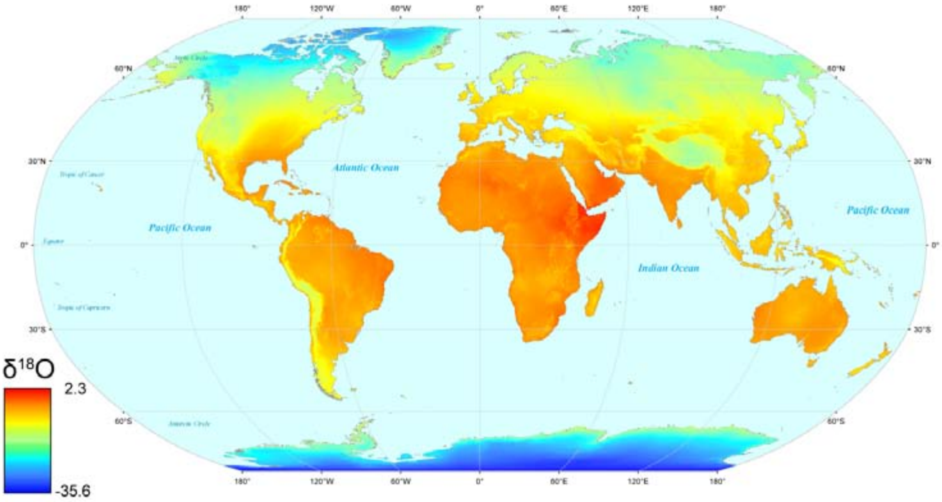

Fig 1.

Projected isoscapes on a global scale (Bowen et al, 2003).

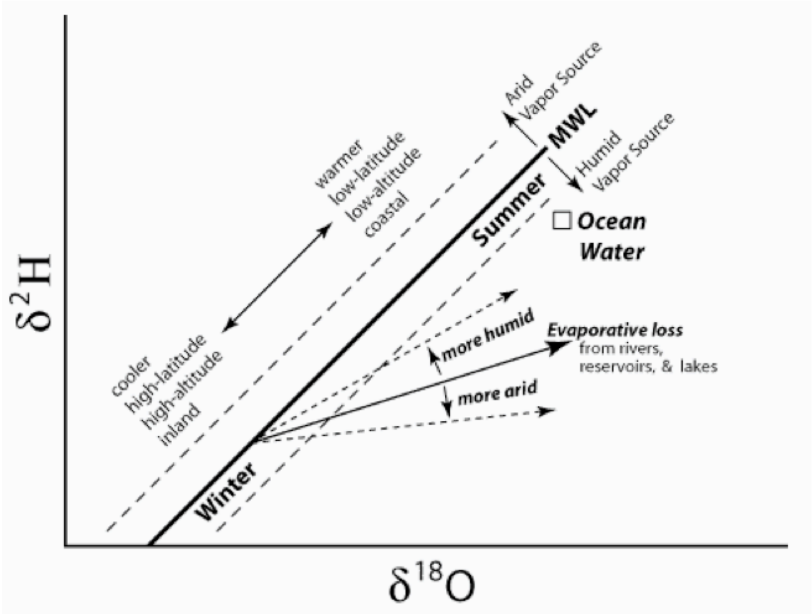

Fig. 2

Oxygen-18 against deuterium plot in order to show Global Meteoric Water Line including three regions of climatic variability (SAHRA, 2005).

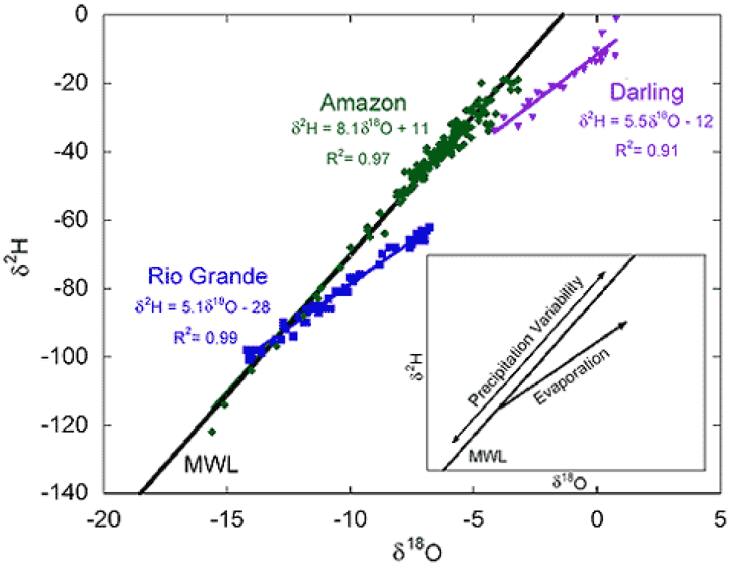

Fig. 3

The Global Meteoric Water Line plot along with hydrologic processes demonstrating changes based on climatic settings and seasonal changes (SAHRA, 2005).

(a)

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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

(b)

Fig. 4

a) zoomed out view of study area in the South Island, New Zealand. b) zoomed in focus of research area with a latitude/longitude of -43.525, 172.575.

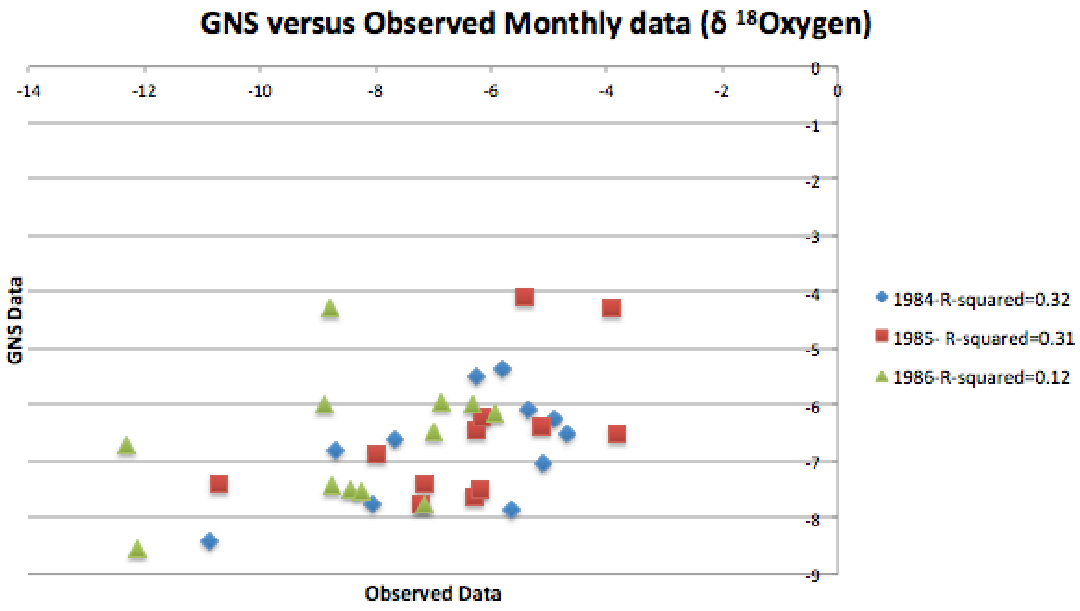

Figure 5. GNS derived data plotted against the observed monthly data during 1984-1986. All data is in regards to oxygen-18 values. R-squared values are displayed next to the years they pertain to.

Fig 5

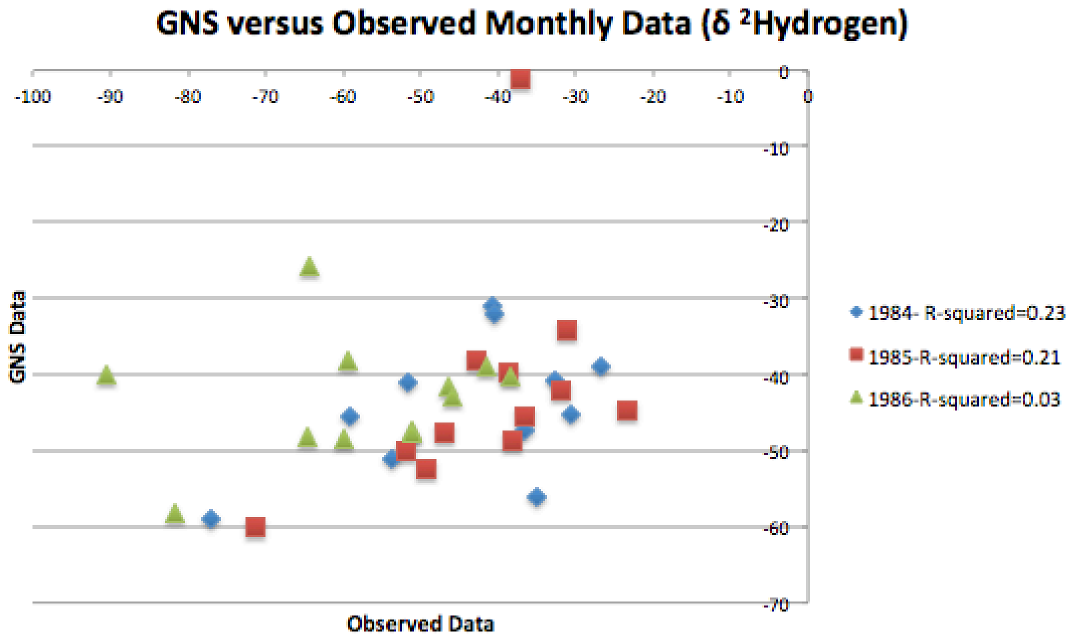

Figure 6. Data computed from the GNS model plotted against the monthly data from Taylor 1990. All data is based on hydrogen-2 values and from the years of 1984-1986. R-squared values are shown next to the years.

Fig 6

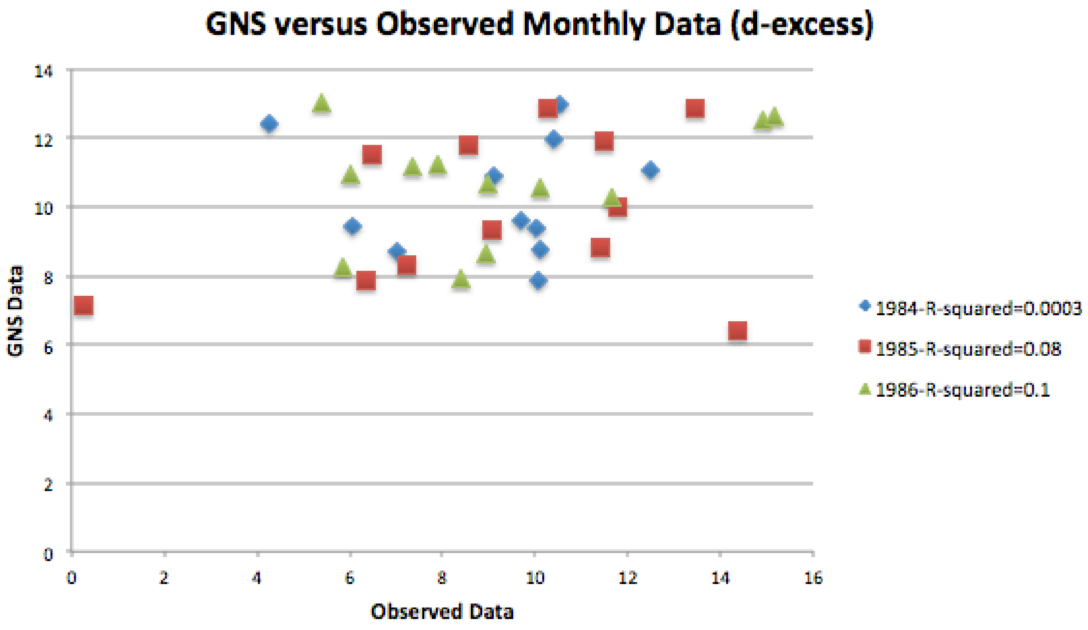

Figure 7. GNS versus monthyl data from Taylor 1990. All data shown is values of d-excess. Years are shown with r-squared values beside them.

Fig 7

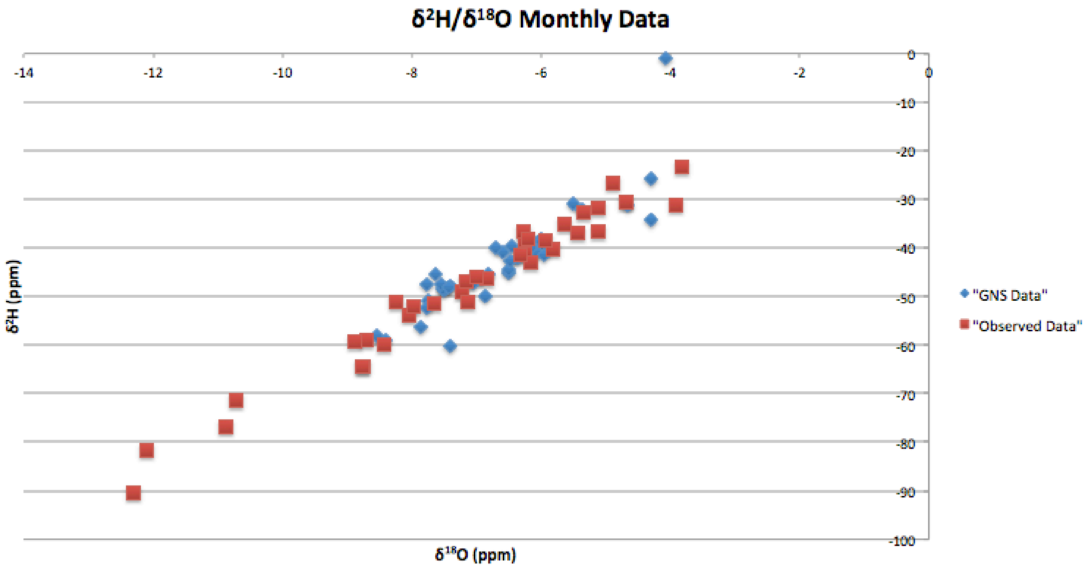

Figure 8. Ratios of hydrogen and oxygen shown along the global mean water line. Two sets of data are set here, the GNS isotopic compositions and the data derived from taylor.

Fig 8

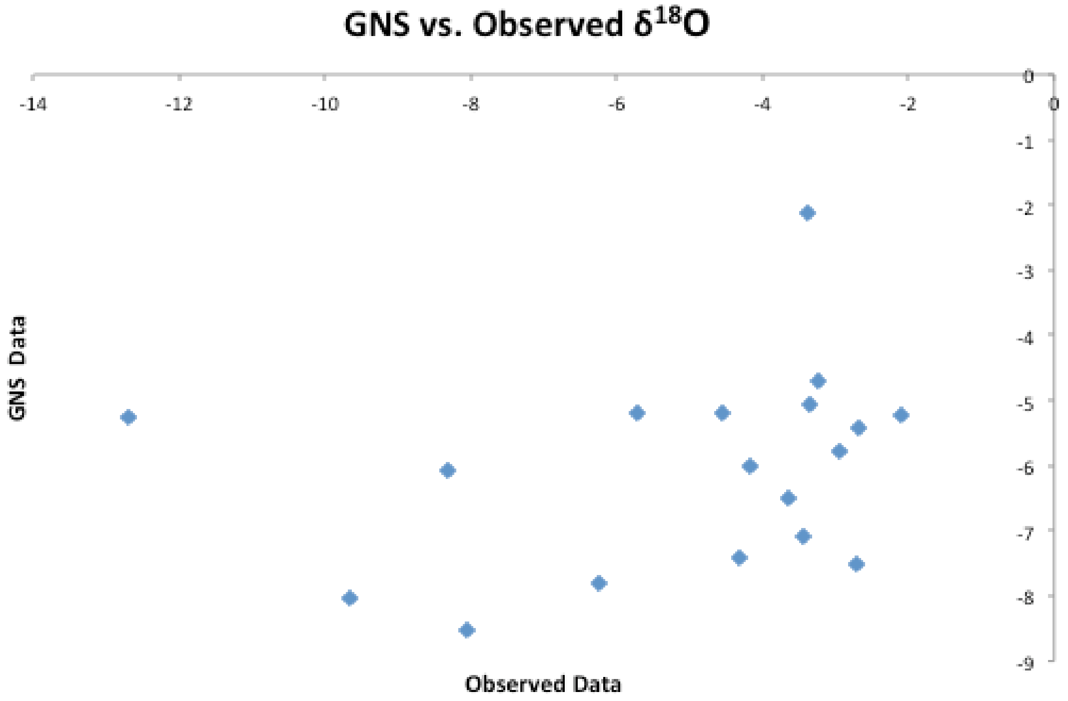

Figure 9. GNS derived data versus observed data from Blackstock 2010 for oxygen-18 isotopes over daily time periods. Measurements were taken for 24 hours on 18 different dates. R-quared values are 0.07.

Fig 9

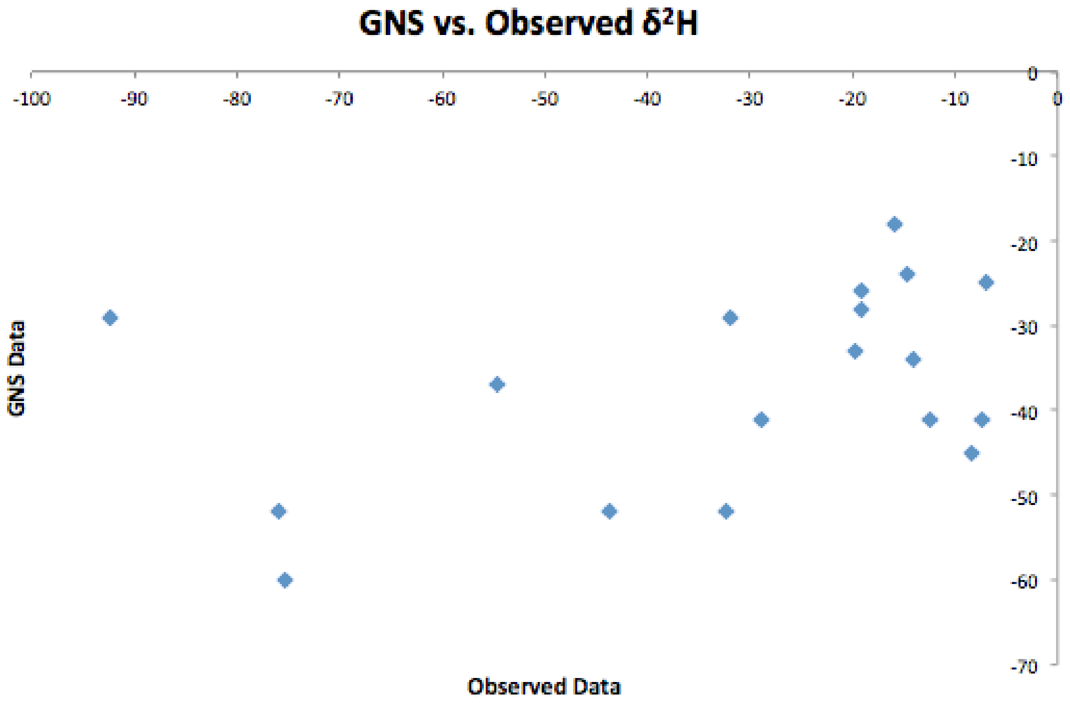

Figure 10. GNS data versus observed data for the hydrogen-2 isotopes over a daily time period. All measurements were taken for 24 hours on 18 different dates. R-squared values are 0.17.

Fig 10

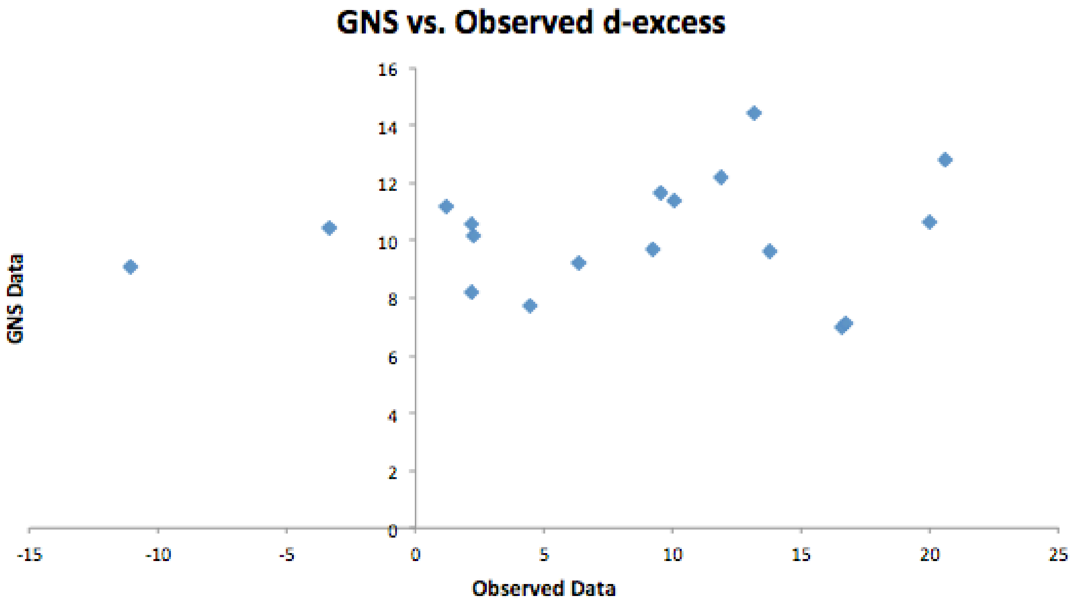

Figure 11. GNS data versus observed data for d-excess over a daily time period. All measurements were taken over a 24 hour period for 18 different days. R-squared value is 0.02.

Fig 11

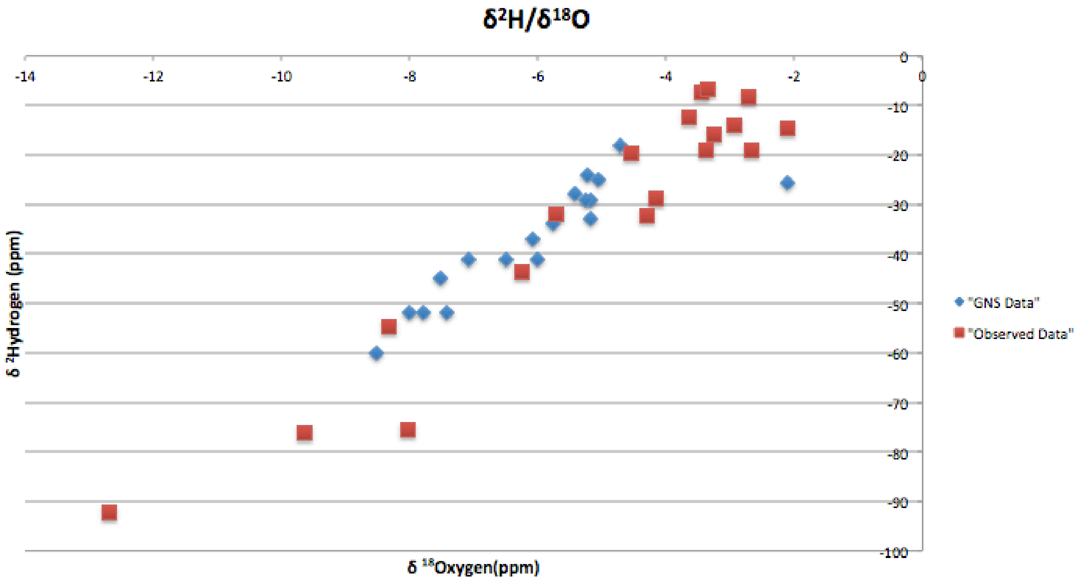

Figure 12. Hydrogen-2 versus oxygen-18 ratios plotted for GNS derived data as well as the observed data from Blackstock 2010. All values are produced from daily collection over 18 different days.

Fig 12

Sample	Date	Daily total	VCSN Total	Percent collected
6	24-Sep	2.1	0	n/a
8	4-Oct	1.4	0	n/a
12	16-Oct	3	1.7	176.4705882
15	28-Nov	6.9	2.1	328.5714286
18	2-Dec	6.6	3.9	169.2307692
20	6-Dec	2.6	2.6	100
21	10-Dec	1.2	0	n/a
22	14-Dec	12.4	16.6	74.69879518
23	20-Dec	5.1	7.2	70.83333333
29	11-Jan	0.8	11.8	6.779661017
33	14-Jan	1.7	2.3	73.91304348
34	16-Jan	3.4	4.9	69.3877551
37	22-Jan	14	23.8	58.82352941
39	17-Feb	3.1	9.1	34.06593407
40	18-Feb	7.2	4.5	160
41	26-Feb	1.1	0	n/a
42	17-Mar	2.1	0	n/a
43	24-Mar	1	1.2	83.33333333

Chart 1. Percentage of daily precipitation collected based on Blackstock 2010, and the VCSN data. In 7 of the sample dates percentage collected was above 70%. In some cases data was unavailable due to “zero” rain collection.