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Hydrologic and Climatologic Conditions that Shape Groundwater Resources in Utah and the Great Basin

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1. Introduction

In Utah, the declining trend of groundwater levels, combined with the rapid growth of urban population and water withdrawal, are already a cause for concern for water planners throughout the state. Previous research has identified a significant link between the region's hydroclimate to Pacific Ocean sea surface temperature anomalies (SSTA). Using this link, from which the SSTA impact extends to groundwater, we use the Community Earth System Model (CESM) to diagnose and predict groundwater levels for potential future climate scenarios. The CESM performs well in replicating both the seasonal cycle and the quasi-decadal oscillation (QDO) teleconnection (Wang *et al.* 2011) for Utah's groundwater level variations. In addition, the CESM was chosen for a focused analysis, as groundwater is not a standard output from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Building upon such model capability, this study analyzes the effects of greenhouse gas (GHG) on groundwater level change. The results indicate a troubling future for groundwater over the Great Basin and Utah in particular.

2. Data/methodology

Groundwater levels over northern Utah were recorded using 400 active wells that were obtained from the

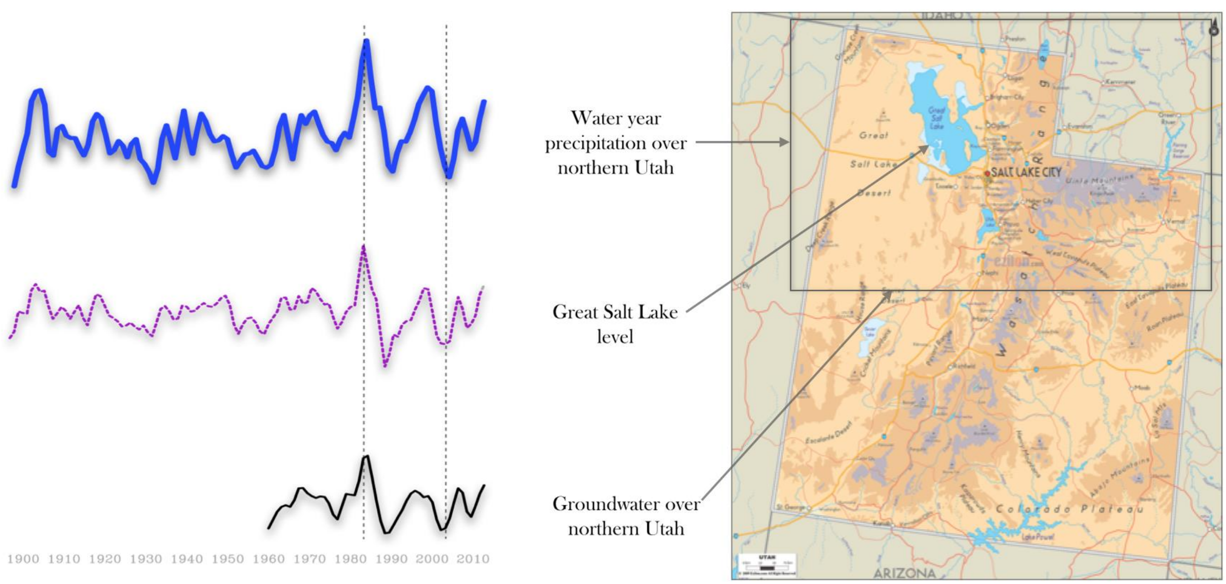

Fig. 1 Observed precipitation, plotted on top, oscillates in tandem with GSL level (tendency) and northern Utah groundwater (tendency). Dashed lines were provided to highlight the consistency in oscillations. A map of Utah is provided to the top with arrows designating the location of the GSL and the region of northern Utah.

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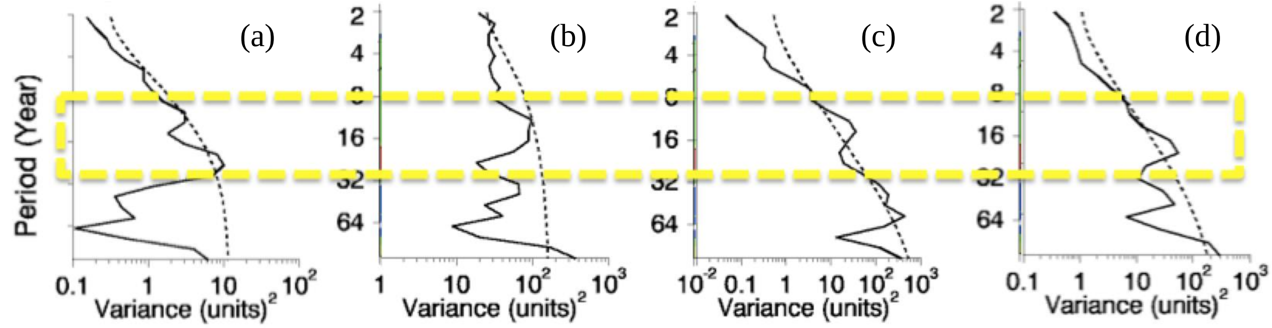

Fig. 2 Wavelet spectral analysis was performed on (a) modeled groundwater, (b) modeled precipitation, (c) observed GSL, and (d) observed groundwater. A prominent spike can be seen at the 10-15 year frequency throughout all datasets. This strong coherence throughout all datasets exemplifies the CESM's ability to replicate the predominant climate oscillations in the region.

United States Geological Survey (USGS) Active Groundwater Level Network[1, 2], with data since 1960. These wells are measured at least once within the past 13 months, primarily during the spring. Springtime groundwater levels were standardized prior to averaging among the 400 wells. Other datasets include: station-derived, monthly Global Precipitation Climatology Centre (GPCC) dataset at a 1° horizontal resolution (Schneider *et al.* 2013); the Great Salt Lake (GSL) surface elevation[3]. Outputs from the CESM version 1 were generated by the Pacific Northwest National Laboratory (PNNL) at a resolution of 2.5° long. × 1.875° lat. The CESM was chosen for its noted ability to simulate the ENSO evolution and precursors. We used the Historical Experiments of the CESM that were initialized at 1850 under preindustrial conditions and added with external forcings of aerosol, GHG, and natural – volcanic eruptions and solar cycle.

3. Results

The average groundwater level over northern Utah exhibits variability that fluctuates at a quasi-decadal frequency. In order to understand the hydrological forcing that leads to the observed periodicity of groundwater levels, we plotted observed precipitation alongside the tendency of the GSL level (*i.e.* current year minus the previous year) and the tendency of groundwater level over northern Utah, shown in Figure 1. It is noted that fluctuations in the precipitation are in good agreement with the tendency of GSL level and groundwater. Figure 1 also shows a pronounced quasi-decadal frequency within all observed data sets (10-15 year time period). This variability in precipitation, reflected by the alternating dry and wet spells, is particularly pronounced after the 1960s. The pervading quasi-decadal variability shown in all observational data suggests a potential for decadal climate prediction.

The unique timescale of 10-15 years, observed in the datasets discussed above, echoes an emerging Pacific climate mode – the Quasi-Decadal Oscillation (QDO) – described in a growing number of articles focusing on low-frequency variability in the Pacific SST (*e.g.* Allan 2000; Tourre *et al.* 2001; White and Tourre 2003; White and Liu 2008; Wang *et al.* 2011). The Pacific QDO alternates between warm/cool status in the central equatorial Pacific near the NINO4 region (160°E-150°W, 5°S-5°N), and features distinctive phases in atmospheric circulation perturbations.

The CESM output of groundwater levels and precipitation are analyzed next; the CESM appears to replicate the QDO, as is shown in the wavelet spectral analysis in Figure 2. Results show a strong coherence between CESM output and observational data, which alludes to the model's ability to pick up the predominant climate oscillations in the region. CESM model years cannot be directly compared to observational years, and thus wavelet spectral analysis provides an insightful way to diagnose the model.

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[1] Utah Water Science Center of the USGS, Active Groundwater Level Network, 1930-present. http://ut.water.usgs.gov/ (July 28, 2012).

[2] http://groundwaterwatch.usgs.gov/default.asp

[3] http://waterdata.usgs.gov/nwis

Building upon the CESM's noted ability to replicate the QDO and teleconnection patterns, we then analyzed modeled groundwater, from 1850 to 2005, with the ensemble historical runs shown in Figure 3. CESM runs for greenhouse gas forcing (GHG), aerosol (AERO), natural (NAT) and all forcing (ALL) were compared to identify each forcing's effects on groundwater. Each CESM ensemble is comprised of two members with the exception of the ALL ensemble, which consists of four members. Results show the effect of NAT, AERO and ALL forcing is oscillatory with the last half a century showing a steady increase in groundwater. In contrast, the effect of GHG on groundwater shows a persistent drying tendency throughout the last 80 years. This suggests that the system may initially be able to cope with an influx of GHG up to a point, but resilience is limited and groundwater will eventually be depleted by continued increases in GHG.

Figure 3 shows CESM historical groundwater in two separate time periods: (a) 1960-2005 and (b) 1850-2005. The overall drying effect of GHG can be seen by the steady decrease in groundwater in both plots. It can be seen in Figure 3b that around 1928, GHG has destabilized the hydro-climatic system and groundwater decreases steadily thereafter. For future scenarios, we then utilized CESM's representative concentration pathways (RCP) simulations to depict the outcome of groundwater behavior. The RCP simulations begin in year 2006 and projections are carried out to year 2100. RCP simulations are initialized with new levels of CO2 and therefore do not directly carry over from any particular historical run. RCP4.5 represents a specific concentration of CO2 in the atmosphere defined as stabilization without overshoot pathway to 4.5 W/m2 (~650 ppm CO2), reaching stabilization after year 2100. RCP8.5 represents a higher concentration of CO2, defined as rising radiative forcing pathway leading to 8.5 W/m2 (~130 ppm CO2) by year 2100. Figure 4 shows the ensemble run of RCP4.5 and RCP8.5, each consisting of two members, for groundwater. Results show that the higher levels of CO2 in RCP8.5 cause a greater decrease in groundwater level over time, resulting in an

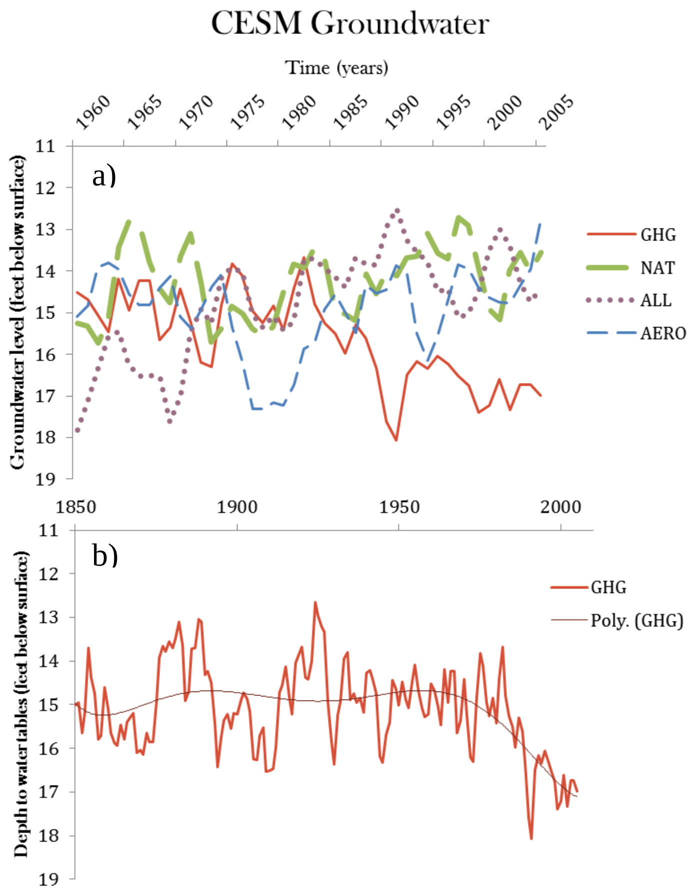

Fig.3 a) CESM historical groundwater is plotted above from 1960-2005. The plot shows the ensemble runs for GHG, NAT, ALL, and AERO forcing. Each ensemble run is the average of two members, with the exception of ALL forcing, which has four members. b) CESM groundwater is plotted above from 1850-2005. This plot isolates the ensemble run for GHG for the longer time period so as to highlight the decreasing trend in groundwater that begins in the late 1920's.

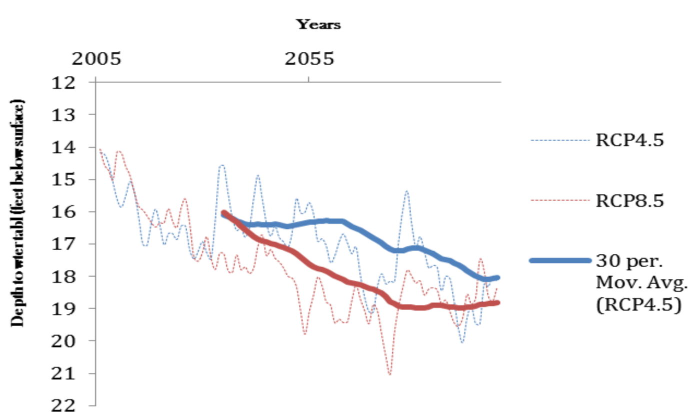

Fig.4 CESM – RCP ensemble 4.5 (blue) and RCP ensemble 8.5 (red) of groundwater are depicted above. Each ensemble is the average of two members.

approximate five-foot drop in groundwater level by year 2100. RCP4.5 also shows a decreasing trend in groundwater level, with an approximate one-foot difference between the two simulations by year 2100.

4. Concluding remarks

In Utah, groundwater is the source of 58 percent of public supply use and is a vital contributor for irrigation when surface water resources are depleted late in the growing season. According to the USGS Annual Groundwater Conditions Report for 2013 (Burden *et al.* 2013), the total estimated withdrawal of water from wells in Utah during 2012 has increased about 215,000 acre-feet from 2011 usage and 145,000 acre-feet more than the 2002-2011 average annual withdrawal. This increase in withdrawal resulted mostly from increased irrigation and public-supply use. As discussed in this paper, groundwater resources in Utah and the Great Basin are already susceptible to depletion by the effects of GHG. This issue is then exacerbated by the increasing trend in water withdrawal for irrigational and public-supply purposes. Therefore, research on the predictive nature of groundwater resources is vitally important and the increase of GHG in the atmosphere can have a direct influence on this drought-prone region. This research hopes to pave the way for the utilization of long-term prediction of groundwater and strives to inspire the need for better water management in light of the changing climate.

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