Poster H11F-1317

Relationship of Short-Term Precipitation Records at Yucca Mountain to Long-Term Climate Records

1. INTRODUCTION

Performance assessments for a potential high-level radioactive waste repository at Yucca Mountain, Nevada, depend upon assumptions about future climate for time periods of thousands to a million years. Precipitation data collected from a number of Yucca Mountain Project (YMP) meteorological stations over the past 10 to 20 years are combined with data from nearby meteorological stations (~50-yr records) as input to models for estimating net infiltration for the modern climate. Because the characteristics of past and potential future climates are often scaled to modern or Holocene climate, the question arises

Do the measured data reflect a representative modern climate covering the Holocene Epoch?

The climate at Yucca Mountain is believed to have been generally hot and dry for the past 8,000 to 11,000 years, following a period of glacial transition when the climate was cooler and wetter. For longer periods, climate records have been developed based on correlations to Earth's orbital patterns (the Milankovitch cycle) and to analog data based on isotopes and fossil records. The longer paleoclimatic records are not considered further here.

This analysis assesses the overlap of

1. Short-term 10- to 20-year YMP meteorological records
2. 50- to 100-year records from meteorological stations in the surrounding areas of Nevada and California, and
3. 8,000-year records supported by tree-ring data collected in the nearby White Mountains and focuses on the scale of cyclical patterns

The 1990s decade included an anomalously high number of El Nino events, which may have resulted in greatly enhanced winter precipitation in southern Nevada. If the 10- to 20-year period of record at the YMP stations was anomalously wet, averages developed from this record may be a biased indication of long-term climate.

2. Objectives

- Show influence of ENSO on precipitation near Yucca Mountain and in southern Nevada
- Determine if short-term measured date sets reflect important characteristics of the longer term records, such as trends and cyclical variations during the Holocene Epoch
- Explore the use of tree-ring data sets closer to the Yucca Mountain climate zone than the Methuselah Walk, California data set

3. Why is the Scale of Climate Variability Important?

Dampening of deep percolation by a nonwelded tuff horizon at Yucca Mountain is sensitive to the scale of climate variability.

Short-term variability is dampened, thus supporting use of a steady state approximation for the Holocene.

Longer-term variability can be incorporated by a series of quasi-steady state steps.

Intermediate scale variability is the focus of this poster.

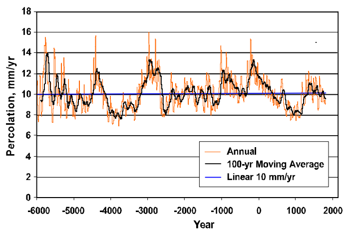

Figure 1. Temporal variation in deep percolation using annual variations for Holocene.

- Seasonal and annual variability
  - Winter precipitation dominates net infiltration estimates
    - Longer duration storms
    - Higher initial water contents
    - Saturation-induced runoff more likely than Hortonian
  - Isotope measurements in the Spring Mountains suggest that summers provide only 10 percent of the recharge and 30 percent of the precipitation (Winograd, et al., 1998)
  - Seasonal to short-term annual variations on climate, are encompassed in meteorological inputs used to estimate net infiltration for Yucca Mountain (eg., Stothoff, 1999)
- Decadal to millennial variations:
  - Have been shown to affect percolation rates (Manepally, et al., 2006), and hence seepage into drifts, but have received little attention. A steady state assumption is typically assumed for the Holocene ("linear" in Figure 1).
- Long-term climate variations using the Milankovitch cycle and paleoclimatological records (e.g., isotopes, pack rat middens, ostracods):
  - Address changes from the current inter-glacial period to a glacial transition, full glacial, or monsoonal
  - Have been based on paleoclimatologic records and have been integrated into net infiltration estimates

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4. Measured Data Sets and Short –Term Cycles in ENSO and PDO

Conditions in the Pacific Ocean drive changes in climate conditions in southern Nevada. Studies of these processes are generally focused on identifying these telecommunications, or linkages, between tropical and northern Pacific Ocean conditions and climate in North America (see reviews by Jones and Mann, 2004, and McCabe and Dettinger, 1999). Figure 2 illustrates the shift in the jet stream, and thus storm tracks, that links conditions in the Pacific Ocean with climate in North America.

Two indices have been widely used:

1. Southern Oscillation Index (SOI) is the temporal variation of sea surface pressures (or temperatures) in the central and eastern tropical Pacific Ocean. This signal is often referred to generically as the El Nino Southern Oscillation (ENSO). Following Redmond and Koch (1991), an index based on differences in pressure between two locations, Tahiti and Darwin, is used here.
   - Characteristic SOI cycle is 3 to 7 years and may have durations of 1 to 3 years
   - El Ninos are associated with negative SOI values and are periods of wetter conditions in the desert southwest of the US because of a shift in the jet stream bringing moisture directly to the area. The local Yucca Mountain stations exhibit a prominent increase in winter precipitation during El Nino years (Figure 3).
2. Pacific Decadal Oscillation (PDO) is based on pressure differences between interior and coastal areas of the northern Pacific area (Mantua, 1997).
   - The PDO is a longer cycle generally described as ~ 50 yrs, or multi-decadal, which leads to difficulties when assessing its influence on short-term measured records.
   - The PDO is may be a "reddened" ENSO (Newman, et al. (2003). This refers to the PDO being driven by deep ocean storage of the ENSO signal, thus integrating the ENSO signal as a lagged forcing function.
   - Positive values of the PDO index are associated with periods of enhanced El Nino.

It has been postulated that the multi-decadal cycles might be initiated by solar cycles (Landscheidt, 2000), such as the 22-yr Hale cycle.

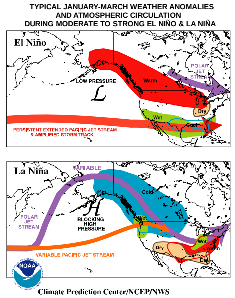


Figure 2. Schematic of jet stream patterns during El Nino and La Nina taken from WRCC-NWS-NOAA at http://www.wrcc.dri.edu/enso/enso.html.

Figure 3. Effect of El Nino on winter precipitation at stations near Yucca Mountain.

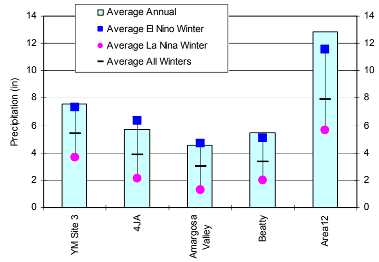
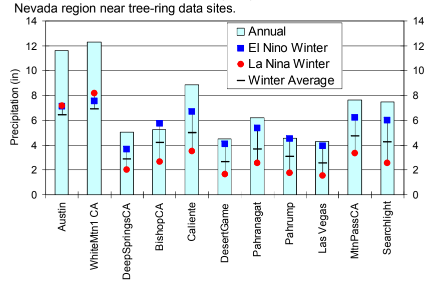


Table 1. Sites evaluated for tree-ring (Type=TR and in bold) and precipitation records (Type=P). Tree-ring data obtained from International Tree-Ring Data Bank. Precipitation data obtained from Western Region Climate Center (http://www.ymp.dri.edu/index.html and http://www.wrcc.dri.edu/Climsum.html), Nevada Test Site (4JA and Area12, http://www.sord.nv.doe.gov/SORD_Rain.html)

Site or Station	Type	Start	End	Latitude	Longitude	Elevation, ft
Yucca Mountain Area						
YM Site 3	P	1989	2004	36.85	-116.45	4,195
4JA	P	1958	2005	36.78	-116.29	3,422
Amargosa Valley	P	1966	2005	36.57	-116.47	2,450
Beatty	P	1948	2005	36.92	-116.75	3,310
Area12	P	1959	2005	37.19	-116.22	7,,490
Regional, Southern Nevada						
Spring Mountains	**TR**	**320**	**1984**	**36.32**	**-115.7**	**9,843**
Charleston Peak	**TR**	**800**	**1984**	**36.27**	**-115.7**	**11,237**
Las Vegas Airport	P	1937	2005	36.08	-115.17	2,170
Searchlight	P	1914	2005	35.47	-114.92	3,540
Desert Game WL Refuge	P	1948	2005	36.43	-115.37	2,920
Pahrump	P	1948	2005	36.25	-116.0	2,870
Panaca	**TR**	**1556**	**1982**	**37.77**	**-114.18**	**6,900**
Caliente	P	1928	2005	37.62	-114.52	4,400
Sawmill Canyon	**TR**	**1605**	**1977**	**36.67**	**-115.17**	**8,999**
Pahranagat WL Refuge	P	1964	2005	36.28	-115.12	3,400
Clark Mountain	**TR**	**1596**	**1968**	**35.53**	**-115.58**	**7,201**
Mountain Pass, CA	P	1955	2005	35.47	-115.53	4,800
Pete's Summit	**TR**	**1439**	**1982**	**39.18**	**-116.78**	**7,700**
Austin	P	1890	2005	39.50	-117.08	6,600
Methuselah Walk	**TR**	**-6000**	**1996**	**37.43**	**-118.17**	**9,203**
White Mountain 1, CA	P	1955	1977	37.50	-118.18	10,150
Deep Springs, CA	P	1948	2005	37.37	-117.98	5,230

Figure 4. Effect of El Nino on winter precipitation at stations in southern Nevada region near tree-ring data sites.



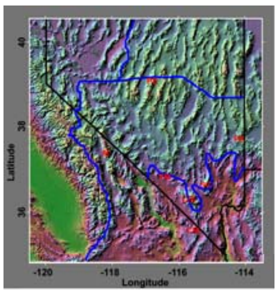
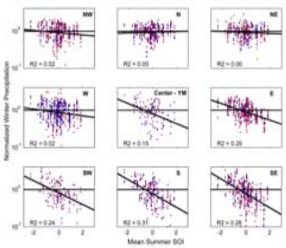


Figure 5. Climate regions over laid on topographic base map (modified from Sterner, 1995) of central and southern Nevada and parts of California. The climate regions, delineated based on ENSO influence, are derived from the Climate Prediction Center (1997) analyses. Yucca Mountain (YM) and locations of tree-ring records (M, PE, PA, S/C, CM, SC) are also shown (see Table 1 for abbreviations).

Figure 6. Spatial analysis of ENSO influence by quadrants, centered on Yucca Mountain region. Precipitation data are from http://www.wrcc.dri.edu/Climsum.html



Spatial Variation of ENSO Influence and Selection of Regional Data Sites

The paucity of meteorological stations with long-term records near Yucca Mountain led to search for other data sets in the region. The longer term stations would better support interpretations of tree-ring data.

Based on the (i) physiography, (ii) the climate region delineations, (iii) length of record, and (iv) elevation, regional meteorological stations were selected to extend the Yucca Mountain climate information to longer periods in conjunction with tree-ring data. Selected meteorological stations and tree-ring sites are listed in Table 1. Figure 4 illustrates the large increase in winter precipitation during El Nino years (October-March) for the regional sites.

Clearly, physiography (Figure 5) influences the climate in conjunction with the jet stream pattern. The Sierra Nevada Mountains are prominent on the western edge of Figure 5.

Figure 5 shows the climate regions used by NOAA. Yucca Mountain resides between the South Central Nevada and Extreme Southern Nevada climate regions. The former is an area of transition from no ENSO influence to the north to the strong El Nino influence of the Extreme Southern Nevada climate region. In California, these two regions are lumped together. Figure 6 illustrates the variation in El Nino influence for on winter precipitation.

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5. Do Variations in Local and Regional Meteorological Measurements Reflect Longer-Term Variations?

To put the short-term records in context with longer term climate patterns, the short-term local YM stations patterns are visually compared to successively longer-term data sets (Figure 7 A-D). The annual data are smoothed using a 10-yr moving average. Some observations are:

- The wet 1970s and 1980s clearly show up in all data sets: meteorological, tree-ring, and Pacific Ocean indices. The smaller signal for the 1990s occurs in some of the data sets.
- The cycles in the longer-term regional meteorological stations appear to track cycles in the PDO (Figures 7B & C)
- A qualitative teleconnection is illustrated by the temporal patterns linking long-term PDO and the estimates of precipitation from the tree-ring data (Figure 7C). Since 1880, the periodicity of El Nino years has increased from 24% (1880-1962), to 30% (1963-1990), to 47% (1990-2005).
- The correlations are not perfect; local physiographic differences likely confound the comparisons.

Comments on the trend and patterns in the long tree-ring records covering the Holocene are made in the section to the right on tree-ring data as a proxy.

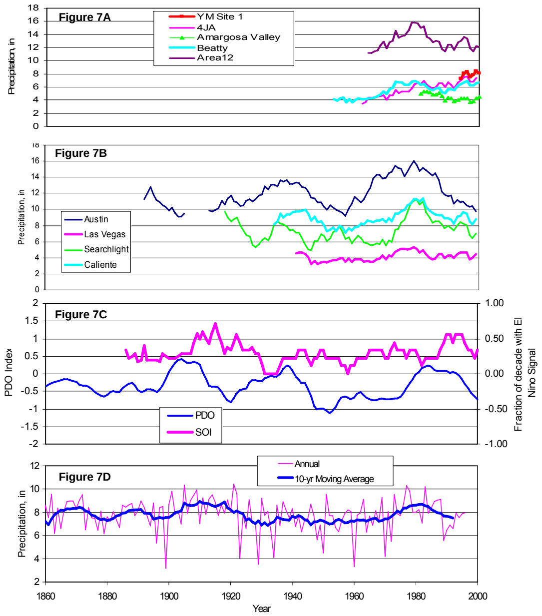

Figure 7. For the period 1860 to 2005, (A) Smoothed annual precipitation data for stations near Yucca Mountain, (B) smoothed annual precipitation data for long-term stations in southern Nevada, (C) inverse relationship of PDO index and number of El Nino periods per moving decade, and (D) annual and smoothed precipitation estimated from the Methuselah Walk tree rings index by Hughes and Graumlich (1996).

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6. Tree-Ring Data as Proxy for Precipitation

Tree-ring widths can be used as a proxy for climate data, extending the time frame from less than a century to thousands of years. In the analysis here, we presume that variations in precipitation are the primary driver for the rate of tree growth.

Clearly, other factors affect tree growth, such as changes in temperature, CO_2 levels, and seasonality of conditions. Rises in the CO_2 levels and temperatures associated with recent global climate change due to man-made influences, thus would be confounding influences for interpreting tree-ring widths, particularly over the past 50 to 100 yrs.

Hughes and Graumlich (1996) used the Methuselah Walk tree-ring data to estimate precipitation variation over the past 8,000 yrs using a variety of proxies to support the relationship between tree-ring width and magnitude of annual precipitation. Methuselah Walk is the longest tree-ring data set from the southern Nevada region and is located in the White Mountains in California (Figure 5). Figure 8 illustrates the variations in the tree-ring width over the past 8,000 years derived from an assemblage of tree-ring data sets, which Hughes and Graumlich (1996) used to develop an estimate of the precipitation record.

Using the standard deviation of the precipitation estimate from Methuselah Walk for each millennia as an indicator of increased variability, the last 3,000 yrs had a stable standard deviation of ~1.6 in. During the period 8,000 to 3,000 before present, the standard deviation varied between 1.68 and 1.91 in. Multi-century cycles appear to be more common in the early than the late Holocene.

Also, the trend in Figure 8 is consistent with a reconstruction for the Sierra Mountains in California where it was noted that the climate over the last 3,500 yrs was more stable than during the early part of the Holocene, and that temperatures peaked at ~6,500 yrs ago (Potito, et al., 2006). The Methuselah Walk precipitation estimate, however, did not exhibit a correlation to El Nino indices.

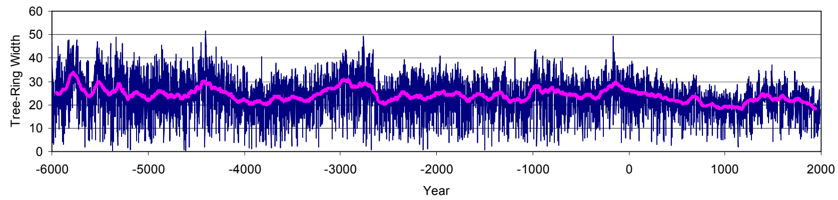

Figure 8. Annual (blue) tree-rings widths (units of 0.01 mm) for Methuselah Walk (Hughes and Graumlich, 1996). A 100-yr moving average (violet) illustrates the smoothed tree-ring widths over the 8,000-yr period.

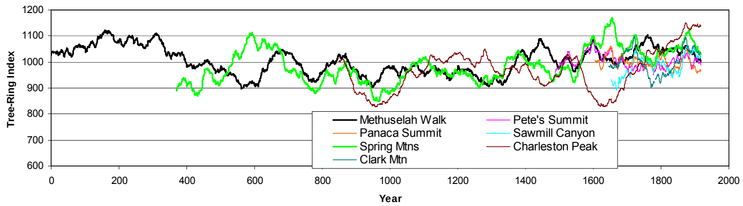

Figure 9. Tree-ring widths from the International Tree-Ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html; data sets from D.A Graybill, J.P. Cropper, and C.W. Stockton) including bristle cone pine, white fir, and single leaf pinon. Values are 100-yr moving averages.

Exploratory evaluation of six tree-ring data sets surrounding Yucca Mountain in southern Nevada was performed with the objective to identify scales of cyclical variations. Location and elevation of each site are shown in bold in Table 1 and are plotted in Figure 5. Figure 9 illustrates the smoothed variations of tree-ring widths. The tree-ring sites surround Yucca Mountain.

The patterns, when acknowledging effects of local physiographic-based differences, are generally consistent in the group, except for the Charleston Peak site.

Figure 10 shows a reconstruction of the Spring Mountain tree-ring data, scaled to a 1,500-m elevation. The differences between Figures 7D and Figure 10 may reflect both physiographic differences and the effect of selecting proxy precipitation stations not co-located with the tree-ring data.

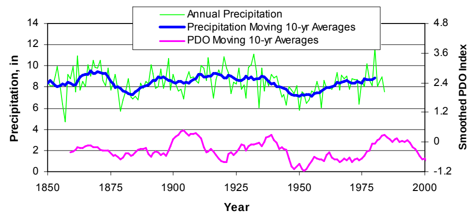

Figure 10. Estimated precipitation at an elevation of 1500 m, which is the Yucca Mountain elevation, based on a simple model derived from the Spring Mountain tree-ring indices and Searchlight meteorological data. The Hevesi, et al. (1992) lapse rate for precipitation as a function of elevation was used.

8. Possible Future Analyses

Further analyses to better support the correlations and interpretations of paleoclimatology are warranted for the tree-ring sites in the same climate region as Yucca Mountain.

Not factored in for correlation of tree-ring width and precipitation are:

- Snow
- Temperature variation (except for Methuselah Walk data)

Additional supporting information and approaches to better support modeling of precipitation based on tree-ring could include:

- Laminated lake and ocean sediment analysis, such as bioturbation sequences
- Analysis of glacial icepacks
- Historical documentary material

Cycles in solar variation during the Holocene may help explain cycles noted in tree-ring data.

7. SUMMARY

There is a strong El Nino signal in precipitation near Yucca Mountain, which indicates that wet winters have occurred cyclically. Winters provide proportionately greater recharge, which may only occur in the wettest winters of the semi-arid climate of southern Nevada.

The short-term records of regional meteorological stations appear to be consistent with decadal to multi-decadal cycles of the PDO, which when positive is associated with enhanced El Nino precipitation.

Several scales of climate cycles appear in the tree-ring data covering various portions of the Holocene Epoch, including a 50- to 100-yr cycle and a multi-century cycle scales of variation in climate. Variations on these time scale would affect deep percolation rates (Figure 1) at Yucca Mountain according to numerical models (Manepally, et al., 2006).

Unit Conversions 1 m = 3.28 ft.; 25.4 mm = 1 inch