Sandia National Laboratories Estimates of Precipitation

Presented to:
Nuclear Waste Technical Review Board

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Outline

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Primary Contributors

- **Joshua Stein (SNL) – Principal investigator and team lead**
- **Daniel Levitt (Los Alamos National Laboratory) – Conceptual models**
- **Robert Walsh (Apogen Technologies) – Precipitation and uncertainty analysis**
- **Cedric Sallaberry (SNL) – Precipitation and sensitivity analysis**
- **Sandra Dalvit-Dunn (Apogen) – Precipitation**
- **Steve Miller (SNL) – Precipitation**
- **Saxon Sharpe (Desert Research Institute) – Present and future climate consultant**

Background

- **Sandia National Laboratories (SNL) was tasked to review the U.S. Geological Survey net infiltration model, INFIL 2.0, and develop a replacement model (MASSIF) for use at Yucca Mountain (YM)**
  - **The representation of precipitation uncertainty was one of SNL's focus areas**
- ***Future Climate Analysis* (2004) estimates features and timing of three climate states expected in the next 10,000 years at YM**
  - **Identifies analog meteorological stations to represent upper bounds (UBs) and lower bounds (LBs) for these climates**

Background (continued)

- **U.S. Nuclear Regulatory Commission provides guidance in the *Yucca Mountain Review Plan* (NUREG-1804, REV 02) to ensure that**
  - **"The effects of…time-varying boundary conditions…are considered, such that net infiltration is not underestimated" (Section 2.2.1.3.5.3: Acceptance Criterion 2(3))**
  - **"Models use parameter values…that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate" (Section 2.2.1.3.5.3: Acceptance Criterion 3(1))**
  - **"…the treatment of conceptual model uncertainty does not result in an under-representation of the risk estimate" (Section 2.2.1.3.5.3: Acceptance Criterion 4(3))**

Motivation

- **MASSIF model estimates long-term average net infiltration flux and uncertainty for each climate state**
- **MASSIF needs a set of weather years for each climate state that include daily values of**
  - **Precipitation**
  - **Minimum and maximum temperature**
  - **Mean daily wind speed**
- **Climate variability occurs over time-scales that are shorter than the climate durations expected at YM**
  - **Such variability may bias mean values calculated from historical weather records**

Motivation (continued)

- Precipitation must be applied to grid cells covering the infiltration model domain (~125 km^2) over an elevation range from 964 to 1,964 m above sea level; top of YM is at 1524 m

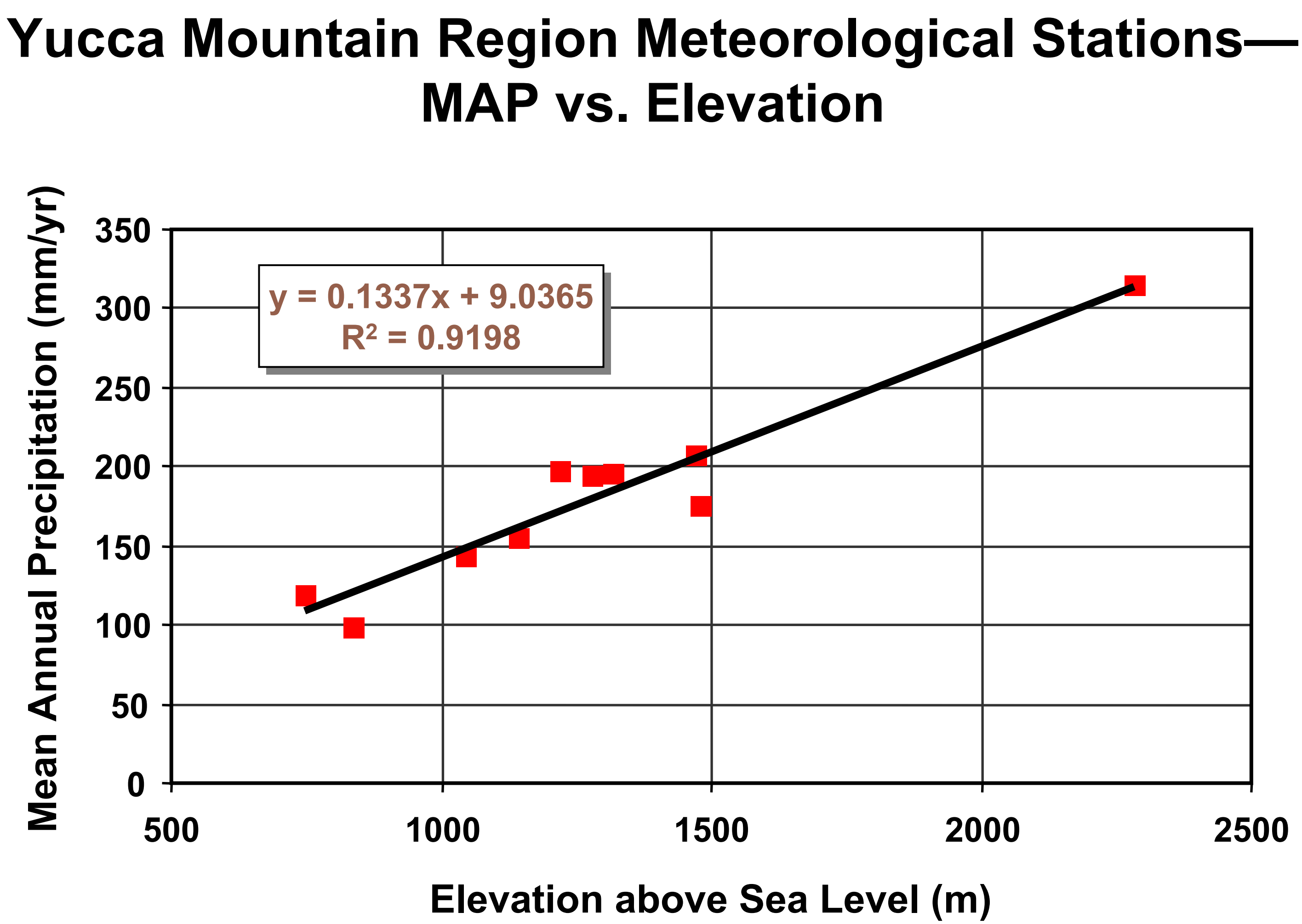
Climate States and Analog Records

- **Present Day**
  - Duration—400 to 600 years
  - Analog stations
    - “Yucca Mountain region”
- **Monsoon**
  - Duration—900 to 1,400 years
  - Analog stations
    - LB—Present day
    - UB—Hobbs, NM and Nogales, AZ
- **Glacial Transition**
  - Duration—Greater than 8,000 years
  - Analog stations
    - LB—Beowawe, NV and Delta, UT
    - UB—Spokane, Rosalia, and St. John, WA

Present-Day Climate Precipitation

- Precipitation is significantly influenced by elevation
- Published estimates of mean annual precipitation (MAP) for YM region vary significantly
  - Spaulding (1985) estimated 189 mm/yr (based on Nevada Test Site records 1963 to 1972)
  - Thompson et al. (1999) estimated MAP = 125 mm/yr at YM (based on climate division normals from NV region 3 and 4 (1951 to 1980))
    - NV- 3 (1931 to 2000)—195 mm
    - NV- 4 (1931 to 2000)—141 mm
    - Daly (2002) estimated that precipitation division normals in NV regions 3 and 4 are underestimated by as much as 25% due to elevation bias
- Analysis of meteorological data (up to 2004) from 10 regional stations suggest MAP at top of YM to be approximately 200 to 220 mm/yr

Present-Day Climate Precipitation



Monsoon and Glacial-Transition Climates

- **Monsoon**
  - Climate during this period would vary between episodes of intense summer rain to present-day-like climates with relatively more winter and less summer precipitation
  - UB MAP—405 to 420 mm/yr (analog station MAP)
- **Glacial transition**
  - The climate during the glacial-transition period would consist of a typically cool, usually wet winter season with warm (but not too hot) to cool summers that are usually dry relative to present-day summers
  - LB MAP—207 to 241 mm/yr (analog station MAP)
  - UB MAP—419 to 455 mm/yr (analog station MAP)
- **MAP from analog stations assumed to be representative at the top of YM (1,524 m above sea level)**

Long-Term Precipitation Simulation

- To include the effects of low probability, high precipitation years on long-term average net infiltration, we chose to generate a long simulation of precipitation (1,000 years)
- Well-established approach for stochastic simulations of precipitation that includes seasonal variations (Woolhiser and Pegram, 1978)
  - Markov chain model of precipitation frequency
  - Probability distribution for daily precipitation amount
- Meteorological records used to parameterize the simulation

Simulation of Daily Precipitation

- **Seasonal representation of daily precipitation**
  - **Stochastic parameters, *p(d)* include**
    - ***$p_{00}(d)$*—The probability that day *d* is dry, given that day *d*-1 is dry**
    - ***$p_{10}(d)$*—The probability that day *d* is dry, given that day *d*-1 is wet**
    - ***$\lambda(d)$*—Mean of the lognormal precipitation distribution, given that day *d* is wet**
    - ***m(d)*—Mean of the natural logarithm of the amount of precipitation, given that day *d* is wet**
  - **Parameters are each represented by an annual 1st order Fourier series constrained by parameters *a*, *b* and θ:**

$$p_X(d) = a_X + b_X \sin(\theta_X + 2\pi d / 365)$$

Implementation

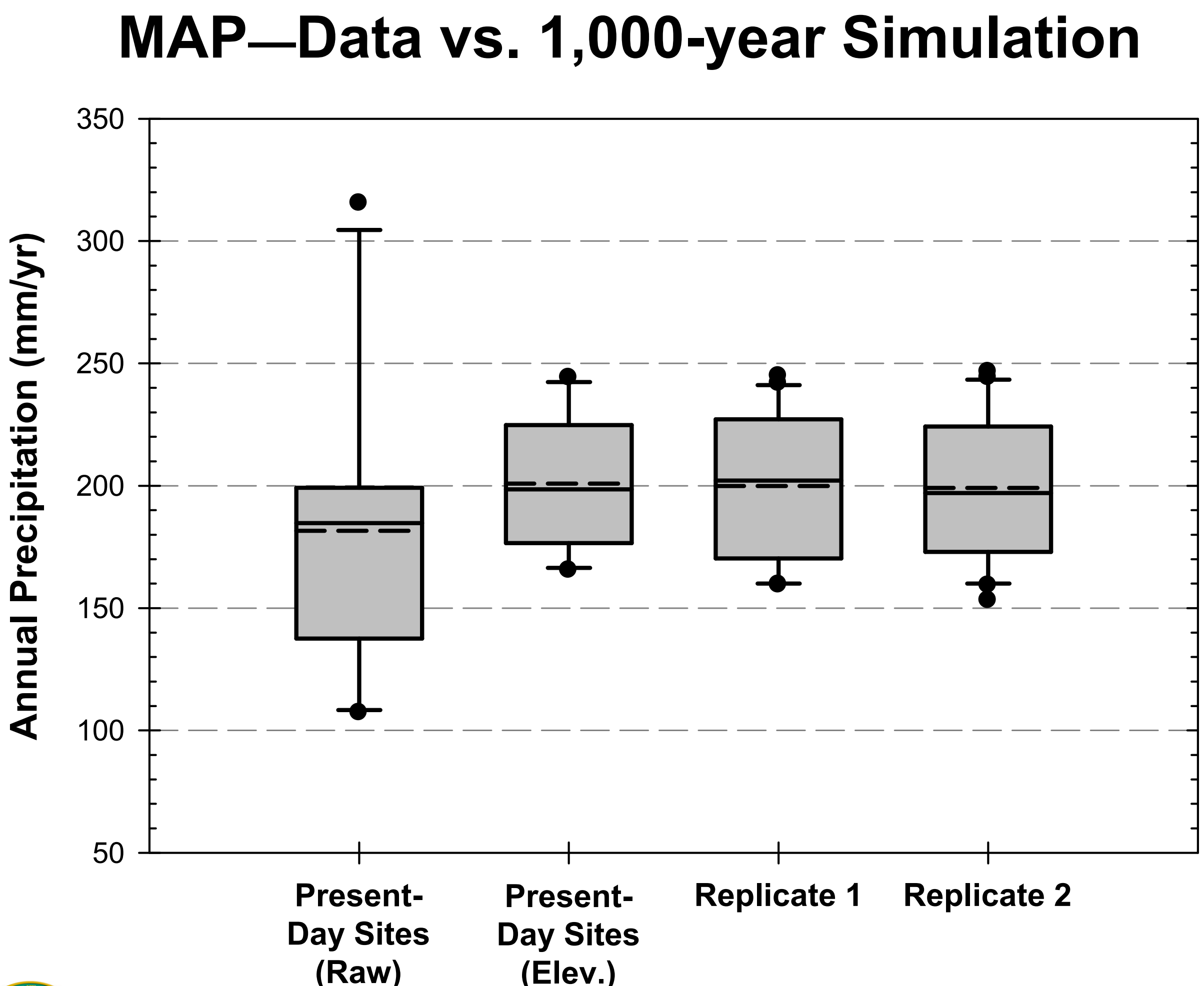
- **For each climate state**
  - 12 stochastic parameters calculated for each meteorological station using least-squares approach
  - Parameter distributions are defined for each stochastic parameter
  - Stochastic parameters are screened for inclusion in Latin Hypercube Sampling (LHS) by a relative uncertainty threshold (15%)
  - Two LHS replicates (2 x 20 = 40 realizations total) generated
- **For each LHS realization**
  - A large set of random numbers are generated and saved
  - 1,000 years are simulated (using random numbers, day of year, and Fourier model with sampled fitting parameter values)

Definition of Representative Years

- **For each LHS realization (1,000-year simulated record)**
  - Years are sorted by annual precipitation and split into 10 bins of unequal weight
  - A year is randomly selected and weights assigned according to each bin size

Representative Year	Weight	Recurrence (years)	Present-Day Mean Precipitation (mm/yr)
Y1	0.001	1000	708
Y2	0.002	333	549
Y3	0.007	100	430
Y4	0.02	33.3	360
Y5	0.07	10	292
Y6	0.18	3.6	227
Y7	0.18	2.2	186
Y8	0.18	1.6	157
Y9	0.18	1.2	126
Y10	0.18	1	89

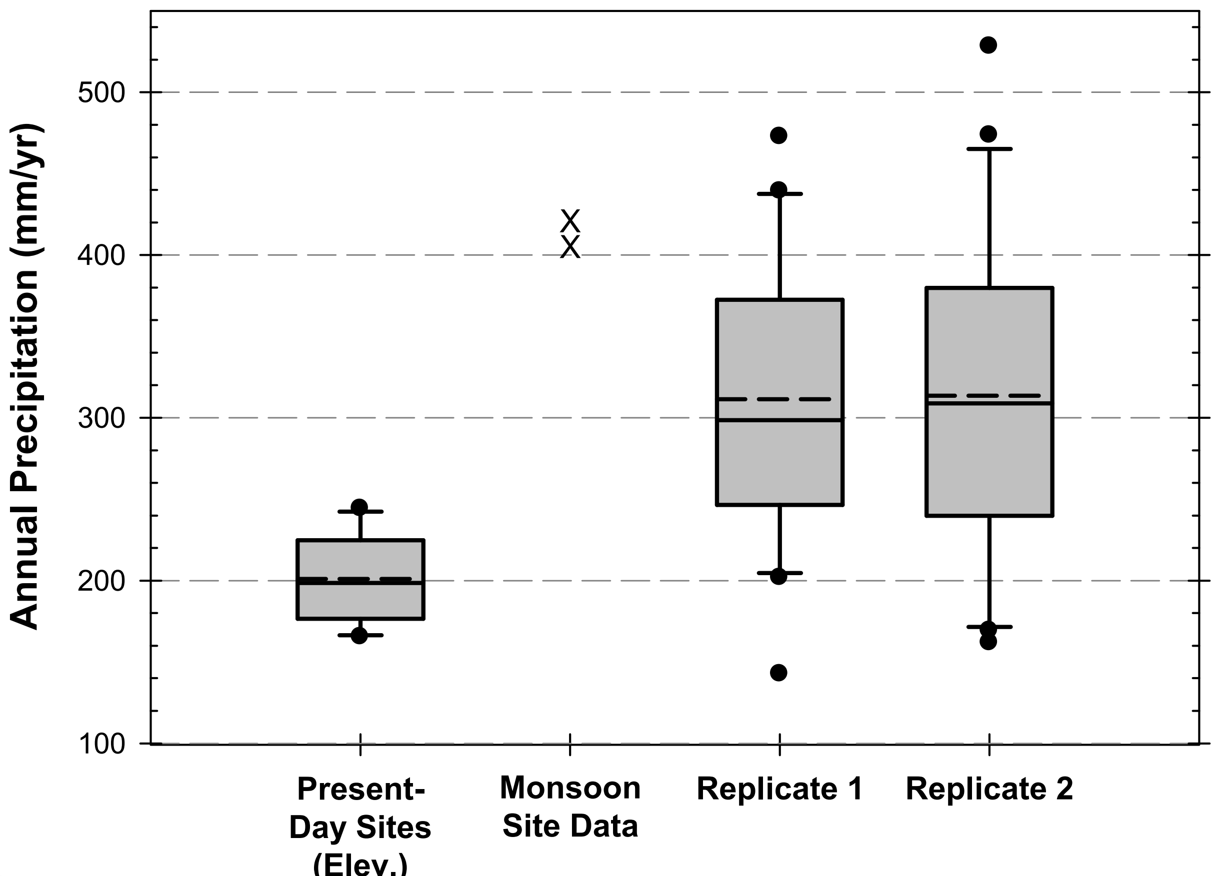
Preliminary Results
Present-Day Climate



- **Station range ≈ 165 to 244 mm/yr (YM Site 9 – Cane Springs)**
- **Simulation range = 153 to 246 mm/yr**
- **Station MAP ≈ 201 mm/yr; standard deviation ≈ 25 mm/yr**
- **Simulation MAP = 199 mm/yr; standard deviation = 29 mm/yr**

Preliminary Results
Monsoon Climate

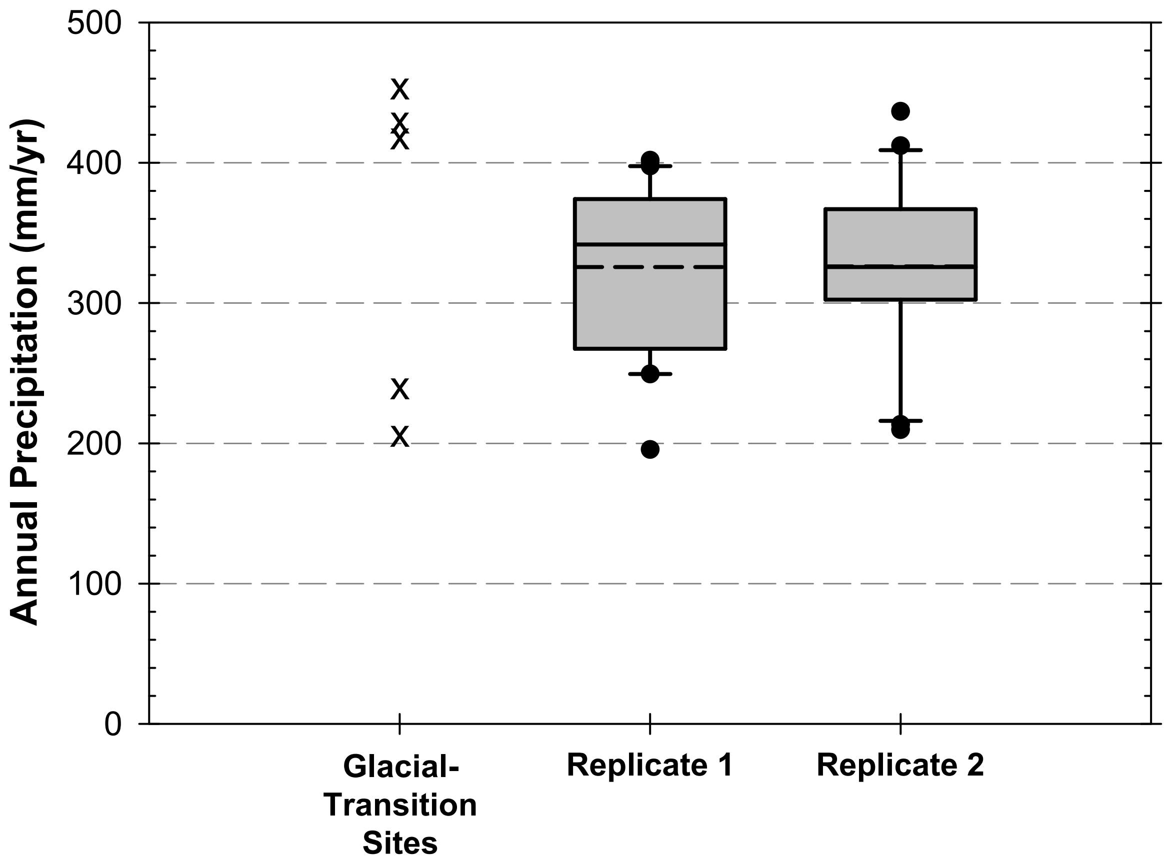
MAP—Data vs. 1,000-year Simulation



- **Station range ≈ 165 to 420 mm/yr (YM Site 9 – Hobbs)**
- **Simulation range = 143 to 528 mm/yr**
- **Station LB MAP ≈ 201 mm/yr; UB MAP ≈ 413 mm/yr (mean of Hobbs and Nogales)**
- **Simulation MAP = 313 mm/yr**

Preliminary Results
Glacial-Transition Climate

MAP—Data vs. 1,000-year Simulation



- **Station range ≈ 207 to 455 mm/yr (Delta – Rosalia)**
- **Simulation range = 195 to 437 mm/yr**
- **Station LB mean MAP ≈ 224 mm/yr; UB mean MAP ≈ 435 mm/yr**
- **Simulation MAP = 326 mm/yr**

Summary and Preliminary Conclusions

- Future precipitation is represented as a stochastic process conditioned on historical data from analog meteorological stations
- Seasonality is represented by a 1^{st} order Fourier series (e.g., one wet and one dry season)
- Stochastic simulations generate 1,000 years for each LHS of parameters
- Ten representative years are selected as input to the MASSIF net infiltration model
- Simulated precipitation matches climate uncertainty based on observations from the historical record