Intensification of droughts in a warming environment: Trends, uncertainties and possible impacts

Shih-Chieh Kao and Auroop R. Ganguly

Computational Sciences and Engineering Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Introduction

- Drought is perceived as one of the most expensive and least understood natural disasters
- Agricultural losses are around $6-8 billion annually
- This exceeds damages from floods and hurricanes
- High potential for intensified hydro-meteorological extreme events in a future climate (IPCC AR4)

Climate Drought Assessment Using SPI

- Standardized precipitation index (SPI) by McKee et al.
- Based on a given window size, the rainfall depth is transformed to its corresponding cumulative probability, and then mapped onto the standard normal scale.
- Probabilistic measure of precipitation deficit
- Gamma distribution with seasonality adjustment

Assessment of future drought potential

- 3-, 6-, 9-, and 12-month SPI parameters estimated from 1970-1999 monthly 20C3M control run
- The parameters are used to compute the 2070-2099 SPI for various emissions scenarios
- The computed SPI reflects the deficit status comparing to the 20th century level.

Drought category and probability

- D0 (20~30%), D1 (10~20%), D2 (5~10%), D3 (2~5%), and D4 (~2%)

Atmospheric Warming and Rainfall Intensification

- Clausius-Clapeyron relationship
- Rising temperature => Enhanced air moisture holding capacity => More precipitation
- Standardized global CCSM3 meteorological variables
- Temperature, specific humidity, precipitable water, precipitation
- All variables increase in a consistent manner
- More rainfall implies fewer droughts?

Figure 1 - Standardized CCSM3 outputs for temperature, specific humidity, precipitable water, and precipitation

Figure 2 - CCSM3 3-, 6-, 9-, and 12-month global drought frequency in decades 2070-2099. More D1-D4 droughts are projected.

- Global drought frequency in decades 2070-2099
  - While more wet events are simulated (as expected), more drought events (D1-D4) are projected as well.
  - More drought months for the A2 emission scenario, then A1B and others.
  - Intensification in both directions: wetter regions become much wetter, drier regions become much drier

Figure 3 - Global maps of projected CCSM3 drought (D0-D4) frequency using 3-month SPI. Intensification observed in both directions.

Multi-model Uncertainty and Inconsistency

- Comparison of nine climate models:
  - (1) CCSM3, (2) CCM3, (3) GISS Model E, (4) GISS Model E-R, (5) IAP_FGOALS1.0_g, (6) MIROC3.2MEDRES, (7) MRI_CGCM2_3_2a, (8) UKMO_HADCM3, and (9) UM3_HADGEM1
- Intersite variability is aggregated to a T68 grid (1.9 x 1.9 spatial resolution with a total of 18,048 grid cells)
- Monthly precipitation, A1B scenario, 2070-2099
- Inconsistent spatial patterns
- Large multi-model uncertainty
- Regions with more agreement among models
- Does model agreement mean credibility?

Figure 4 - Projections of 2070-2099 A1B drought (D0-D4) frequency from various climate models using 3-month SPI. Regions that are wetter than they were during the 20th century have been masked out.

Challenges in Planning and Decision Making

- Is this feasible with the current climate models?
- Cascading uncertainty from temperature to precipitation and evaporation, and their difference
- Multi-model differences remain the major sources of uncertainty
- Potential impacts on population must be considered

Figure 5 - Maximum, mean, and minimum projected multi-model drought frequency under A1B emissions scenario. Regions that are wetter in the 21st century have been masked out.

Figure 6 - Agreement among the 9-model drought projections. The number of models projecting more droughts (D0, D2, D4) in 2070-2099 is illustrated.

Figure 7 - Climate change of available A1B A/P (43) from 1990s to 2030s. Upper left: A1B scenario, upper right: Landscan population, lower left: GISS Model E-H projection, lower right: Miroc3.2 (medres) projection

References


Higher drought (20-30%), Mid-drought (10-20%), Low-drought (5-10%), Very low-drought (2-5%), and Lowest-drought (~2%)