Aridification of the United States Northern Great Plains during the 21st Century

Imtiaz Rangwala[1,2,3]

[1]Cooperative Institute for Research in Environmental Science, University of Colorado Boulder; [2]North Central Climate Adaptation Science Center
[3]Western Water Assessment; Imtiaz.Rangwala@colorado.edu

Motivation

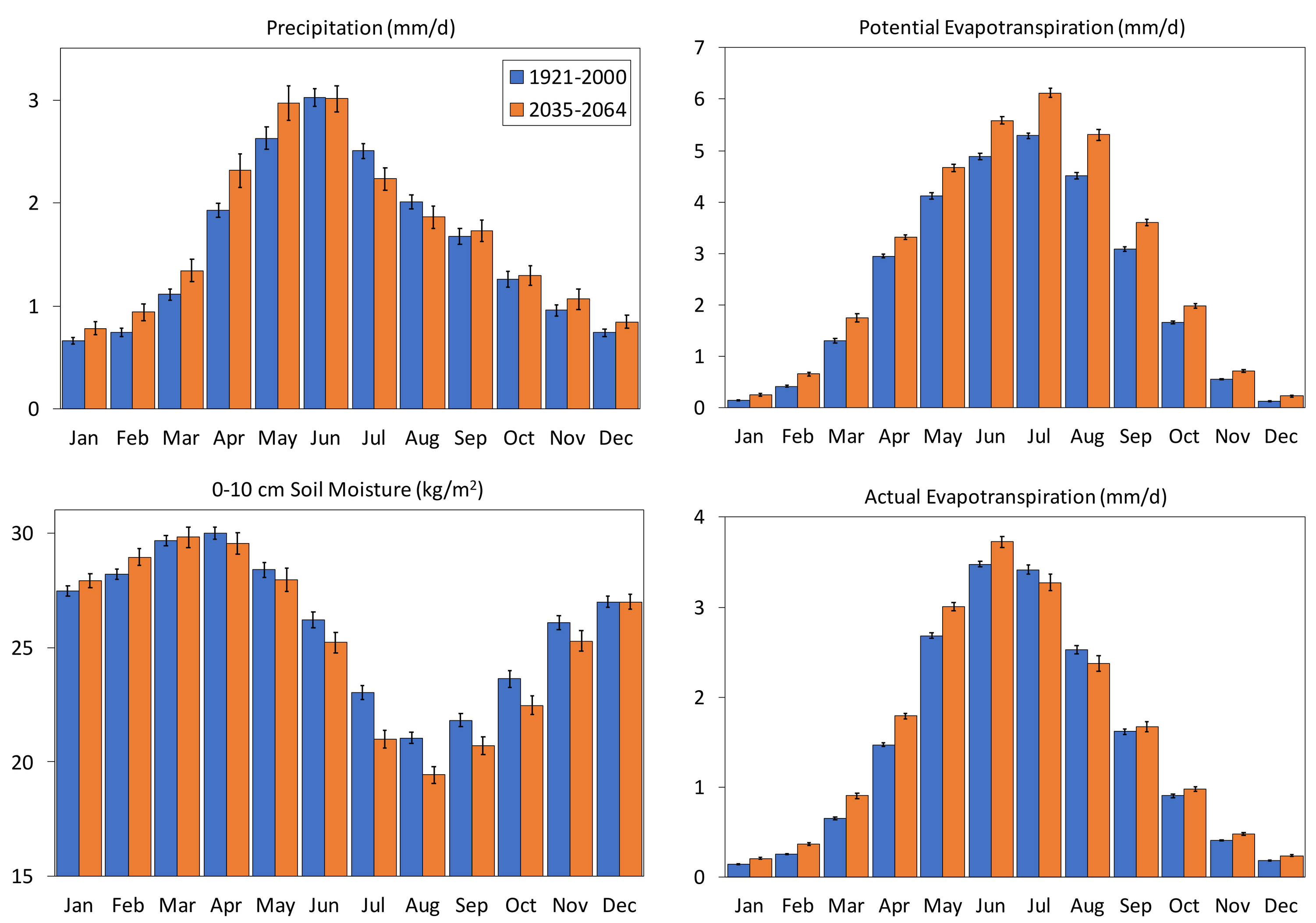
To examine potential changes in surface water balance in the US Northern Great Plains (NGP) by mid-21st century based on a large ensemble of Global Climate Model projections

Questions

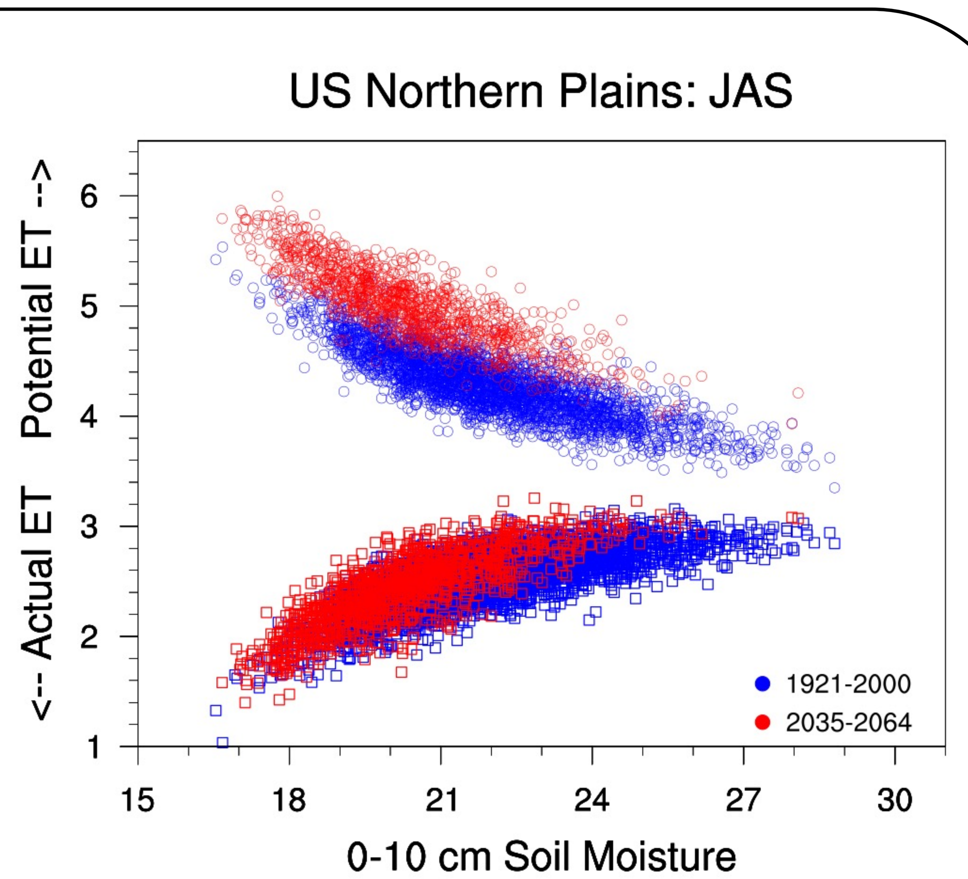
- ❖ How are different climate and hydrological variables changing on monthly timescales by 2050 (2035-2064) relative to 20th century (1921-2000)?
- ❖ How do patterns of water availability in shallower (0-10 cm) and deeper (0-1 m) layers of soils change across the year?
- ❖ How do relationships between precipitation, atmospheric evaporative demand, evapotranspiration and soil moisture explain the changing nature of water availability?
- ❖ How does the frequency of 20th century extreme drought conditions change by 2050?

Monthly changes by 2050 relative 1921-2000

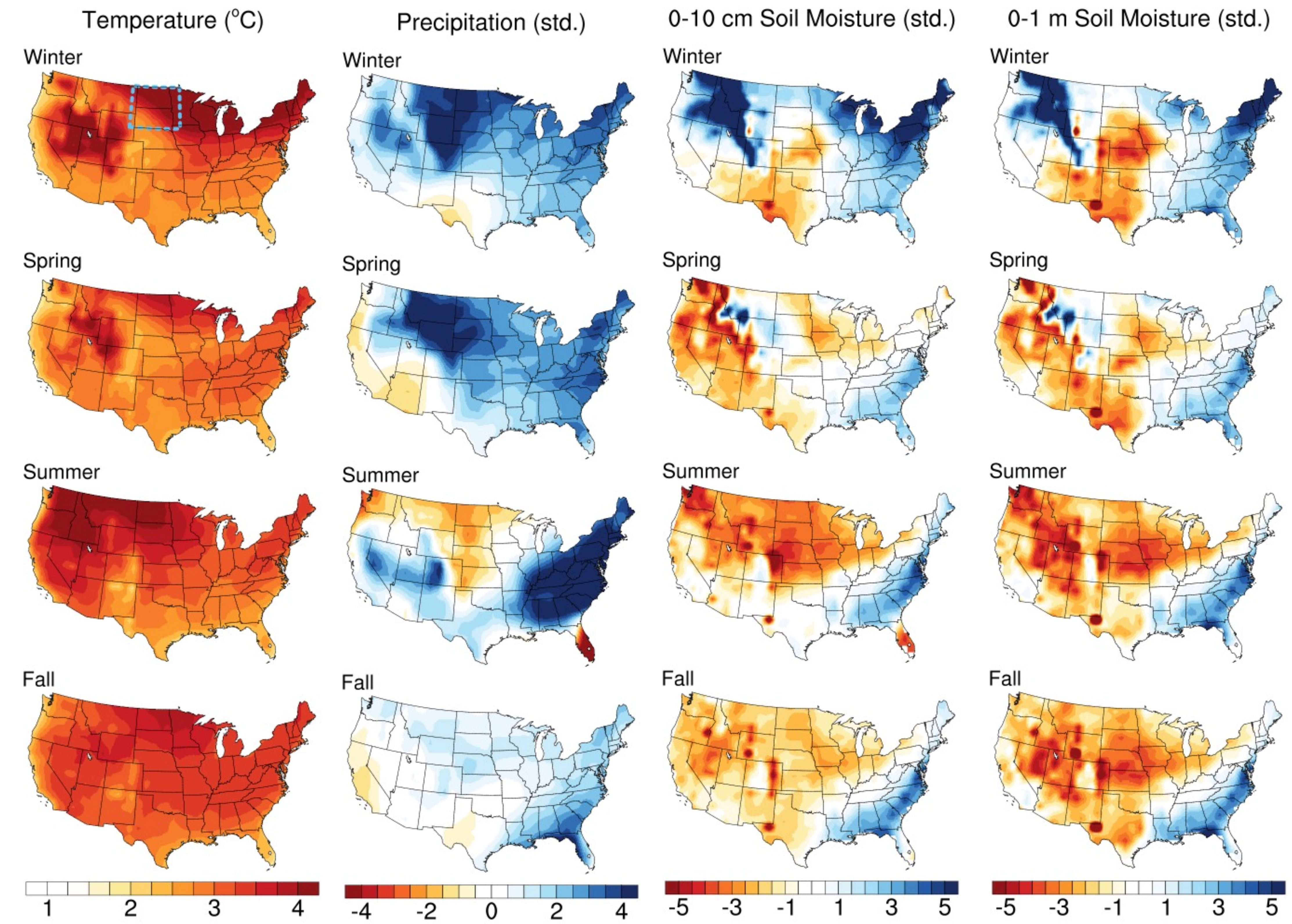
- ❖ Increases in precipitation in the earlier half of the cold season, particularly Oct through Jan, when evaporative losses are not very high, ensures that there is a net increase in soil moisture (SM) by Jan which continues to increase into Feb.
- ❖ By Mar, there is only a modest increase in SM even though there is a large increase in precipitation that month. This is because there is a large increase in AET. For Apr and May, SM decreases despite large increases in precipitation again b/c of a proportionally greater increases in AET.
- ❖ By Jun, the deficit in SM starts to increase further owing to both a slight decrease in precipitation but also the elevated AET fluxes, and a steadily increasing deficit in SM through Apr and May.
- ❖ By Jul and Aug, the deficits in SM increase further, and the soil moisture level reaches its lowest value by August. These large deficits in the sunniest and warmest part of the year are driven by decreases in precipitation and substantially elevated evaporative demand (PET); the latter tends to further drive evaporative losses from the already water-depleted soils at the end of Jun.
- ❖ By fall (Sep through Nov) the region experiences increases in precipitation however they are not sufficient to increase SM to historical levels, as the severe SM deficits from summer as well as elevated PET and AET in fall ensures that there are substantial deficits in SM throughout the fall. It is only by Dec, when the evaporative stress is about its lowest that the excesses in precipitation facilitate the SM to attain historical levels.



- ❖ Relationship between top 10 cm soil moisture (kg/m²), and the PET (mm/d, circles) and AET (mm/d, squares) fluxes for the NGP region for July-September. Each data point represents mean condition (July-September) of an individual year for the historical and future periods from each member of CESM1 LENS.
- ❖ There is a significant depletion in soil moisture conditions by 2050. Only about 40% of time by 2050 are the soil moisture levels above the historical median value, and there is a 350% increase in situations when the soil moisture levels are below the historical 5th percentile value, which the US Drought Monitor classifies as "Extreme" droughts.
- ❖ Figure on the right demonstrates the complementary relationship between PET and AET, i.e. decreases in AET corresponds to increases in PET as soil moisture decreases below a certain critical threshold. There is little overlap between the future and historical values of PET, implying significant increases in evaporative and heat stress on the system. However, this is not necessarily true for AET. Although future increases in PET tend to drive some increases in AET, the limits from depleted soil moisture conditions and increases in water use efficiency of plants because of elevated atmospheric CO_2 concentrations constrain substantial shifts in AET at low soil moisture values.



Seasonal changes by 2050 relative 1921-2000



For NGP: Temperature increases by 2.5°C to > 4°C with strongest warming in summer and winter. Large increases in precipitation in Winter and Spring, considerable decreases in summer and relatively smaller increases in Fall. Despite increases in annual precipitation, soil moisture decreases in all seasons except during winter when there are increases in 0-10cm soil moisture. Largest decreases in both 0-10cm and 0-1m soil moisture occur in summer followed by fall. There is a more sustained reduction in 0-1m soil moisture across the seasons as compared to 0-10cm soil moisture. These results point to significant aridification of the central and northern great plains region in summer and fall. Precipitation and soil moisture are plotted as standardized departures from 1921-2000 mean conditions.

Methods

- ❖ Model: Community Earth System Model version 1 Large Ensemble (CESM1 LENS) (N=40)
- ❖ Monthly data for temperature, precipitation, actual evapotranspiration, 0-1 cm and 0-1 m soil moisture for each of the 40 member of CESM1 LENS (RCP 8.5 only) were obtained from NOAA's Facility for Climate Assessments*
- ❖ Seasons: Winter (DJF), Spring (MAM), Summer (JJA), Spring (SON)
- ❖ Monthly PET calculations are done using monthly meteorological input from the 40 members of the CESM1 LENS between 1920-2100 using a Penman-Monteith based potential evaporation formulation
- ❖ Northern Great Plains (NGP) region: 43°N-49°N latitude and 95°W-105°W longitude as also marked in the temperature (winter) figure above
- ❖ CESM1 LENS represents the observed historical climate of Northern Great Plains. See comparisons of monthly temperatures and precipitation climatology between CESM1 LENS ensemble mean and GRIDMET (observed gridded data) for the 1981-2010 period

*https://www.esrl.noaa.gov/psd/repository/facts/

Northern Great Plains Model vs. Observed