ATTRIBUTION OF NATURAL VARIABILITY TO CLIMATES OF THE COASTAL WESTERN UNITED STATES

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Natural climate variations are a result of both radiative forcing (seasonal insolation and orbital changes) and internal interactions between components of the atmosphere, the oceans, and land surfaces. In a system composed of many gears with very different response times and non-linear interactions, the components are never quite in equilibrium, and are constantly changing over different timescales.

When insolation changes occur, the response time within the climate system is highly variable. The troposphere responds relatively quickly, from days to weeks. The stratosphere is balanced over a span of months. Oceans, with their large heat capacity, take much longer to respond, distributing heat over decades to centuries. The Earth's surface interacts with the troposphere but is slowed by the oceans' response time, so this component of the climate system can vary from months to decades. The biosphere and the human domain respond both quickly, as in the case of droughts and seasonal fluctuations, and slowly, as with human-induced changes. Climates also vary due to internal changes within the system through relationships between oceanic and atmospheric behavior, independent of direct solar influence (IPCC, WG1, 2014).

Interactions between the ocean and the atmosphere have important implications for meteorology and climatology around the world. Large-scale phases of climate variability can disrupt local climate processes and shift weather patterns that are generally associated with seasonality. While it is difficult to tease-apart the work of climate change from naturally variable processes and natural variability from solar-induced processes, the Pacific United States has revealed a robust response to natural variations, both seasonal and long-term, that is allowing for improved attribution to particular modes of variability by climate scientists.

Observed climate variability in the Pacific U.S. has been attributed to key modes, or fluctuations, in seasonality (external) and intraseasonal, interannual, and multidecadal activity (internal). Seasonality is external variability caused by meridional insolation changes throughout the year due to the planet's tilt on its axis and its orbit around the Sun, and includes associated shifts in the Intertropical Convergence Zone (ITCZ), meridional position of the subtropical and polar jet streams, and position of semi-permanent high and low pressure cells among which the jet streams flow, among others. Intraseasonal variability refers to internal, ocean-atmosphere coupled activity taking place between 30-60 days, and is attributed to the equator-tracing Madden-Julian oscillation, the MJO (Climate Prediction Center, 2016). Interannual variability is dominated by ENSO-related activity and its interaction with the other internal modes of variability (Ghil, 2002). Multidecadal variability is attributed to low-frequency ocean-atmosphere coupled behavior that modulates on a cycle greater than 10 years (JPL, 2016).

While the solar-seasonal influence initiates the mechanisms that provide a foundation for the region's climate, the internal modes of variability can induce wet and dry periods or cooling and warming phases that alter the usual patterns of temperatures on land, sea-surface temperatures, precipitation, atmospheric pressure, and wind. The integration of these external and internal movements at any juncture is thus very complex; their blended influence on a region's climate is a result of each's particular phase or condition and the temporal and spatial interrelationships between their states (Wang, 2009).

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SEASONAL VARIABILITY

Seasonal variability in the Pacific U.S. is a result of seasonal changes in solar angle, shifts in the semi-permanent high- and low- pressure systems in the North Pacific Ocean, and the subsequent migration of the Northern Hemisphere subtropical and polar jet streams.

From spring through summer in the Northern Hemisphere (late March to late September) the ITCZ migrates more northward, and with it the poleward reach of Hadley-cell circulation migrates. At the extent of this cell, on average around 30°N and 30°S, dense, cold air sinks downward to the Earth's surface, warming and drying in the process. This subsiding air creates a belt of high-pressure zones around the subtropics. Such a zone produces clear, sunny skies while blocking the potential inflow of storm tracks, cold fronts, and moisture-laden air, for better or worse. Certainly the planet's great deserts and arid regions are located within the subtropical high pressure belt. One of these high-pressure zones, the North Pacific High, persists throughout the year, shifting slightly in location and size between the warm and cold seasons. Its location in the North Pacific Ocean between Hawaii and California is maintained by continually subsiding air from meridional Hadley convection, stabilizing surface waters that are relatively cooler than the warm mainland, and the mountains of the Western U.S., the Sierras and the Rockies, which inhibit the eastward flow of sinking air.

The other semi-permanent barometric phenomenon pertinent to Pacific U.S. climate variability is the Aleutian Low, which forms in the North Pacific around the Aleutian Islands. This low-pressure zone forms from sea surface temperatures (SSTs) that are comparatively warmer than winter land temperatures. Its lifting, cyclonic flow draws moist Pacific air toward the mainland while collecting moisture and generating instability in the region. Storms and migratory low pressure systems often reach maximum intensity in this area during the cold season, from late fall to late spring, when the Low is most active. In summer, as surrounding land warms up, the temperature gradient decreases, and the Aleutian Low weakens, retreating towards the polar region. During this time, the North Pacific High replaces it, and dominates.

The dipole pattern seesaws together northward and southward with the Sun, the High reaching its northernmost extent and maximum size at the end of the Northern Hemisphere summer, and the Low reaching its maximum effect by the end of the winter. The displacement of the Aleutian Low by the North Pacific High during the warm season is responsible for the deflection of moist conditions to the north or south, and in this way brings warm and dry conditions to the Pacific U.S. Conversely, the displacement of the North Pacific High by the strengthening Aleutian Low in the winter steers moist and unstable conditions to the northern mainland where cold, dry Polar air masses meet warm, wet Gulf of Mexico air, producing precipitation and inclement weather events for the rest of the United States (Dettinger, 1998).

The jet streams are strong currents of upper-level atmospheric wind that blow from west to east around the Earth. Beneath the tropopause, around 30°N and S, the Subtropical Jet is formed where Hadley and Ferrel cells converge aloft, and their relatively different air temperatures drive a strong pressure gradient from south to north in the Northern Hemisphere. The Coriolis Effect balances the pressure gradient force towards the right, and the current is steered along the gradient geostrophically from west to east (Wind-Global Systems, 2016). The generally stronger Polar Jet is formed in the same way further poleward where the Ferrel and Polar cells meet around 60°N and S. The jets follow the boundaries between warm and cold air, dipping into troughs around colder air masses and pushing into ridges around warmer air masses. Jets may stop, restart, split into two or more channels, recombine, and even flow retrogressively depending on the pressure systems they encounter and the conditions manipulating them. Therefore it is prudent to regard them as ever-meandering ribbons of fast-moving air conveying atmospheric conditions across the globe as they transport heat poleward and cold air equatorward (“Jet Streams”, NOAA, 2016).

During winter, when encountering the Aleutian Low, the Polar Jet will typically veer south of it, passing between the Aleutian Low and the North Pacific High, waving northward around the Rocky Mountains, then moving somewhat southward into the Central U.S. During the winter, the North Pacific High is drawn further south which gives the counterclockwise-spinning low pressure zone the ability to drive storms and moisture to the Pacific coast (“Mean Wintertime Jet Streams”, 2016). Both the Pacific Northwest and Southwest receive the majority of their rainfall and snow in the cold months between October and February when the Aleutian Low is sizeable and the North Pacific High has this weakened effect (NOAA, 2016). During the warm months, the Low fades, and the High moves north and increases in size. This inhibits the southward troughing of the Polar Jet and the northward migration of the Subtropical Jet, and warm clear skies dominate over the region. The interplay of the jet streams and the two semi-permanent pressure areas not only defines the majority of the Pacific West Coast’s temperature and precipitation regime, it also determines the ingredients for weather development over the rest of the contiguous United States (Climate of the US, 2016).

INTRASEASONAL VARIABILITY

While responsible for only an intraseasonal fluctuation in the Pacific West Coast’s total annual precipitation, a planetary-scale tropical disturbance can have a routinely dramatic effect on the amount of precipitation that falls in other parts of the globe. The Madden-Julian Oscillation (MJO) (Madden and Julian, 1972) involves planetary-scale atmospheric circulations and their interaction with mesoscale convective activities.

The MJO is a persistent, eastward-moving, dipole vertical circulation cell in the tropics characterized by anomalous convection and rainfall on its west side and subsidence and suppressed rainfall ahead of it to the east. Studies place the ocean-atmosphere coupled phenomenon’s origin in the Indian Ocean where very warm SSTs contribute to the convection and uplift that initiates it. Rising air in the upper Troposhere diverges and flows eastward toward upper-level convergence and subsidence. The pressure gradient completes the circulation cell by returning sinking air at the surface back into the area of convergence. This produces an atmospheric Kelvin wave that carries momentum eastward around the Earth like the belted, continuous-track propulsion of an army tank. The MJO moves along the tropical rainbelt over the oceans where it picks up and releases added moisture. When it moves over the cooler East Pacific and South America, the convection dissipates, but the upper-level Kelvin wave endures. Once over the Atlantic Ocean, convection and rainfall return. Convection decreases again over the East Atlantic and Africa, but increases again as the cell returns to its theorized point of origin in the Indian Ocean. A full circumequatorial trip takes about 30 to 60 days, carrying with it a track of intense rainfall and wind throughout the year, season to season. As described below, the MJO can enhance the effects of El Niño and La Niña globally.

While the MJO tracks the tropics, its influence can be felt several times during the year when it contributes to mesoscale circulation patterns and various extreme events in the United States. When heavy rainfall and upper-level moisture associated with the MJO shifts from the Indian Ocean into the West Pacific, a large synoptic-scale plume of moisture extends into the central North Pacific. The high-pressure anticyclone in the North Pacific typically steers the Polar jet around it to the north, blocking weather conditions from entering the window of the Pacific coast, but the warm-air moisture plume, weakens the high-pressure zone aloft and moves it to the west. The westerly upper tropospheric flow increases with this added warm plume, causing a split in the Polar jet to the south which effectively sends moist air directly to the Pacific coast from the tropics. Such an atmospheric river has been termed the “pineapple express” because of its northeastward flow over the Hawaiian Islands to the West Coast of the mainland.

The MJO has been attributed to massive flood events that occurred in California, Oregon, and Nevada in 1862 during which heavy rain pounded the West Coast for 45 days, and in 1952 when Northern California received record-setting precipitation and snowfall that caused disastrous flooding around the San Francisco Bay. More recently, in 1997, 2005, 2010, and 2014, Southern California received the brunt of the MJO's influence with anomalous winter rain that resulted in catastrophic mudslides and damages. In 1997 and 2006, the Pacific NW was the inheritor of extended excessive rain that flooded all major rivers and reservoirs, resulting in similar mudslides and damage. While the Madden-Julian Oscillation is well-examined, the timing and extent of its influence on different parts of the globe are less predictable; potential effects on the Pacific United States are usually recognizable 7-10 days out.

INTERANNUAL VARIABILITY

El Niño and La Niña events, with the neutral phase in the continuum, are the ocean components of the El Niño/Southern Oscillation (ENSO), Events typically recur every 2 to 7 years (some estimates say 3-5 years) and develop slowly between April and June over the tropical Pacific Ocean. El Niño is an anomalous warming of the ocean surface and SSTs in the central and eastern tropical Pacific Ocean. The easterly trade winds, which normally blow from east to west along the equator, weaken or blow in the other direction. Convection accompanies these higher SSTs in the Central and East Pacific, driving warm ocean Kelvin waves eastward 100-200 meters below sea level. Sea-level pressure (the atmospheric Southern Oscillation component) and levels of outgoing longwave radiation change accordingly, and the thermocline in the tropical Pacific, typically very steep from warm piled-up water in the Western Pacific and strong cold upwelling in the Eastern Pacific, levels-off. Rainfall decreases over Indonesia and increases over the tropical Pacific Ocean. Alternately, La Niña is the anomalous *cooling* of SSTs in the central and eastern Pacific associated with increased warming and extending westward convection in the Western Pacific and over Indonesia and Northern Australia. Often, but not always, negative-phase La Niña conditions directly follow El Niño events interannually. Each of these events tend to reach maximum conditions in the boreal winter, December through February, and can persist for 9 to 12 months, sometimes lasting up to 2 years.

Specific criteria define extra-neutral conditions over the tropical Pacific officially as El Niño (positive phase) or La Niña (negative phase) phenomena. To reach El Niño (La Niña) status, average sea surface temperatures in the Niño3.4 region must be +0.5°C (-0.5°C) or higher (lower) than average in the preceding month. Such an anomaly must have persisted for 5 consecutive, overlapping 3-month periods (DJF, JFM, etc.), a total of 7 months. The atmosphere over the tropical Pacific must also exhibit at least one of the following conditions: weaker (stronger) than usual easterly trade winds; or reduced (increased) cloudiness and rainfall over Indonesia, and a corresponding increase (drop) in the average surface pressure; or increased cloudiness and rainfall in the central or eastern part of the Pacific basin, and a corresponding drop (increase) in the average surface pressure.

Conditions in the Pacific Basin may suggest the emergence of full positive or negative phase several months out. For an El Niño, such conditions would include 7 months of warming and weakening or reversal of winds in the Niño 3.4 region, cooling and less cloud cover in the western Pacific, and warming and more cloud cover in the eastern Pacific will be present. A La Niña event would be signified by 7 months of cooling and stronger easterly winds in the Niño 3.4 region, cooling and less cloud cover in the eastern Pacific, and increased warming and cloud cover in the western Pacific.

Many studies have emphasized the relationship between West Coast precipitation and ENSO events (Ropelewski and Halpert, 1996; Schonher and Nicholson, 1989; Cayan and Peterson, 1989; Cayan and Webb, 1992; Redmond and Cayan, 1994). A common finding in ENSO/Western U.S. literature is that during El Niño there is a higher probability for above-normal precipitation in the Southwest and below-normal precipitation in the Northwest, and that during La Niña the reverse is more likely (Cayan and Redmond, 1994; Kahya and Dracup, 1994; Schonher and Nicholson, 1989; Mo and Higgins, 1998).

The changes taking place in the tropics during an El Niño episode affect the Pacific West Coast (and virtually all of the United States) in very much the same way that the seasonal and intraseasonal shifts occur, by manipulating the high and low pressure systems over the North Pacific. As described before, the Aleutian Low pressure zone and the North Pacific High pressure zone characterize normal conditions in the region. When trade winds weaken and the Eastern Pacific warms, the Aleutian Low tends to expand southward and the high pressure zone weakens. With the High out of the picture, the Subtropical Jet strengthens and channels moist, unstable conditions, the “storm track”, directly into central North America. The Polar Jet, meanwhile, is shifted far to the north which prevents Alaskan and Northern Canadian winter storm systems from troughing down into the Pacific NW, Rockies, and Midwest, enabling relatively mild and dry winters across the northern half of the country.

The California Current typically brings a strong flow of cold water southward along the coast promoting Eckman transport and generating cold coastal upwelling. During El Nino episodes, however, warmer waters flow northward along the North American coast, warming and slowing the current. This promotes the strengthening of the warm Davidson Countercurrent opposite the California Current that promotes downwelling along the West Coast. This inflow of warm water further contributes to local if not regional convection, evaporation, and instability.

The most reliable ENSO-correlated precipitation signal occurs along the coasts of the Gulf of Mexico; related rainfall increases have occurred 80% of the time on record. In the Western U.S., the correlation between ENSO and above-normal precipitation is much weaker, thus the expected influence on Pacific NW and SW precipitation regimes is strongly dependent on the strength of the ENSO event. *Weak* El Niños have a peak Oceanic Niño Index (ONI) greater than or equal to 0.5°C and less than or equal to 0.9°C. *Moderate* El Niños have a peak ONI greater than or equal to 1.0°C and less than or equal to 1.4°C. *Strong* El Niños have a peak ONI equal to or greater than 1.5°C. La Niñas are measured in the same way but with negative, or decreasing, SST anomalies. Certainly it has been the strong-to-very-strong El Niños that have brought catastrophic flooding to California. Similarly, stronger La Niñas have meant greater increases in rainfall in the NW and more persistent drought in Southern California.

During El Niño events, the added influence of the MJO on the East Pacific can compound the effects of El Niño on the West Coast. The MJO increases the amount of moisture and heat content in the air and increases the warm water pile up at the sea surface within its path. This can enhance the SST and convective conditions that migrate northward along the tropical North American coastline, and further magnify the conditions that bring anomalous rainfall to the region. However, research shows that during neutral stages of ENSO or before the onset an El Niño or La Niña period, when convection is strongest in the *West* Pacific, the MJO influence is greatest and can impact the West Coast most intensely (Rasmusson and Carpenter, 1982; Kousky and Kayano, 1994; NOAA, 1997). This does not mean that ENSO has less of an effect than the MJO, but that ENSO-related conditions happen to be riper for West Coast precipitation extremes during winters exhibiting this behavior (Mo and Higgins, 1998).

MULTIDECADAL VARIABILITY

When precipitation variations in the Western U.S. are decomposed by timescales, the external forcing, low-frequency variability, and high-frequency variability is extracted from the climate record for individual analysis. The International Research Institute for Climate and Society (IRI) Data Library Maproom isolates external forcing (including anthropogenic inputs, solar and orbital fluctuations, and volcanic activity) from the regional precipitation record, and attributes the residual natural, unforced variability to interannual-scale (high-frequency variation) or decadal-scale (low-frequency variation) fluctuations. We have previously examined the drivers of high-frequency variability (intraseasonal and interannual contributors), and now examine influence on the decadal-scale.

The low-frequency class is attributed to large synoptic-scale modes such as the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO), and lesser stochastic occurrences. Principal component and tree-ring analyses show that the Pacific Decadal Oscillation exhibits and has exhibited the most robust low-frequency correlation with Western U.S. rainfall (Fierro, 2014; Biondi, et al., 2001).

The Pacific Decadal Oscillation is often perceived as a longer-term ENSO-type phenomenon, and though both are measured in terms of SST anomalies and dipolar modal states (warm and cold), research has suggested that there are three major differences between the PDO and ENSO (Mantua and Hare, 2001). PDO phases exist on a timescale of 20-30 years (sometimes more), while ENSO events last from 6 to 18 months. The effects of PDO are greatest in the North Pacific extratropics and to a lesser extent in the tropics, while ENSO effects are greatest in the tropics and to a lesser extent in the extratropics. A final difference is that PDO dynamics are not as well understood as ENSO dynamics. The PDO is not a singular, seesaw oscillation like ENSO. Instead, it is an amalgamation of different atmospheric activities and their collective effect on the ocean.

The PDO and its sea surface temperature changes in the North Pacific are a response to aggregate changes in the atmosphere. It is difficult to attribute specific activity to the aggregate whole, but primary participants have been teased out in the literature (Alexander and Deser, 1995; Mantua, et al., 1997; Newman, et al., 2016; Kumar, et al., 2013). The most prominent of these changes may be the Aleutian Low, the Kuroshio Current, and the phenomenon of “reemergence”, but certainly ENSO is a large part of the aggregate and the interannual dynamics of these other prominent components.

As previously mentioned, the Aleutian Low spins counterclockwise. Accordingly, a stronger-than-average Low will blow stronger winds. Strong southerly winds on the eastern side of the Low strengthen the countercurrent along the West Coast, decrease upwelling, and warm the coastal waters. On the western side of the Low, the cold northerly wind and turbulent, unstable conditions stir the ocean, bringing cold water to the surface. This contributes to negative sea surface temperature anomalies in the central Pacific and warmer coastal SSTs in the Eastern Pacific (Kumar, et al., 2013). When annual winter conditions weaken or phase-out the Aleutian Low, a high-pressure area may form during which the opposite occurs; the cyclonic flow of air is reversed. Southerly wind brings warmer waters to the central Pacific, and anticyclonic flow allows the California Current to flow unimpeded to the south and generate upwelling along the coast.

We see how changes applied to ocean currents can alter climate, but currents can also force variations. It so happens that changes in the strength and location of the Kuroshio Current in the western North Pacific also occur on decadal scales (Newman, et al., 2016). Like the Gulf Stream in the Atlantic, any variability in the current’s flow, can alter sea surface temperatures in the western Pacific. Such influence can contribute to the phase change in the PDO.

Reemergence is a mechanism in which one year’s winter temperature anomalies in the deeper mixed layer persist at depth through summer, and are then re-entrained into the mixed layer in the following winter (Alexander and Deser, 1995). It is believed that this lag, or memory, of the oceans is responsible for the winter-to-winter persistence of the PDO (Cassou, et al., 2007).

The warm/positive phase of the PDO is characterized by warmer than average sea-surface temperatures all along the west coast of North America and a large zone of colder than average SSTs in the western to central North Pacific. The cool/negative phase is opposite, with a large zone of warmer than average SSTs in the western to central North Pacific and colder than average SSTs along the West Coast. In the Pacific U.S., a positive phase can impact regional weather and precipitation patterns and extremes through the direct influence of warmer ocean waters. A negative phase, however, promotes colder ocean waters, more upwelling and a southward flow of air, contributing to pervasively dry conditions in the Western U.S., particularly California and the Southwest.

Studies show that a negative phase of the PDO is beginning, or has in fact begun, while some experts believe it is too early to tell. Certainly a phase change is past due. The last phase change, to positive, occurred around 1977,so the PDO is an area of active research focused on observing and deciphering the phenomenon and its cumulative effects on regional climate and mesoscale circulation.

ADAPTATION TO VARIABILITY FOR WATER RESOURCES

In the Pacific Northwest, because any fluctuations in precipitation have been remediated over time, there is no trend of decrease in rainfall. The one major water resource factor being affected by climate change is snow. Snowpack has been nature's storage facility for centuries. Global warming is bringing earlier spring and with it earlier melting of the snowpack. Not only is the snowpack melting more rapidly, but less precipitation is falling as snow. Instead, rainfall contributes to the snowmelt.

The impact of this melting on water resources involves the dams that dot the countryside in the Pacific NW (there are more than 60 dams on the Columbia River watershed alone). Water managers at dams in the Northwest cannot contend with the early surplus of water; levels are too high to store it. The inflows that they need later in the summer when the demand is highest are being supplied earlier in the year, so they have to release it. This puts drought-like strain on management of water needs in the region.

Grand Coulee Dam in Washington is unique. It is the only hydropower dam in the region with hydroelectric pumped storage (PS). Since it was installed in the early 1970's, the PS plant has done what other states are only beginning to accomplish: it stores surpluses of water that would otherwise be released to sea for hydroelectricity production during peak demand.

Gravity is nature's battery. It stores kinetic energy as potential energy until it is needed. Pumped storage works the same way. By creating a reservoir upstream from existing reservoirs, the plant can pump water upward in times of plenty and release it in times of need, powering the grid at the same time. Pumped storage utilizes early snowmelt from earlier warming, decreases fossil fuel use (typically a positive feedback on the problem of earlier snowmelt), and virtually eliminates the need for peak demand storage and associated high costs. It reduces issues of power interruption, quality, and generation supply adequacy, ensures that fluctuations in snowpack and precipitation will not affect reliability of electricity, attempts to store surplus water, and covers demand increases and current peak demand minimizing total costs of energy.

Decreasing our dependency on fossil fuels is paramount to addressing the uncertainty of climate change and the vulnerability of water resources. As state energy portfolios must address ambitious new requirements for increasing renewable sources and phasing-out non-renewables, hydroelectric pumped storage is an ideal adaptive strategy.

In California, closing the gap on imported water from the Colorado River has also required implementation of statewide water conservation policies and programs. Identifying the fact that half of all urban water is used outdoors, rebates have been offered by water agencies for home and business owners to transplant lawns with xeriscaping. The Sustainable Landscape Rebate reimburses $3.50 for every square-foot of lawn removed and replaced with climate-appropriate plants and City specified drip irrigation. Free water use consultations are available for residents and businesses of Los Angeles and San Diego that are trying to save water. During consultation a water conservation expert will check for leaks and provide specific recommendations and resources for conservation. The City of Santa Monica has offered free high-efficiency, low-flow faucet aerators and showerheads to residents. More rebates are available for businesses and landlords to install high-efficiency, water saving toilets and laundry facilities. The cities of Santa Monica and San Francisco even offer rebates for purchase and installation of rain barrels and cisterns for rainwater harvesting. Santa Monica has invested millions of dollars in retrofitting commercial buildings, and single- and multi-family dwellings, and more stringent building codes have mandated the capture of the first quarter-inch of rainfall on new developments.

To conserve its own expenditures of water at landscaping spots and city parks, Los Angeles, for example, has converted conventional spray heads with more efficient rotary nozzles, it has stopped watering ornamental street medians, has removed non-essential turf in public areas and replaced it with mulch, and is installing “smart irrigation control systems” at large parks that require irrigation. Recycled water is used for pressure washing, and surface spraying in large commercial areas have been limited.

The result of these conservation policies and programs has been a sweeping reduction in total water use (in Los Angeles alone, from 16,000 AFY in 2014 to a projected 10,000 AFY, or down 25%). Each of Southern California’s major hubs has been pressed by governor mandate to make ambitious reductions. Becoming self-sufficient saves the cities large amounts of money, but the actual water savings it offers the entire state may be as great. In its sixth straight year of pressing drought conditions, California’s mandatory water cuts are cinching the belt on an already overexacerbated supply of Colorado Aqueduct and Northern California supplies, and cities like Los Angeles and Santa Monica stand to free-up over 100,000 AFY. Los Angeles’ next efforts are aimed at curbing its biggest water wasters, the wealthy home and land owners, who seem not to mind that mandates are in place and that their costs are high. They are also attempting to safely augment its groundwater supply.

Efforts now must be turned to improving conservation and efficiency in California’s agricultural sector which uses 80% of the state’s total water supply. Agribusiness defends their recalcitrance, claiming that over the past 50 years many conservation measures have been instituted. But new conservation must be aimed at more efficient irrigation technologies, better regulated irrigation scheduling, and even regulated deficit irrigation in which drought tolerant crops are forced to do without water for a time. Drip irrigation is slowly being instituted as well. Irrigation canals must all be lined. Farmers need to learn the limits of water-intensive crops and practices with better outreach, education, and state incentives. State mandates have not been made for agricultural water cuts, however. The agricultural sector powers California’s economic stronghold as the 7th biggest economy in the world. This has certainly earned some leeway for agribusiness and the small farmer.

Big choices will need to be made in California if the regional precipitation regime continues as it has. The forecast is much drier still, and business continues as usual. Only when people realize that water is the single most dominant factor sculpting the geography of Earth’s natural and human landscapes will our issues of sustainability begin to improve.

CONCLUSION

Climate variability is the mystery variable in the range of potential systematic responses to global warming and climate change. For this reason research in the field is crucial. While climate models are somewhat effective at projecting the effects of anthropogenic climate change, natural variability produces models of limited accuracy (NCAR, 2016).

In addition to natural climate variability, other factors contribute to uncertainty when evaluating potential climate change impacts. The impacts depend on how climate change interacts with other global and regional environmental changes, including changes in land use, management of natural resources, and environmental pollution. For example, the ocean is affected by human activities such as fishing, habitat destruction, pollution, and invasive species introductions that may be masking more subtle impacts of climate change. In fact, researchers may have been at times misled to interpret climate change impacts as those of local environmental changes. Still, as heat fuels the delicate earth processes that shape our lives on the Earth, it will also fuel the indelicate extremes that are already becoming more commonplace in the Western United States.

Some areas in the West have experienced less rainfall over the past 50 years, and some have received more rainfall. There have been marked increases in the severity and length of dry spells and droughts, especially in the Southwest, but rains have continued to return, albeit with greater severity and uncertainty (USGCRP, 2014). In the Southwestern U.S., even moderately less precipitation or extended dry seasons can have a huge impact on water resources. Less total annual rainfall, less snowpack in the mountains, and earlier snowmelt mean less water is available during the summer months when demand is highest. It is consistently more difficult for water managers to meet the varied demands of industry, cities, agriculture, and ecology throughout the course of the year. While warming temperatures, not precipitation patterns, are revealing significant changes, water supplies in the West will be most tested by reduced snowfall and snowpack, early spring rainfall and snowmelt, and drier dry seasons.

The blended nuances of natural climate variability discussed herein combined with human-induced warming and climate change are expected to create deviations from the climatic events we've grown accustomed to for the past century; extreme events will become the norm. Precipitation patterns can be expected to continue to shift, and one of the first regions to be affected is the Pacific West Coast, the American Southwest predominantly (NCAR, 2016). A storm is brewing. In the near future, climate changes may become most evident and visceral through the coupled effect of anthropogenic warming and these natural intraseasonal, seasonal, interannual, and multidecadal scale climate variations.

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