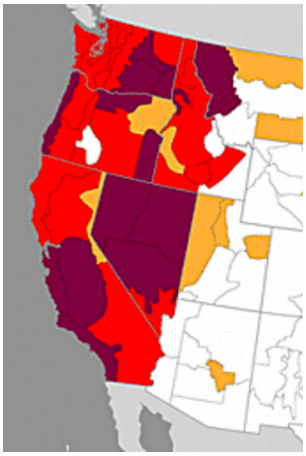
Aspen Global Change Institute Energy Project

December 2015 Quarterly Science Supplement

THE CALIFORNIA DROUGHT AND CLIMATE CHANGE



The drought California is currently experiencing may be the most severe in 1200 years based on paleoclimate reconstructions. It is certainly the state's worst drought of the historical record. How to attribute the effect of climate change on the drought is an active area of research; however, it is clear that the effect of high temperatures is a major factor in driving the unprecedented severity of this drought. This "Hot Drought" effect may become more common as the climate continues to be driven by excess greenhouse gases in the atmosphere. The figure to the left from NOAA shows the state of the drought in the Western U.S. as of September 2015. Dark brown indicates 'extreme' drought, red indicates 'severe' drought.

Key findings from a subset of recent research papers and State of California reports:

For 2015:

- Snowpack on April 1 was at five percent of the average since 1950
- Sierra Nevada winter minimum temperature averaged above freezing for the first time in 120 years
- Statewide 25 percent reduction in potable urban water use was mandated
- The state's 154 reservoirs are at 54 percent of their historic average (September 2015)
- The Department of Water Resources installed an emergency barrier to hold back salt water intrusion into the central Delta at West False River

For the drought overall 2012-2015 for Central and Southern California:

- Worst in the historical record
- Worst in last 1200 years based upon tree ring data
- Driest consecutive 3 years
- Reduced precipitation exacerbated by high temperatures
- Effects by region and sector have ranged from mild to very severe

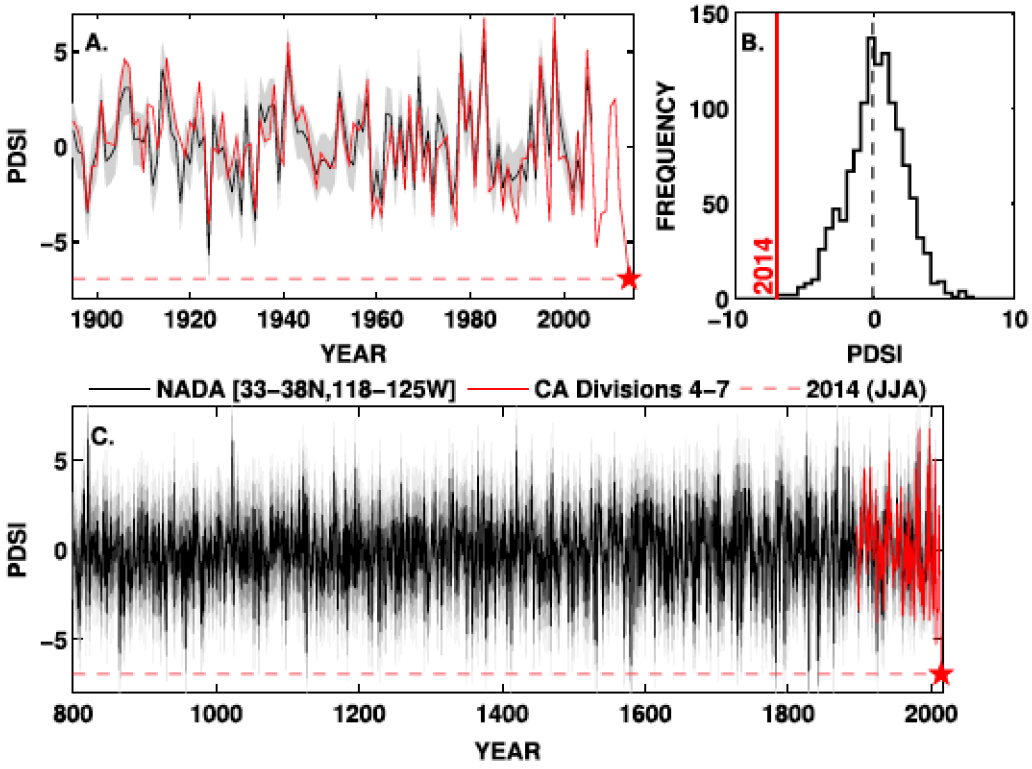
For the future:

- Climate models predict increased mean and extreme higher temperatures this century
- Higher temperature will drive enhanced evaporation
- Water resource supply and management further challenged to meet demand
- Future precipitation patterns and amounts are less certain

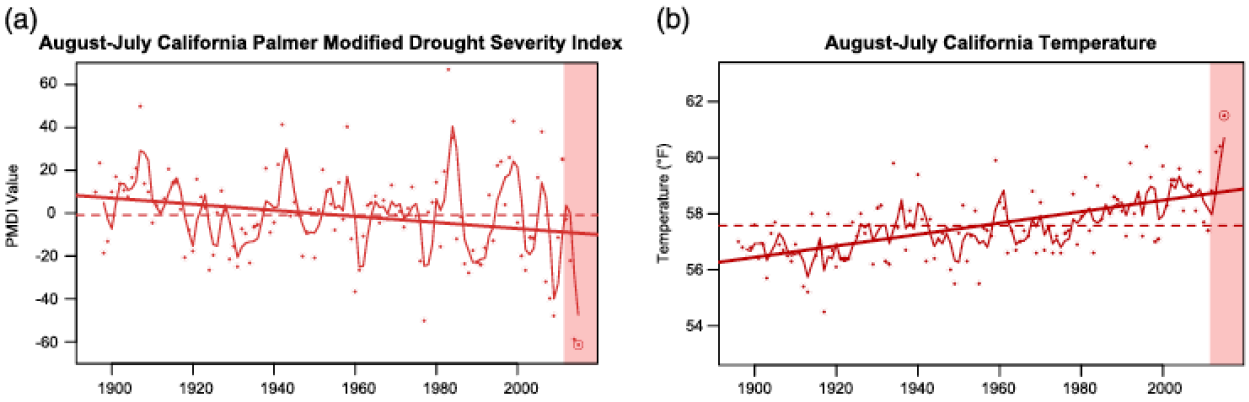
Drought severity is a complex of precipitation, temperature, and duration with major impacts on agriculture, fire risk, ecosystems and urban environments. The effects are not uniform within a region or among different sectors. The coastal population centers have been impacted less than farming regions where the drought has caused multibillion dollar losses and some farms have been forced to fallow their fields. Where water pumping has kept farms viable, significant drawdowns of major aquifers have occurred along with land subsidence.

The Palmer Drought Severity Index (PDSI) characterizes drought as the net effect of precipitation and temperature. Over the historical record, temperature and precipitation measurements can be used to calculate the PDSI. Negative values indicate increasing drought severity. Severe drought starts at values below -3, extreme drought for values below -4.

For the past, tree ring analysis provides a proxy set of data that can be used to build a PDSI record going back in time. The figure below from Griffin & Anchukaitis (2014) shows the PDSI for the historical record in (A), how extreme 2014 was in absolute terms (see the red star) and in terms of frequency of occurrence (B), and in (C), places the historical record in red along with the reconstruction in black going back to 800 AD.



In the following figure from a paper by Swain (2015), 2015 data is added, and uses a Palmer Modified Drought Severity Index to show the August-July index in (a) and the corresponding California annually averaged mean August-July temperatures for the historical record in (b). In both cases, yearly data is shown as dots, a 3–yr running average curve and a trend line are indicated. The pink band shows the period of the 2012-2015 drought (note the last dot in the time series in both (a) and (b) shows the value for 2015 in the context of the historical record.



The trend for precipitation not shown here is far less dramatic than for temperature; however, as these studies point out, the rise in temperature is playing a key role and, when combined with less than average precipitation, makes the probability of drought go up.

Climate models of California's future climate have greater certainty about temperature change than precipitation. Global factors influencing change in the Pacific Ocean, the location of the Jet Stream, storm track location, and the location and persistence of high-pressure areas off the coast are some of the contributing factors to the uncertainty.

The response to the mandated water conservation goal is encouraging in that so far it has been found that there are ways to exceed it. Going forward, more work will need to be done to ensure water availability in a changing climate, from innovative infrastructure design, whole systems approaches, and water use efficiency.

Diffenbaugh, N. S., Daniel L. Swain, and Danielle Touma (2015). "Anthropogenic warming has increased drought risk in California." PNAS.

Griffin, D. a. K. J. A. (2014). "How unusual is the 2012–2014 California drought?" Geophysical Research Letters **41**: 9017-9023.

Overpeck, J. T. (2013). "Climate science: The challenge of hot drought." Nature **503**(7476): 350-351.

Swain, D. L. (2015). "A tale of two California droughts: Lessons amidst record warmth and dryness in a region of complex physical and human geography." Geophysical Research Letters: 2015GL066628.

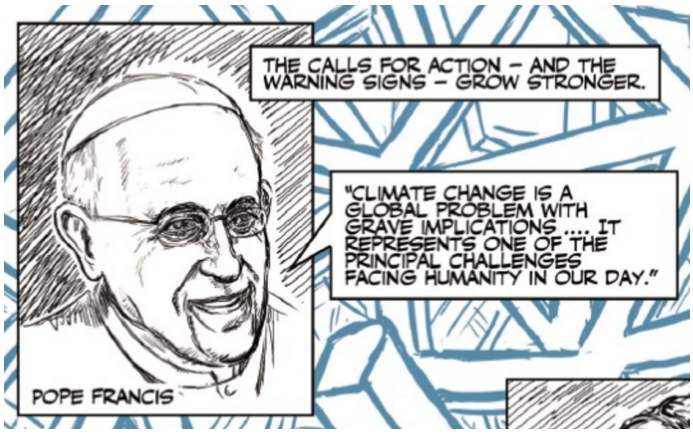
Thomas, T. and D. Carlson (2015). Water Year 2015 Ends as California's Warmest Ever; Many Hope for Drought-Busting El Niño in 2016, California Department of Water Resources.

THE CHANGE IN DISCOURSE BEFORE COP21 IN PARIS

A new tone in the discussion about climate change was introduced leading up to the COP21 summit of leaders in Paris. Amidst the usual arguments for and against international political action to combat climate change - including questions about jurisdiction, financial responsibility, social and environmental justice - a new tone came into play in October when Pope Francis released his encyclical. The Pope's landmark 200-page document has opened the dialogue on climate change by detailing the linkages with consumerist culture, capitalism, poverty, ecology, inequality, and morality.

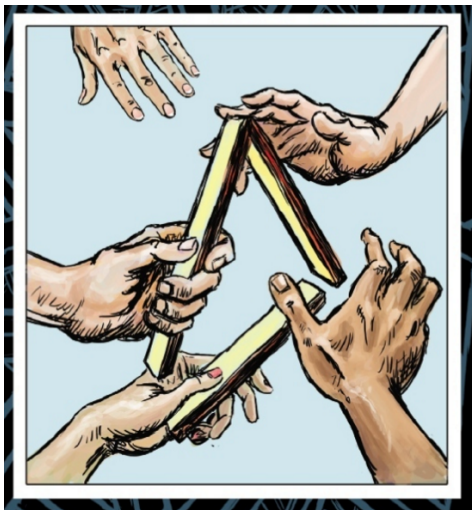
The Pope's perspective obviously has a unique gravity. Coupling that with a rare message challenging longstanding technocratic paradigms, and openly inviting underrepresented citizen engagement, has resulted in a subtle but highly significant shift in the discourse on climate change (Brulle and Antonio 2015, Carvalho 2015). The dialogue on climate change policy, which historically has been largely confined to socio-polticial elites and economists, now has the voice of a Pope dedicated to speaking on behalf of the world's poorest citizens (Brulle and Antonio 2015, Edenhofer 2015). This broadens the conversation, both in terms of audience and substance.

By pointing to the waste, environmental destruction, and poverty generated by consumerism, the encyclical raises thorny questions about seemingly intractable institutions and practices tied to capitalist culture (Carvalho 2015). The Pope asserts that climate change and poverty share the same root and must therefore be addressed together (Edenhofer et al 2015) through the re-imagination and re-assembly of social and economic structures (Carvalho 2015). He does not, however, elaborate on how this revolutionary transformation will or should take place (Wright 2015), and arguably overlooks the highly notable challenge of addressing demographic growth (Ehrlich and Harte 2015). Nevertheless, social scientists point to the importance of this voice, citing abundant research on the imperative of effective framing in guiding social movements - a critical impetus for change that has thus far been lacking in the conversation on climate change (Brulle and Antonio 2015).



This unprecedented dialogue between religion and science elevates climate change to a matter of the global commons, potentially exchanging some of the politicization that surrounds climate policy for ethical responsibility (Brulle and Antonio 2915, Edenhofer et al 2015). It may also serve to help bridge the science-policy gap between the climate science conclusions put forth by Intergovernmental Panel on Climate Change (IPCC) and decision makers who have largely seen that data as reliable but largely inactionable (Edenhofer et al 2015, Petersen et al 2015).

How will this re-framing of the dialogue on climate change be manifested in the outcomes of Paris COP21? The Pope is hardly the first to offer grievances about the state of the global environment, and countless studies indicate that grievances do not lead to action (Wright 2015). But the Pope has undeniably raised the discourse to a new plane, among a larger audience, indicating the need for difficult cultural, economic, and political shifts, in a way that no other leader has succeeded in doing so.



Developing a framework for addressing climate change has long followed a circuitous route. Over the last 25 years progress has been painstakingly slow – as was brilliantly illustrated in Richard Monastersky and Nick Sousanis's recent comic in Nature (some figures of which are in this article). This week, on December 12, that progress culminated in a landmark international agreement that will serve as a guide for the world as it charts a new course in combatting climate change – an agreement that the Pope helped set the stage for, facilitated the adoption of, and praised as a historic step (Bordoni 2015).

This agreement has an air of commonality to it – lifting differentiated requirements between developed and developing nations, requiring all countries to limit and report on emissions with a target of temperature rise "well below" 2 degrees Celsius. It also reaffirms the $100 billion annual fund to be established by 2020 to 2025 in support of sustainable energy development in countries where energy advances are lagging. The agreement is the result of dedicated and skillful diplomacy, including from Pope Francis. It will be truly fascinating to see how the agreement's implementation unfolds over the coming months and years around the world – and whether future actions will reflect the sense of moral obligation and cultural transformation outlined in the Pope's encyclical.

Bordoni, L. "Pope Urges International Community to Follow Up on COP21." *Vatican Radio* 13 Dec. 2015. Online. Web. 14 Dec. 2015.

Brulle, R.J. and R. J. Antonio. 2015. The Pope's fateful vision of hope for society and the planet. Nature Climate Change 5(10) 900-901.

Carvalho, A. The Pope's Encyclical as a call for democratic social change. Nature Climate Change 5(10) 905-907.

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Edenhofer, O., C. Flachsland and B. Knopf. Science and reiligion in dialogue over the global commons. Nature Climate Change 5(10) 907-909.

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Wright, E.O. 2015. Sociological limitations of the climate change encyclical. Nature Climate Change 5(10) 902-903.