Causes of the 2011-14 California Drought: An unfortunate series of weather, ocean-forced variability and/or climate change?

October 2012 to April 2013 % of normal precipitation

October 2013 to April 2014 % of normal precipitation

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Sloan Coats, Jason Smerdon, Ben Cook (LDEO) and Daniel Griffin (WHOI) for paleo-NAM analysis.
The California drought is climatically extreme but socially ghastly

Caltech, Pasadena  Porterville

With Dry Taps and Toilets, California Drought Turns Desperate

By JENNIFER MEDINA  OCT. 2, 2014
Observational data:
NOAA Climate Division precipitation, Jan 1895 to Apr 2014
Hurrell, NOAA ERSST and Hadley SST products
NCEP-NCAR Reanalysis 1949 to Apr 2014

Models:
Seven SST-forced GCMs
from Lamont, IRI, NASA, NOAA CPC and NOAA ESRL(3)
California has a rich history of droughts. Current drought appears as one of many such events both in terms of amplitude and duration, but it is the worst.
Last 3 winters
200mb heights, SST, U.S. precipitation

2011/12 looks like a La Nina

2012/13 ENSO neutral, North Pacific ridge

2013/14 warm west tropical Pacific, North Pacific-west coast ridge

In all three CA/west coast was dry
sea surface temperature, 200mb height and precipitation anomalies averaged over Nov-Apr of 2011-14

models reproduce northeast Pacific ridge and dry west coast as a response to SST anomalies alone and of likely natural origin
No surprise SST-forced models do not fully capture CA P variability

Winter CA Precip(land), SSTA(ocean), 500mb Height(contour)

(A) Dry Years

A composite of observed CA dry winters shows the off-coast ridge but no impressive sea surface temperature anomalies
In contrast, observed wet California winters tend to be caused by El Nino events.

(B) Wet Years
Some models (ECHAM4.5, ESRL CFSv2) appear to have too strong of a La Nina-CA dry relation. Other models (GEOS-5, CCM3) seem to correctly link CA-dry winters to internal atmosphere variability.
All models correctly link wet CA winters to El Nino, though with varying strengths of relation. I.e. models capture the nonlinearity of CA-SST relations.
What is the SST-forced component the models picked up for ENSO-neutral 2012/13 and 2013/14?

To check:
EOF decomposition of Nov-Apr 200mb height for 0-90N, 1979 to 2014 (common model period)

EOF/PC 1 --- ENSO
EOF/PC 2 --- decadal ENSO/PDV/trend

**EOF/PC 3:**
northeast Pacific-west coast ridge
warm (cool to neutral) west (east) tropical Pacific
The SST-gradient/west coast ridge SST-forced mode in 7 models. 200mb height pattern, time series, SST regression (shown where significant)
Ensemble mean $P$ regressed onto PC3, shown where 90% significant. Wet west tropical Pacific, dry US west coast.
Observed and modeled histories of California precipitation

Model skill is variable. Some models, e.g. ESRL CFSv2, suggest notable skill.
Two most recent dry winters partly SST forced but the 97/98 shift to more La Nina-like tropical Pacific state has also favored drying across southwest North America.
Climate models project for California wetter winters/drier springs due to rising greenhouse gases. For DJF, wet-getting-wetter and wave response with southwesterly anomaly at coast.

CMIP5, (2021-2040) - (1979-2005)

\[ \Delta \bar{P} \text{ DJF} \]

\[ \Delta (\bar{P} - \bar{E}) \text{ DJF} \]

\[ \Delta \bar{P} \text{ MAM} \]

\[ \Delta (\bar{P} - \bar{E}) \text{ MAM} \]
and all this raises the question of what caused the west Pacific warm SST anomaly?

Despite the lowly regard in which the “ocean dynamical thermostat” is held, Nature refuses to preferentially warm the eastern equatorial Pacific. The contrast with CMIP5 models is as stark now as at the time of Cane et al. (1997).
The role of temperature variability and change from the Penman-Monteith PDSI perspective
Conclusions on CA drought

Ongoing California drought driven by precipitation drop associated with a persistent eastern North Pacific-west coast ridge. SST-forced models get this.

California droughts almost this serious have occurred before. No clear $P$ trends.

Droughts largely related to internal atmosphere variability. Wet winters tend to be El Nino winters. Link not strong: 1976/77 was both an El Nino winter and a drought!

The drought partly forced by La Nina and ENSO-neutral tropical Pacific SST anomalies.

1997/98 Pacific decadal shift has favored dry conditions in SW since.

Models project rising GHGs will increase precipitation in winter for central to northern CA and decrease it in spring, unlike current drought (but CA does face real climate change problems).

But can we trust model projections of tropical SST change?
Away from CA the North American Monsoon is of importance to water resources, agriculture, ecosystems ...

Apr-Sep $P$ as % of annual

16th Century megadrought and megadeath stands out (Acuna-Soto et al.)
Griffin et al. (2013) use subseasonal banding to divide early (late) wood into record of winter (monsoon) $P$ and it works (for northern NAM)
Late 16th Century megadrought was “dual season”. But winter and monsoon P anomalies can just as likely be of opposite sign.
Multiple regressions of observed P on tropical Pacific and tropical North Atlantic SST indices

Multiple Regr of TP and TNA on UNAM Precip for Nov-Apr 1945-2002, Significant areas (colors)

a) TP

Winter Summer dual season drought:

North NAM: warm TNA, winter and summer La Nina

South NAM: warm TNA, winter La Nina, summer El Nino

Multiple Regr of TP and TNA on UNAM Precip for May-Oct 1945-2002, Significant areas (colors)

a) TP

b) TNA
On interannual timescale, the reconstruction suggests no tendency to same or opposing sign winter and NAM $P$ anomalies.

But, measured by fraction of most severe persistent droughts in each season, dual season megadroughts common over last millennium in nature but not in two models.

Coats et al. (2015)
Conclusions on paleo-North American Monsoon

Dendroclimatology (Griffin, Stahle, Cook and Cook) is only just beginning to work out how to reconstruct North American Monsoon hydroclimate

Indications to date are that the NAM region can also experience decadal scale megadroughts

Also in the north, dual season megadroughts seem possible (though not in CMIP5 models!)

Mechanisms of paleo-NAM variability not understood
# Models:
Seven SST-forced GCMs from Lamont, IRI, NASA, NOAA CPC and ESRL

<table>
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<th>Model</th>
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Winter SSTA (ocean), Precip (land), 200 mb Height (contour)

(a) Jan 2015

(b) Nov-Apr 2013-2014