Impacts of ENSO, global warming, and vegetation on Future Terrestrial Aridity

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LLNL, NASA/GISS, NOAA, PNNL, INRA
DOE- Funded: ECRP, SFA

Lawrence Livermore National Laboratory

Dec 13 2016
AGU Meeting
H23L-01 – Hydroclimatic Extremes: Droughts III
Moscone West, 3022

LLNL-PRES-680158-DRAFT

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Motivation

- Water is the single most important natural resource
- 1/5 population live where the water is scarce
- Climate models project unprecedented droughts risk or increase in aridity in the future

- Difficult to detect in observations that drought behavior becomes driven by human forcing than by internal climate variability

Improve our understanding of the nature and causes of future droughts

Public perception that ENSO events will always be a source of relief /or damage

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Media headlines: a "super El Niño" was expected to provide some drought relief in California

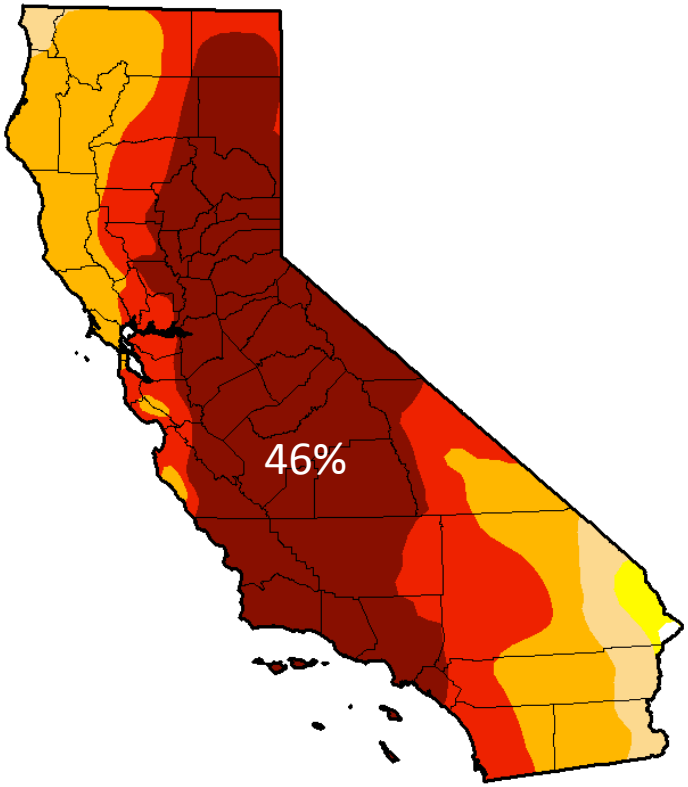
"Hopes rise for a strong El Niño to ease California drought" (Los Angeles Times, 05/28/15)

"Relief Coming for Drought-Ravaged California?" (Wall street journal, 05/19/15)

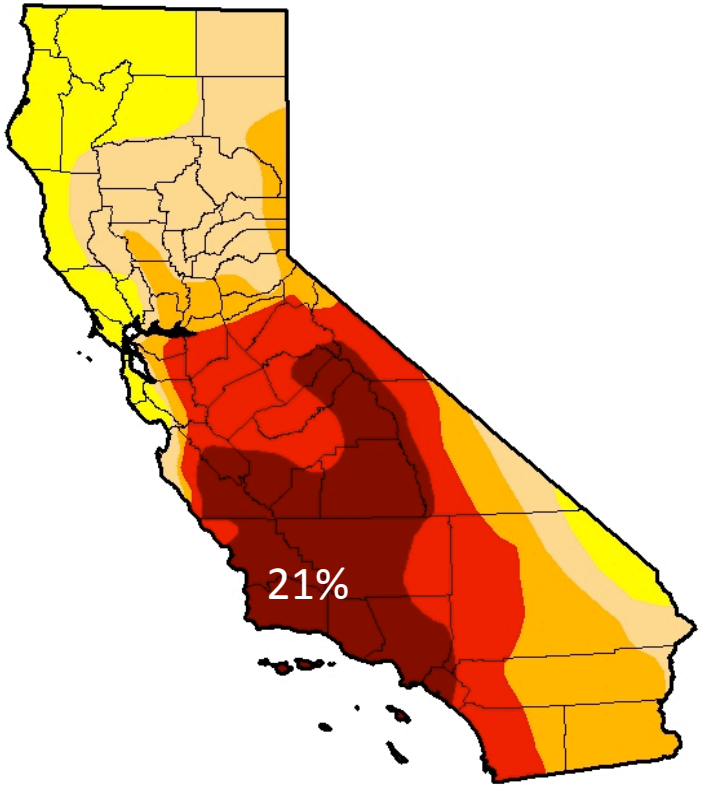
"NASA: El Nino Helpful or Harmful for CA Drought" (CBS News, 08/14/15)

Public perception that ENSO events will always be a source of relief /or damage

June 2015



Oct 2016



Intensity:

- **D0** (Abnormally Dry)
- **D1** (Moderate Drought)
- **D2** (Severe Drought)
- **D3** (Extreme Drought)
- **D4** (Exceptional Drought)

Unrealistic expectation in regions where:

- mean change in terrestrial aridity in response to greenhouse warming becomes larger than the expected range of ENSO variability

- P supply cannot offset increased evaporative demand

Regions where projected future changes in mean aridity exceeds the range of ENSO variability

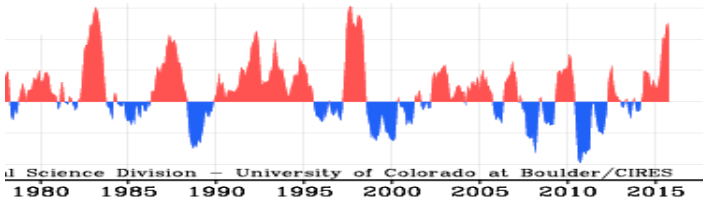
- joint investigation of relative contributions from:
  - changes in moisture supply vs. evaporative demand
  - changes in mean state vs. ENSO variability

- Idealized AMIP climate-change runs to capture:
  1. "slow" warming of the oceans (+WARMING)
  2. "fast" radiative forcing from enhanced CO_2 (+RAD)
  3. "fast" plant physiological effects in response to rising CO_2 (+VEG)

- 5 aridity indices

+ OCEAN WARMING

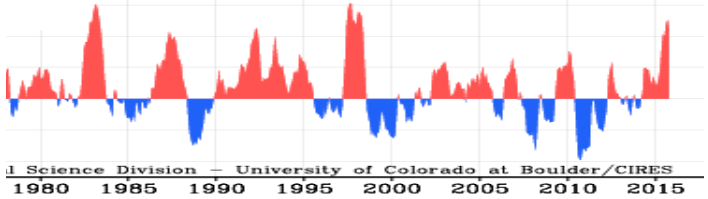
4 AMIP experiments



prescribed observed sea surface temperatures for years 1979 - 2008

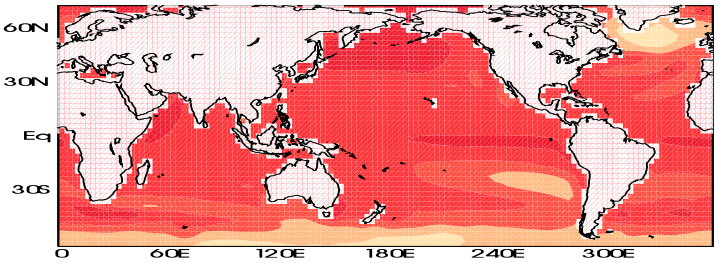
- El Niño: 1982, 1986,1987,1991,1994,1997,2002, 2004,2006
- La Niña: 1983,1984,1988, 1998,1999,2000, 2005,2007, 2008

4 AMIPFUTURE experiments



+ WARMING

Patterned ocean warming applied (mean=4K)



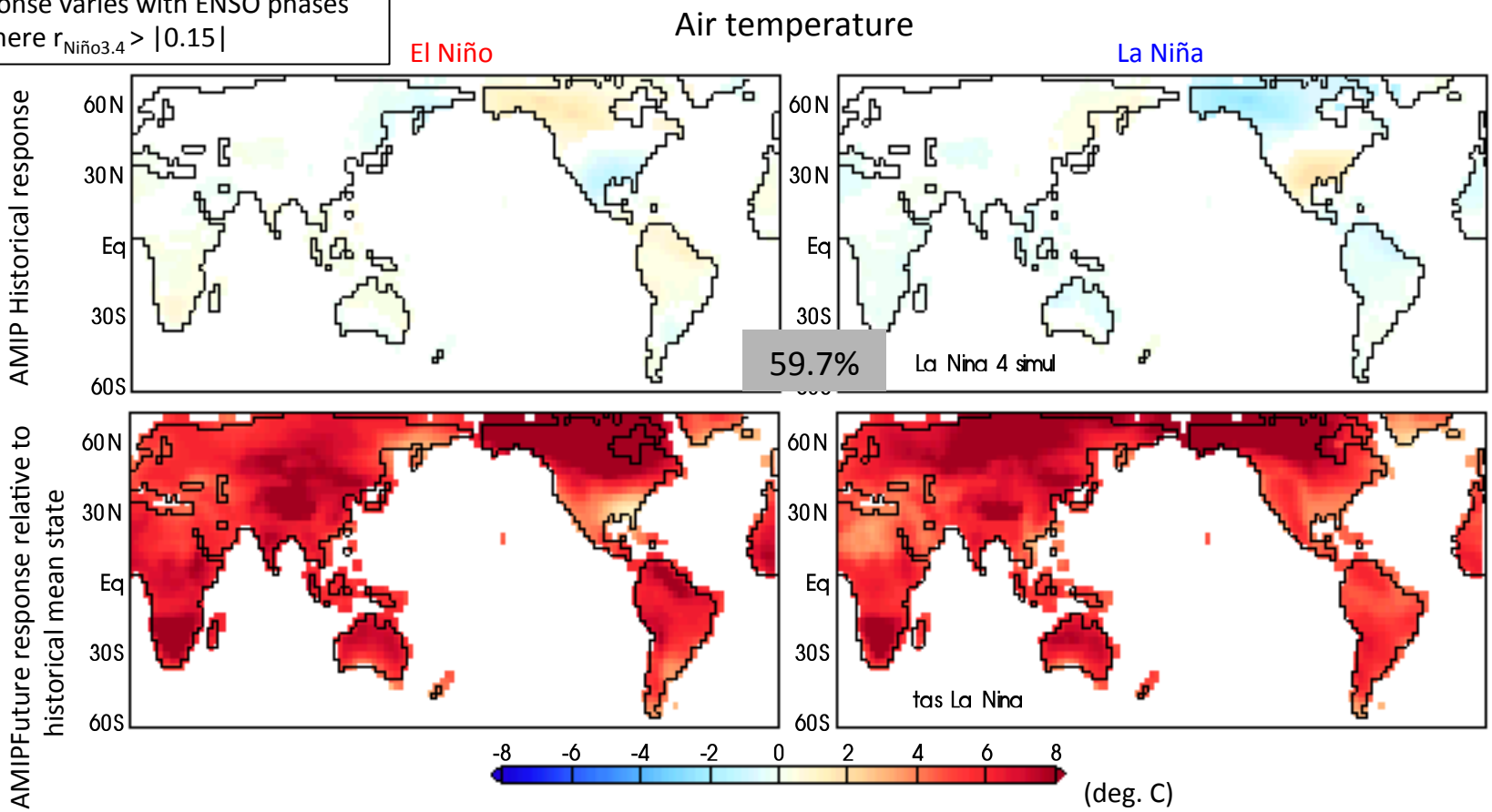
CO_2= CONSTANT!

No intensified radiative forcing

No enhanced plant CO_2 fertilization

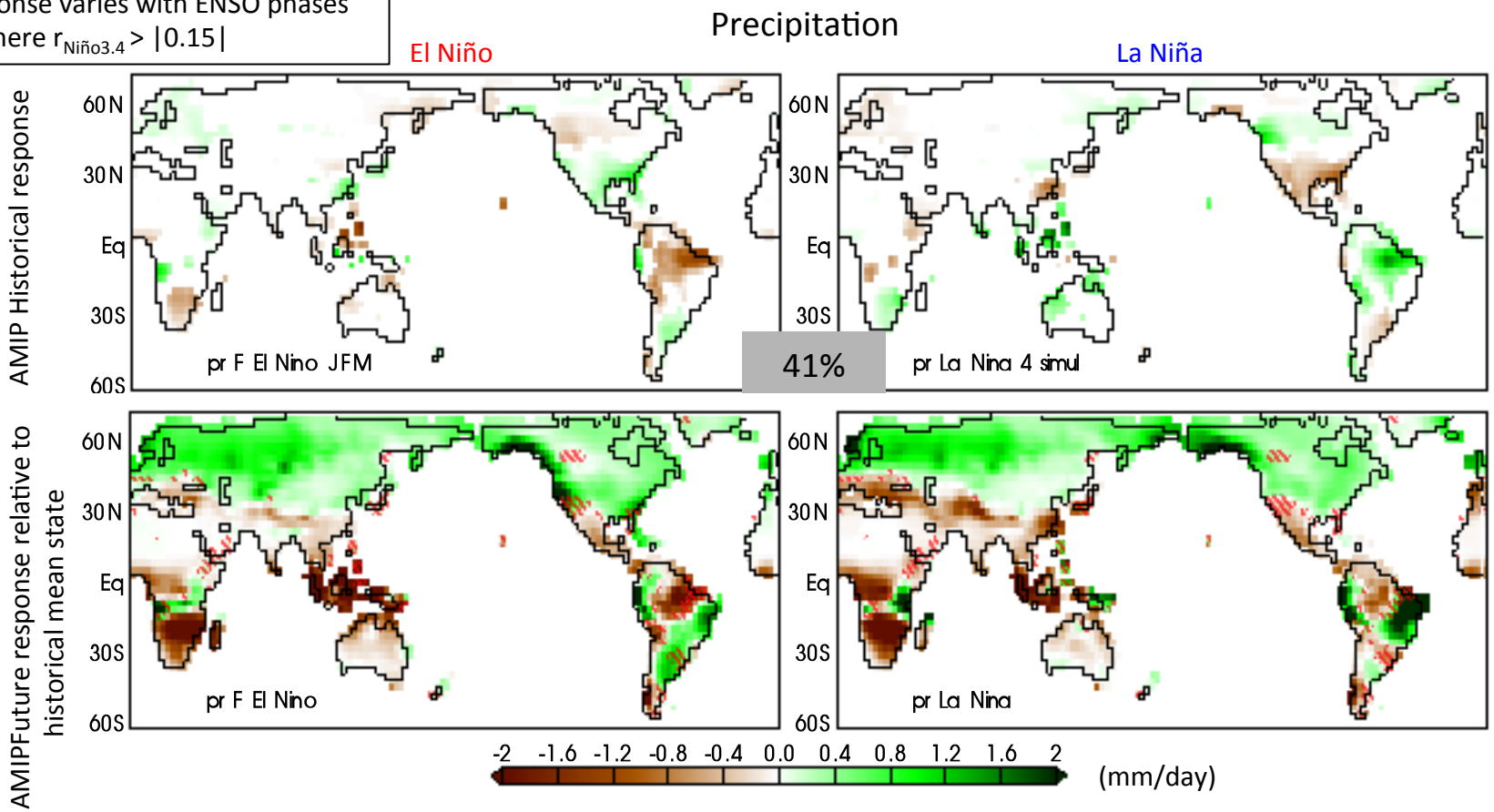
Future warming is expected everywhere, independent of the phase of ENSO

Land area where the sign of the T response varies with ENSO phases & where $r_{Niño3.4} > |0.15|$



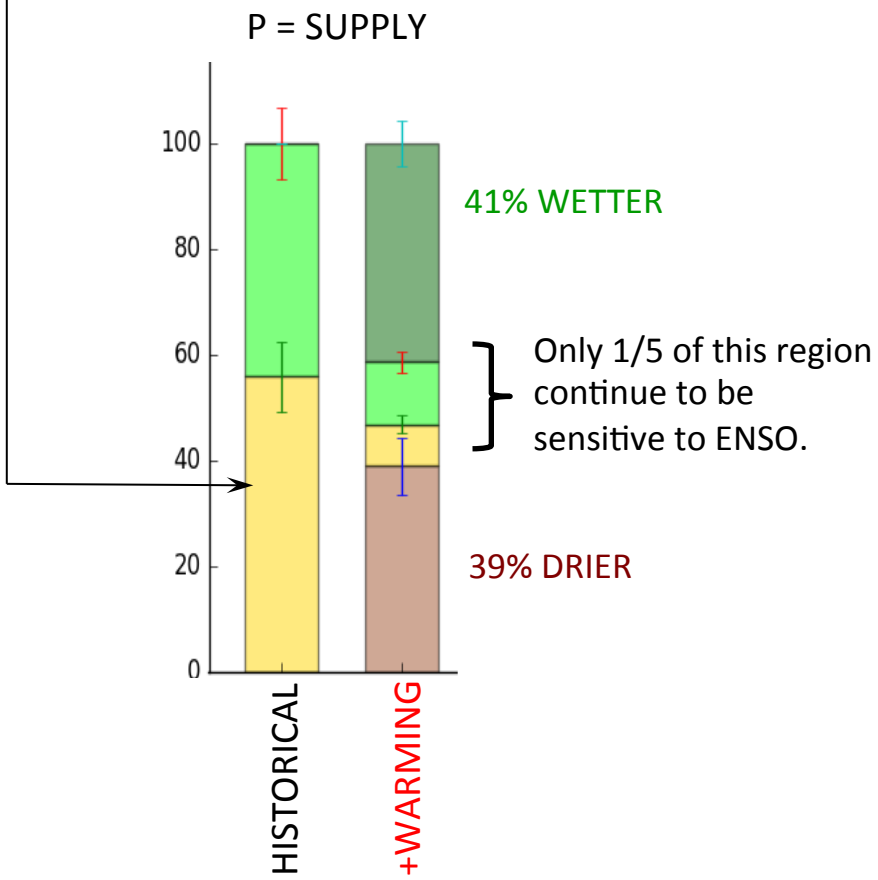
In contrast, expectations regarding the net anomalies in regional precipitation are much more complex

Land area where the sign of the Pr response varies with ENSO phases & where $r_{Niño3.4} > |0.15|$



Always wetter
Wetter with El Niño
Drier with El Niño
Always drier

Historical: 55% of land sensitive in the sign to ENSO is drier during El Niño.



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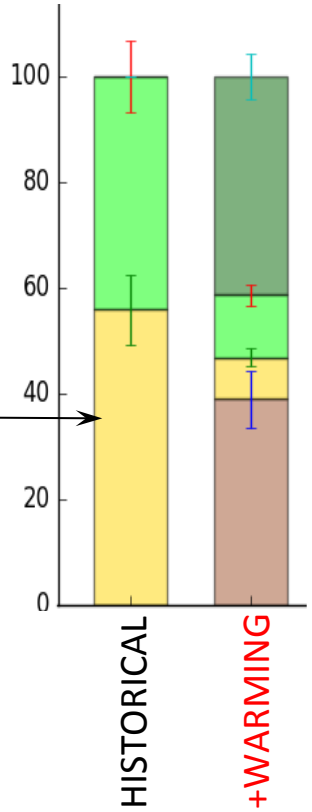
P = SUPPLY



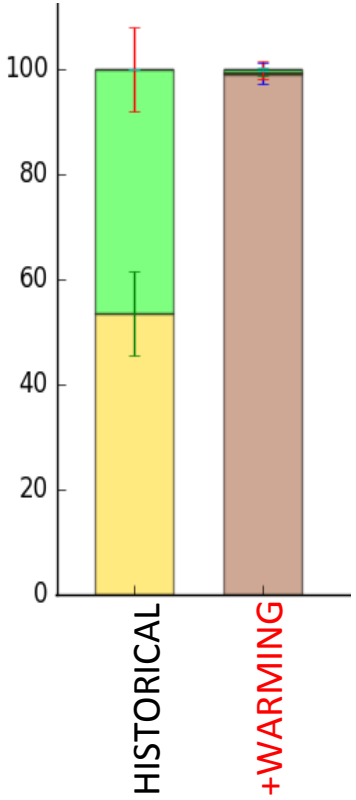
41% WETTER

Only 1/5 of this region continue to be sensitive to ENSO.

39% DRIER

PET = EVAPORATIVE DEMAND

Penman-Monteith=f(Rad,T,hum,wind, r_s=CST)



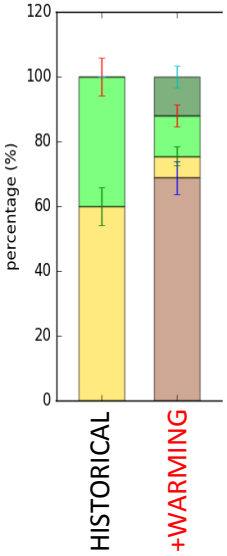
Omnipresent increase in PET (in regions where PET is historically driven by ENSO variability)

Always wetter
Wetter with El Niño
Drier with El Niño
Always drier

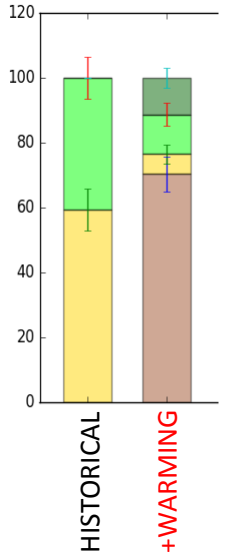
PET-dependent aridity metrics

PET-independent aridity metrics

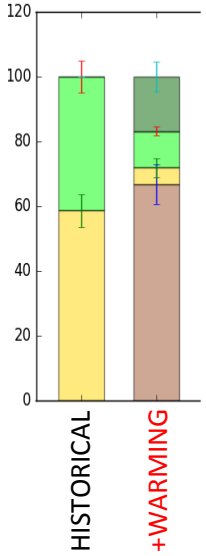
Climate Moisture Index



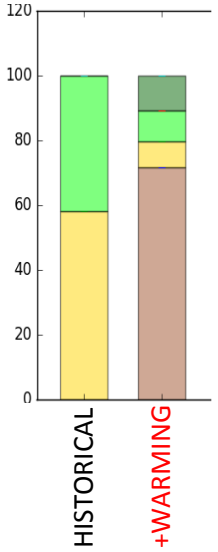
P/(P+PET)



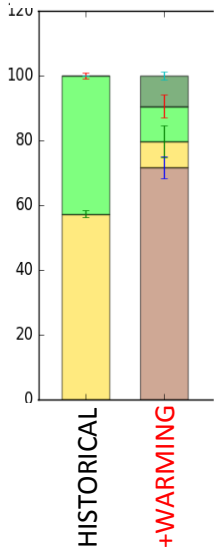
PDSI



Surface Soil Moisture



Total Soil Moisture



Future aridity predicted in ~**67-72**% of the regions where aridity is currently driven by ENSO variability

CMI= (P / PET) -1 when P < PET
CMI= 1- (PET / P) when P = PET

+VEG +RAD

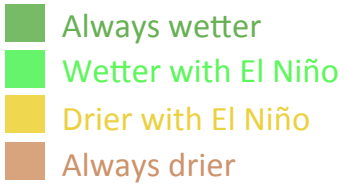
- Add other AMIP-style experiments
- PET from Penman-Monteith r_s=cst

+VEG

Role of plant fertilization

+RAD

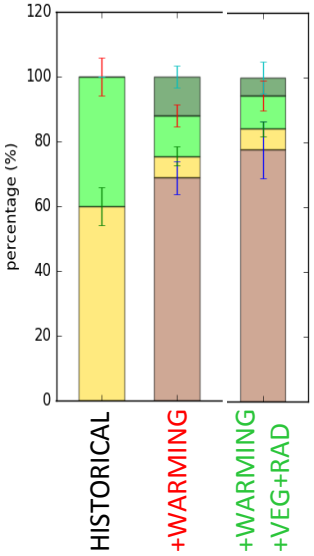
Role of intensified radiative forcing from enhanced CO_2



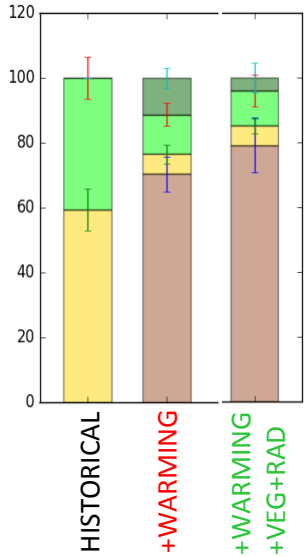
PET-dependent aridity metrics

PET-independent aridity metrics

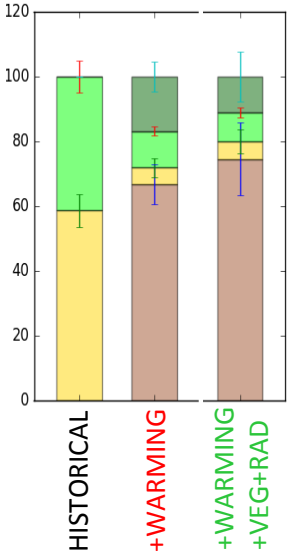
Climate Moisture Index



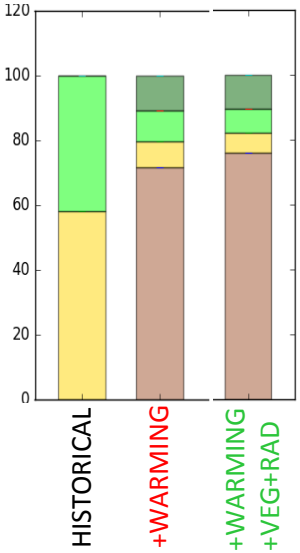
P/(P+PET)



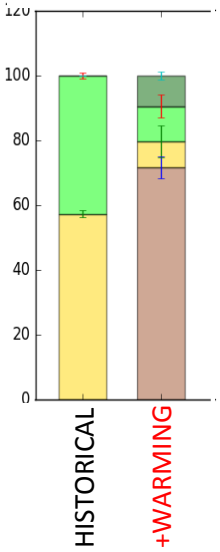
PDSI



Surface Soil Moisture

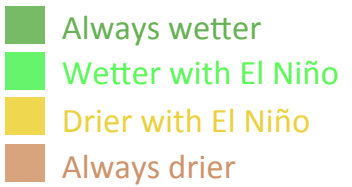


Total Soil Moisture



Future aridity predicted in ~**75-78**% of the regions historically sensitive to ENSO

Stomatal closure → Reduced ET and evaporative cooling → T and PET increase; less recycling *(Berg et al. 2016, Swann et al. 2016, Andrews et al. 2011)*



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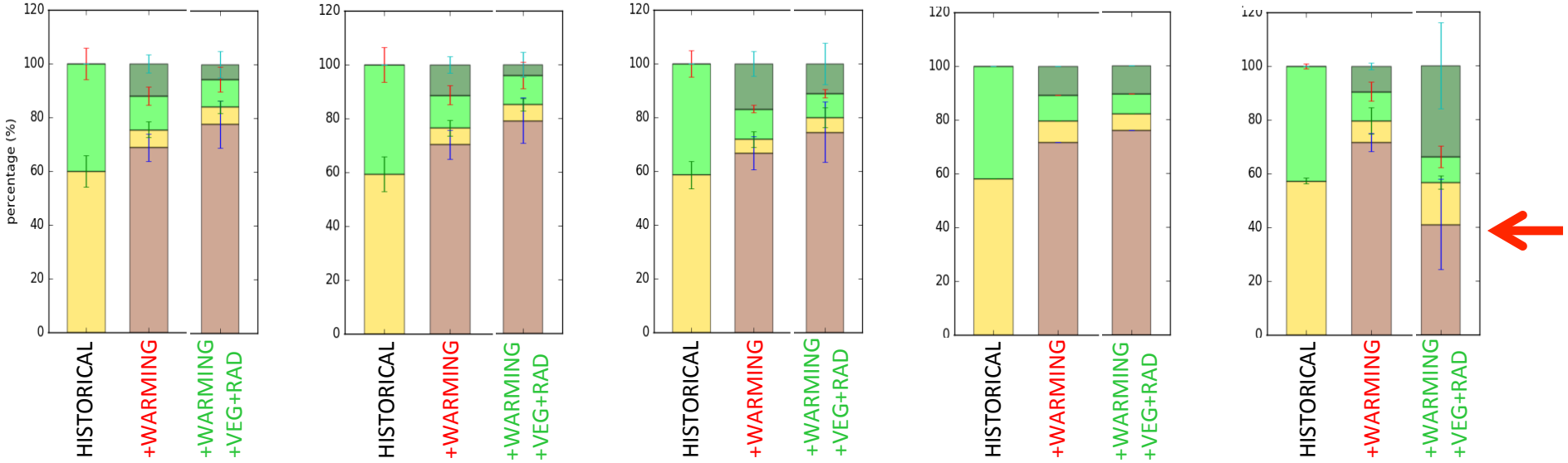
Climate Moisture Index

P/(P+PET)

PDSI

Surface Soil Moisture

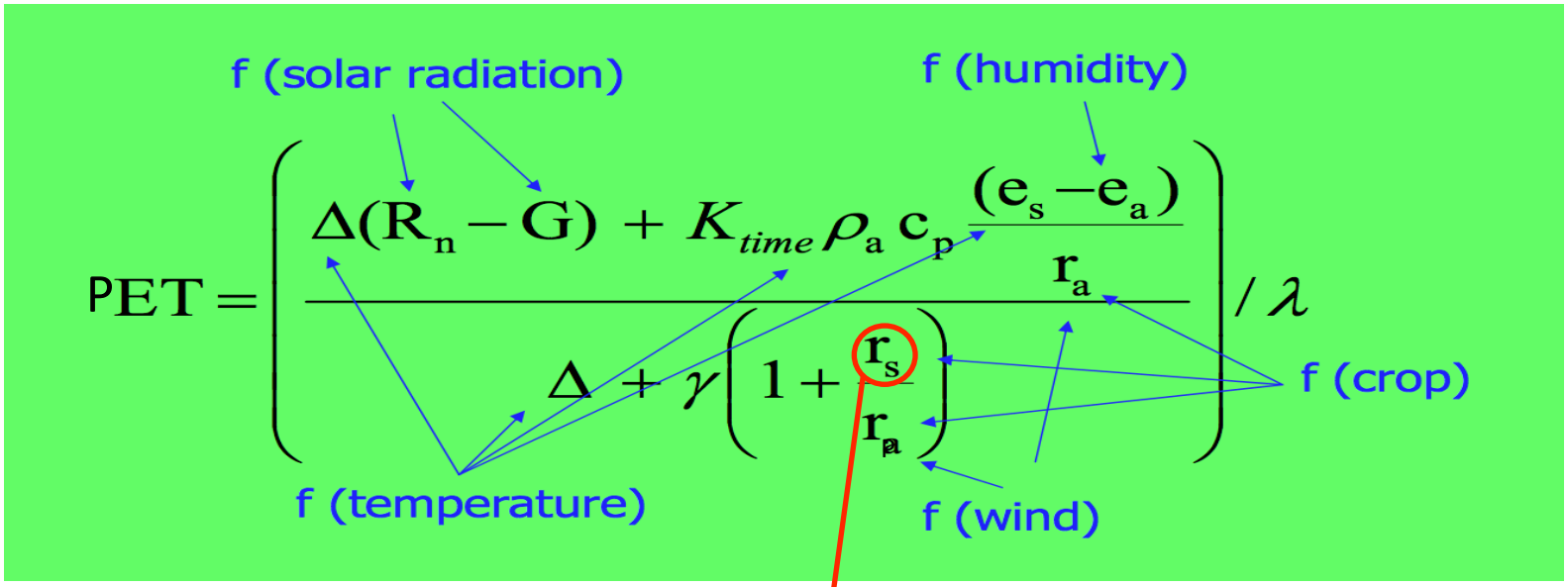
Total Soil Moisture



Future aridity predicted in ~**75-78**% of the regions historically sensitive to ENSO
BUT, much weaker prediction for total soil moisture (41%)

Stomatal closure → improved plant water use →reduced evapotranspiration and soil desiccation

Penman-Monteith equation



Methodological artefact:
→ By neglecting the increase in r_s, PET estimator may overpredict future drying

More work is needed to increase our confidence in future drought risk

Conclusions

- It is not easy to predict the change in the regional aridity. It requires joint investigation of:
  - The relative contributions from changes in moisture supply (P) versus evaporative demand (PET);
  - The competing effects of mean changes and ENSO variability to ameliorate or exacerbate drought;
- Important physiological role of vegetation is often ignored in studies of future aridity.
- "ENSO relief" from relentless warming/regional drying is not always guaranteed

Bonfils C, G Anderson, B Santer, Thomas J. Phillips, Karl Taylor, Matthias Cuntz, M Zelinka, K Marvel, B Cook, I Cvijanovic, Paul Durack, 2016