Climate Change, Climate Variability, and the Risk of Sustained 'Megadrought'

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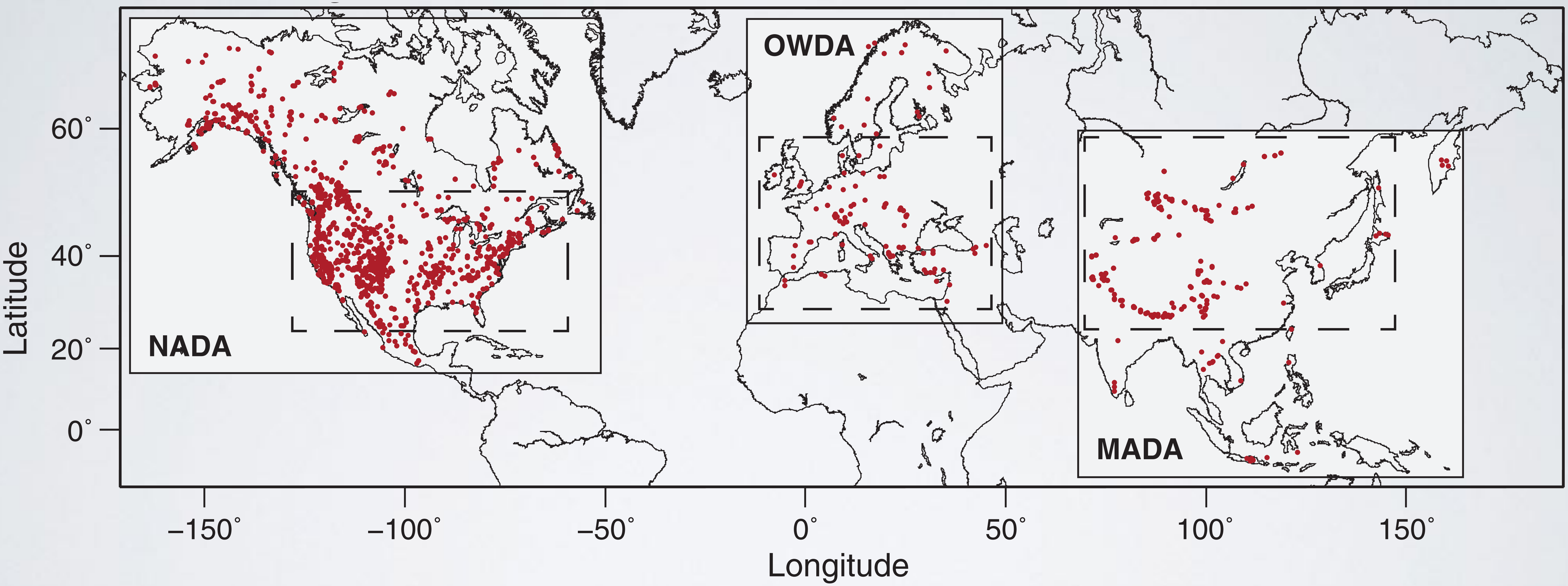
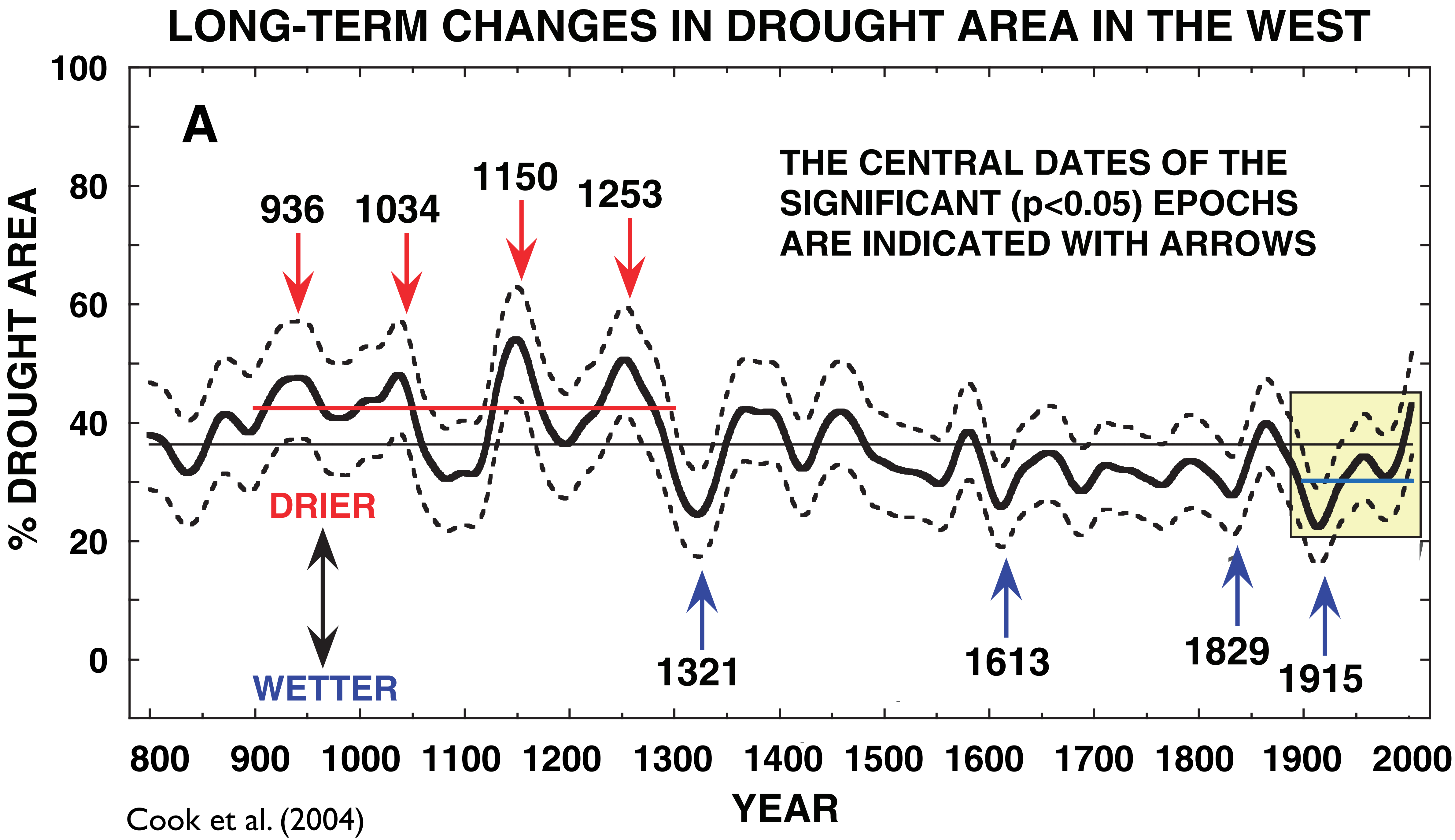
"Drought Atlases" now cover a huge area of the world

NADA = North American Drought Atlas
OWDA = Old World Drought Atlas
MADA = Monsoon Asia Drought Atlas

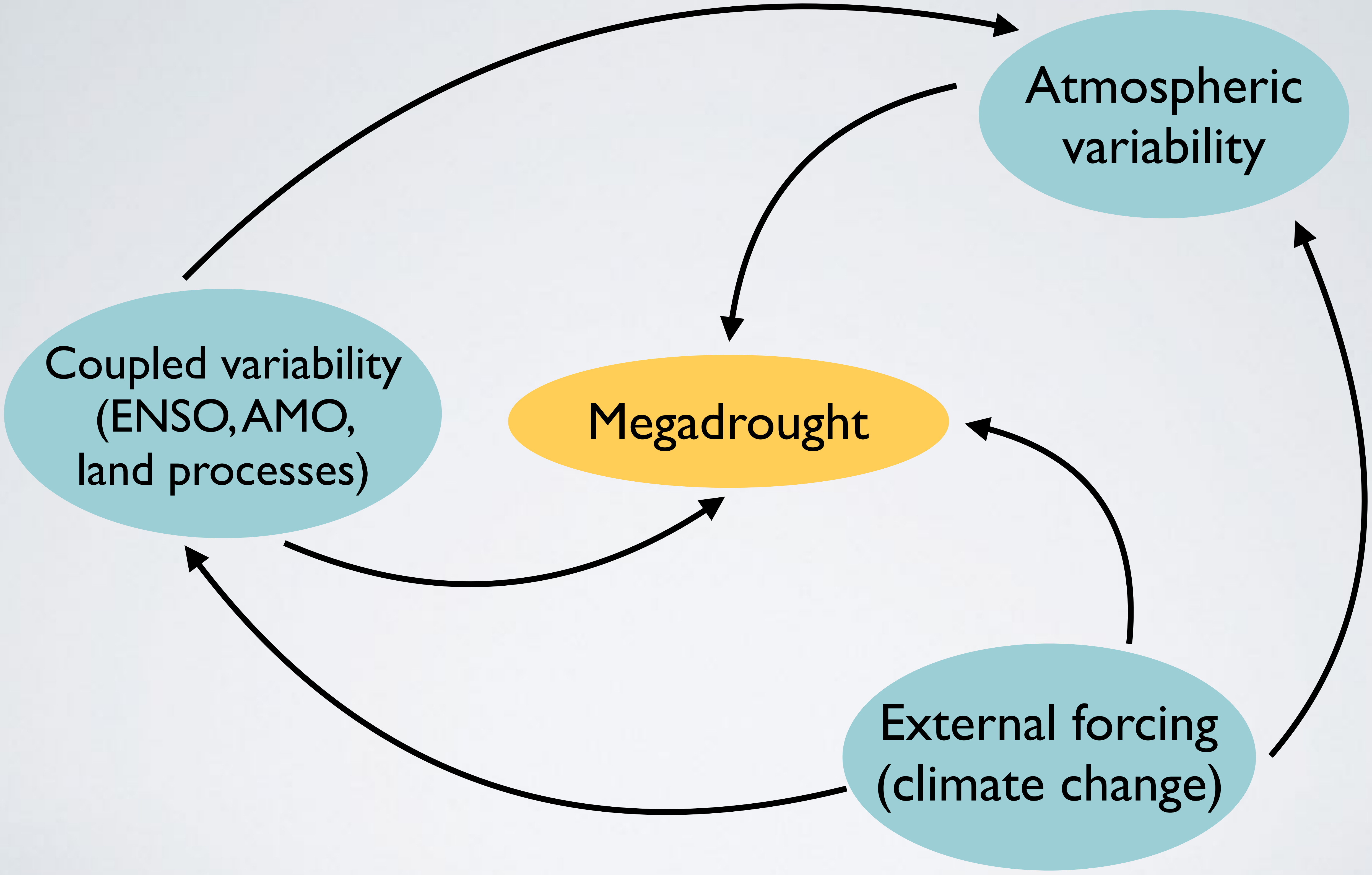


Cook et al. (2015)

Drought atlases: evidence for prolonged 'megadroughts'



Cook et al. (2004)


Atmospheric variability
Coupled variability (ENSO, AMO, land processes)
Megadrought
External forcing (climate change)

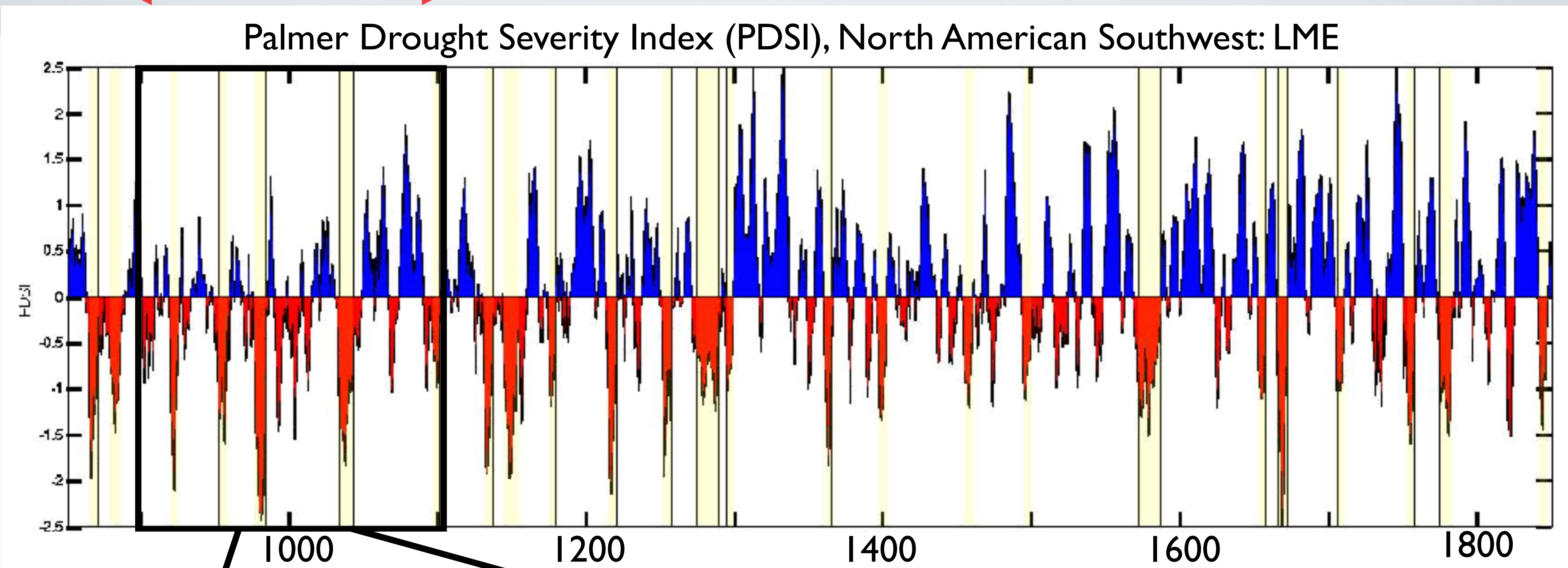
CESM: new large ensemble capabilities

CESM Last Millennium Ensemble (CESM LME):
Otto-Bliesner et al. 2016

Multiple ensembles, varying sizes: different combinations of climate forcings 850-2005
(Orbital, solar, volcanic, GHG, ozone/aerosol, land use/land cover, all of the above)

Megadrought and climate modes: "big data" problem

200-year moving window

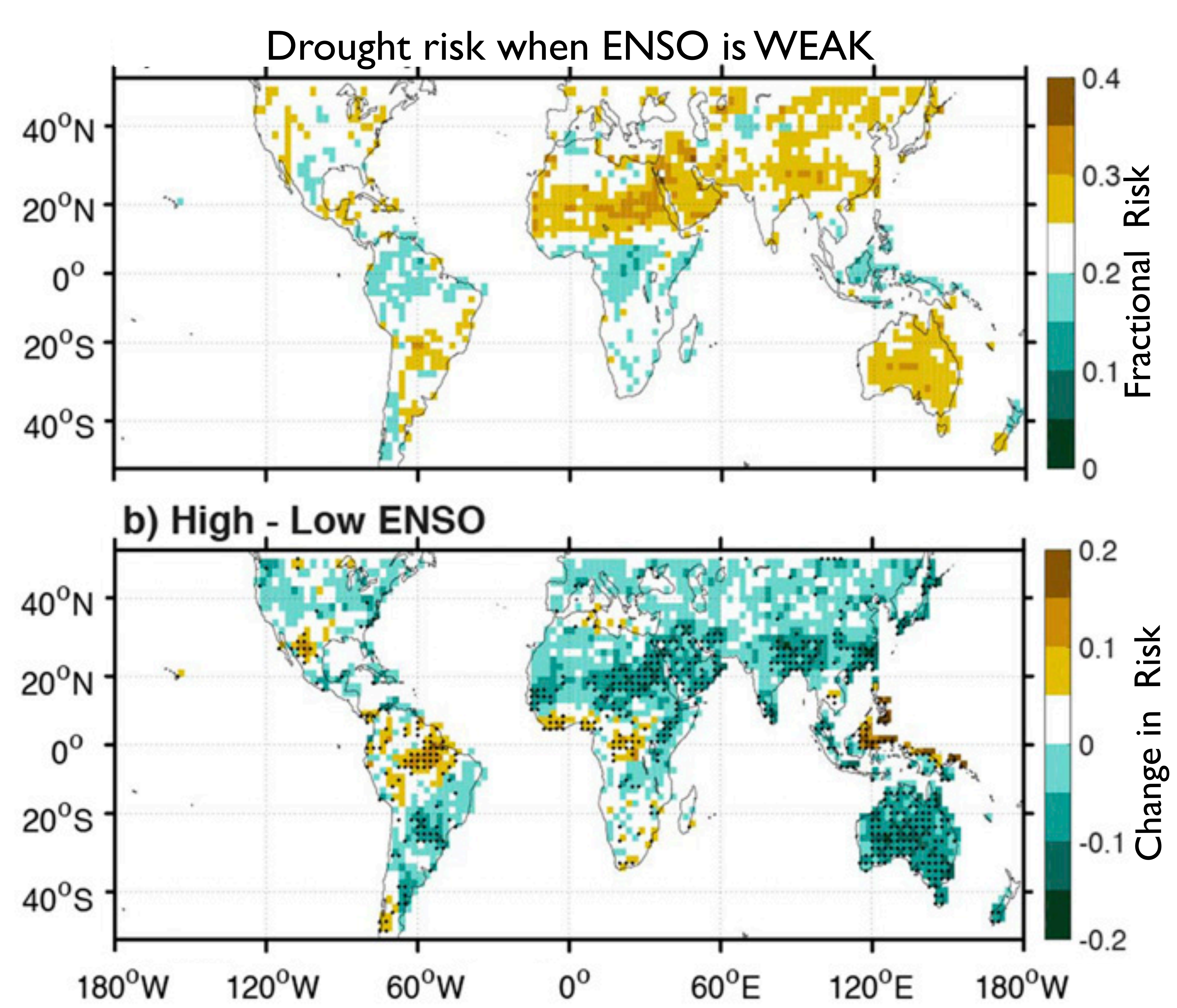


Megadrought persistence, risk

Risk = % years in megadrought

Climate variability:
ENSO amplitude

ENSO: strong influence on drought risk



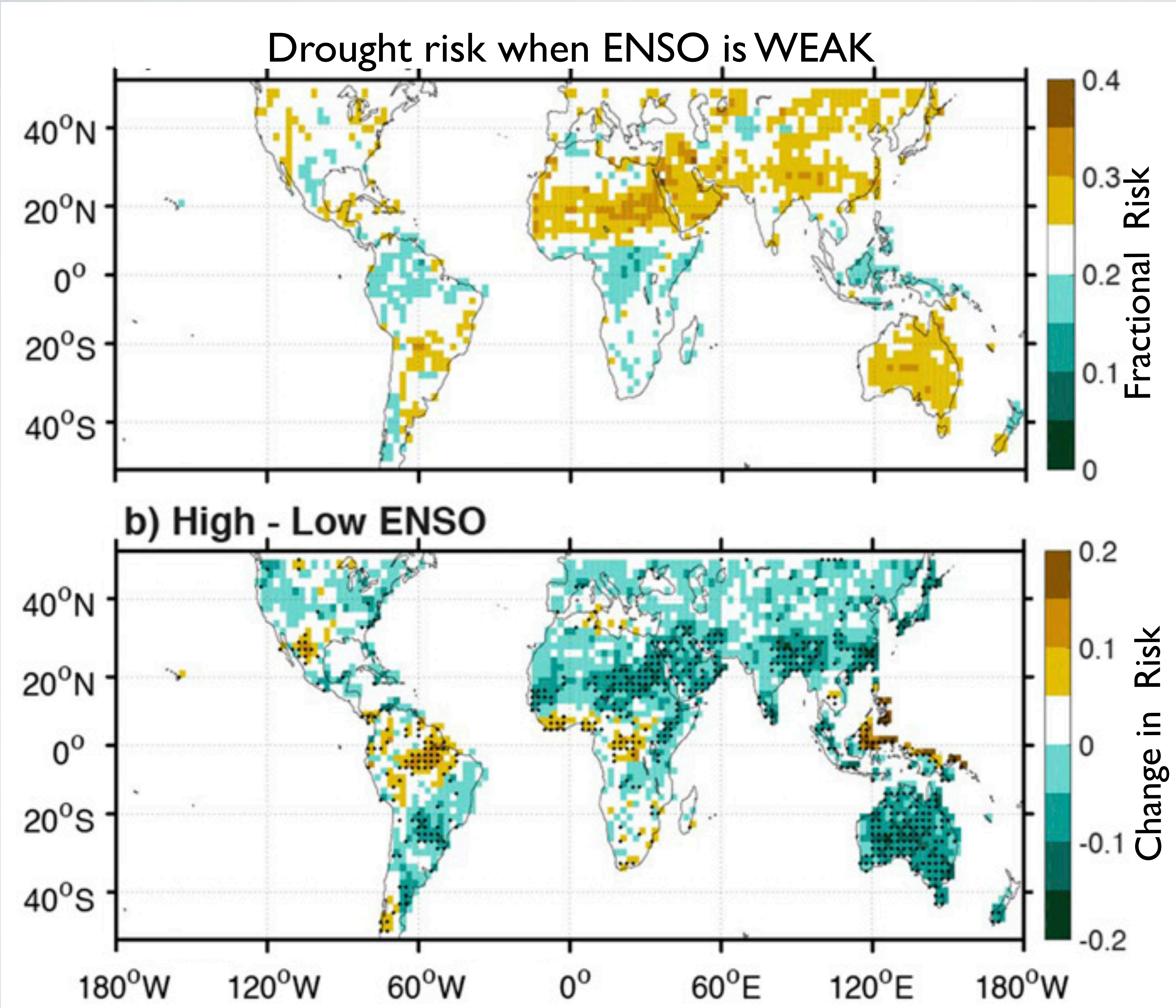
15-year drought (0.5σ threshold)

Stratified by mode (above 60th/below 40th percentile)

Brown = higher drought risk
Green = lower drought risk

Stevenson et al. (2018)

ENSO: strong influence on drought risk



15-year drought (0.5σ threshold)

Stratified by mode above 60th/below 40th percentile)

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Stronger ENSO:

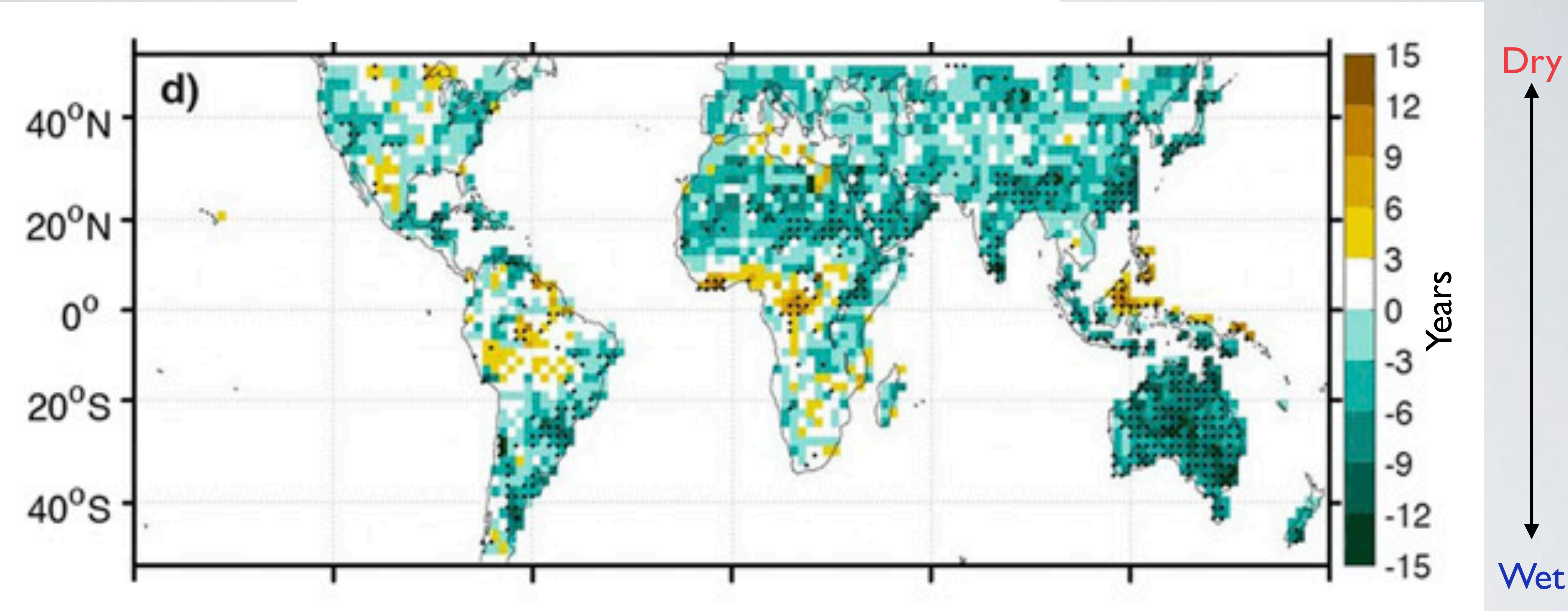
Lower risk of drought in Australia, Africa, Southeast Asia, SW US

Higher risk of drought in Amazon basin, Mexico

Stevenson et al. (2018)

Effects of high vs. low ENSO on event persistence

Change in drought persistence when ENSO STRENGTHENS



Stevenson et al. (2018)

15-year drought/pluvial
(0.5σ threshold)

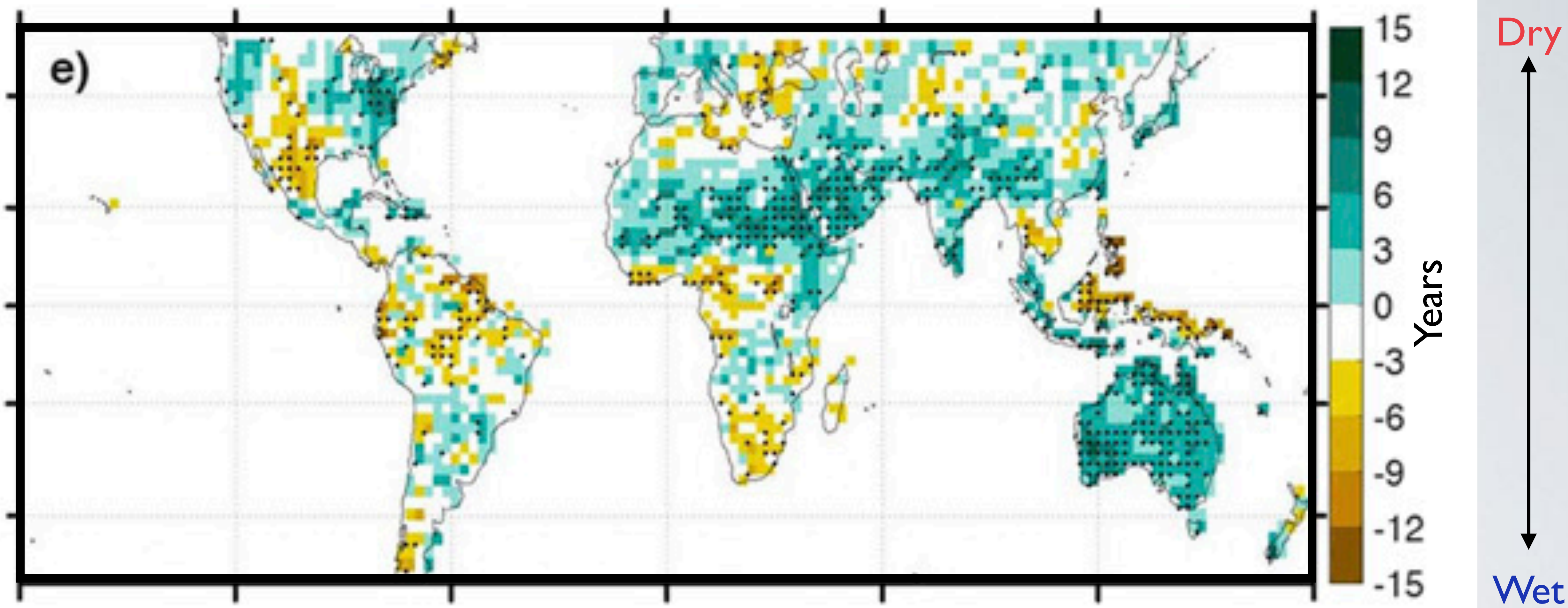
Stratified by mode
(above 60th/below 40th percentile)

Stronger ENSO:

- Shorter droughts in Australia/Sahel/SE Asia
- Shorter droughts in SW US
- Longer droughts in Amazon, Mexico

Effects of high vs. low ENSO on event persistence

Change in pluvial persistence when ENSO STRENGTHENS



Stevenson et al. (2018)

15-year drought/pluvial
(0.5σ threshold)

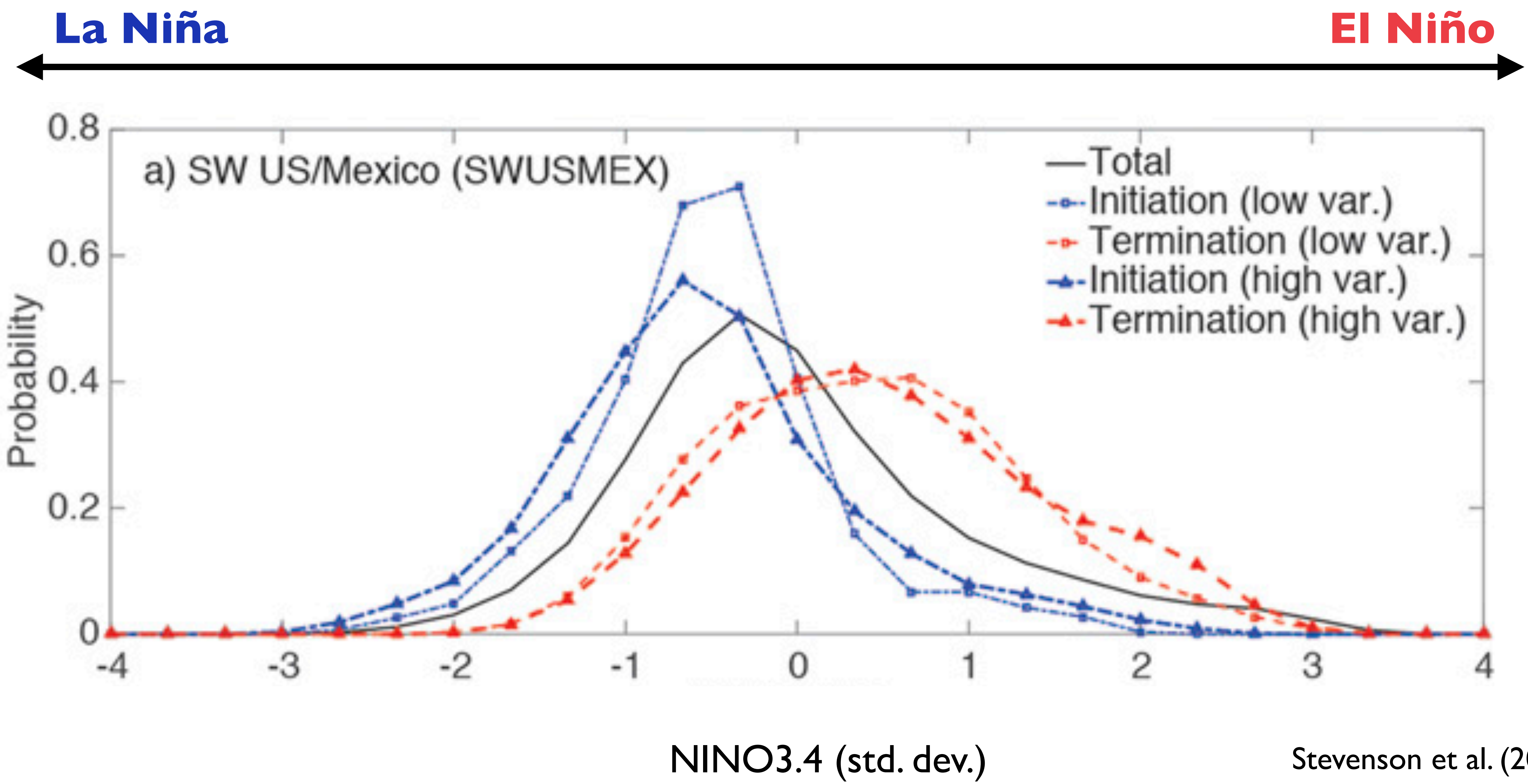
Stratified by mode
(above 60th/below 40th percentile)

Stronger ENSO:

- Longer pluvials in Australia/Sahel/SE Asia
- Not much change in SW US
- Shorter pluvials in Amazon, Mexico

ENSO ‘kicks’ regional hydroclimate in and out of drought

SOUTHWEST US

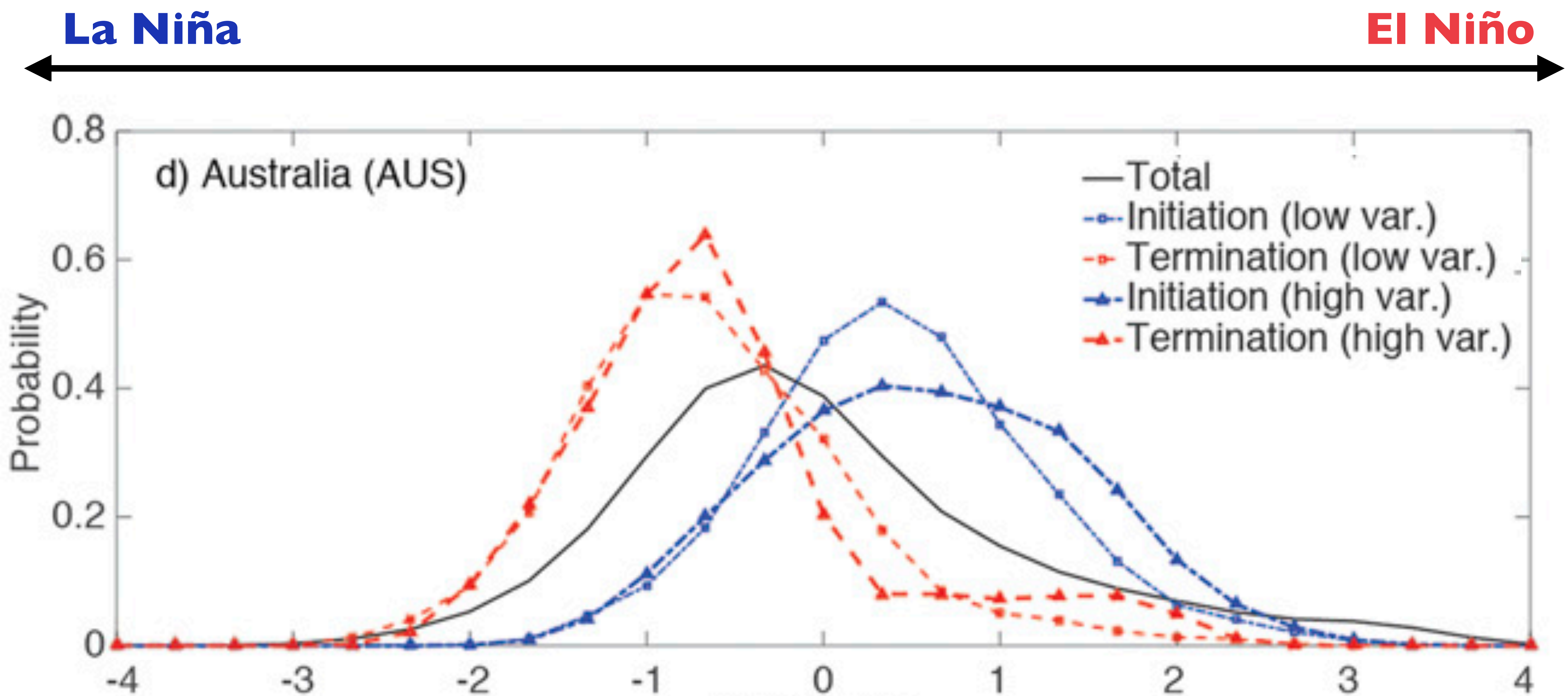


Stevenson et al. (2018)

Probability distribution function of NINO3.4 anomalies in start, end year of megadroughts

ENSO ‘kicks’ regional hydroclimate in and out of drought

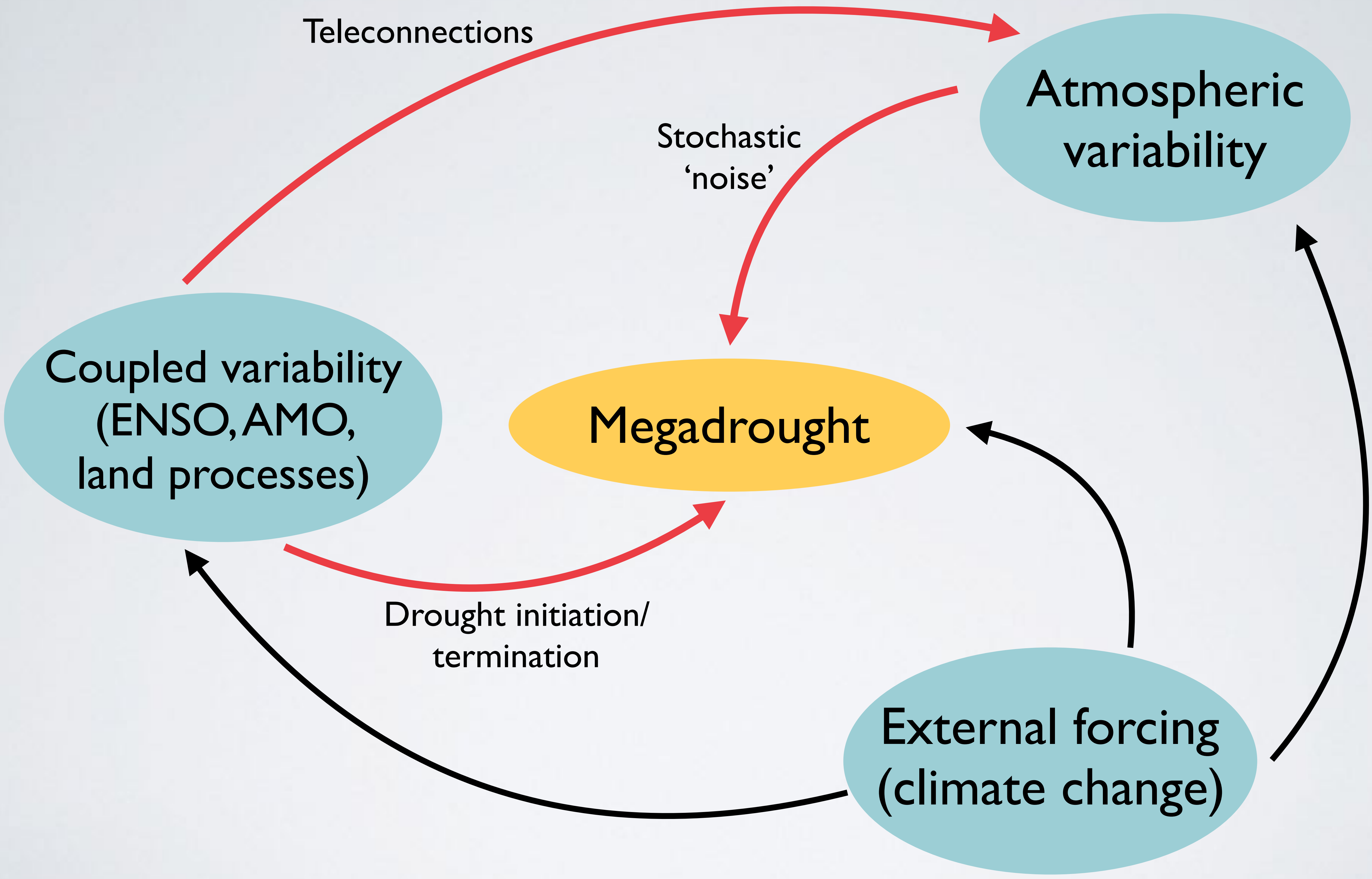
AUSTRALIA



NINO3.4 (std. dev.)

Stevenson et al. (2018)

Probability distribution function of NINO3.4 anomalies in start, end year of megadroughts


Teleconnections
Atmospheric variability
Stochastic 'noise'
Coupled variability (ENSO, AMO, land processes)
Megadrought
Drought initiation/ termination
External forcing (climate change)

CESM: new large ensemble capabilities

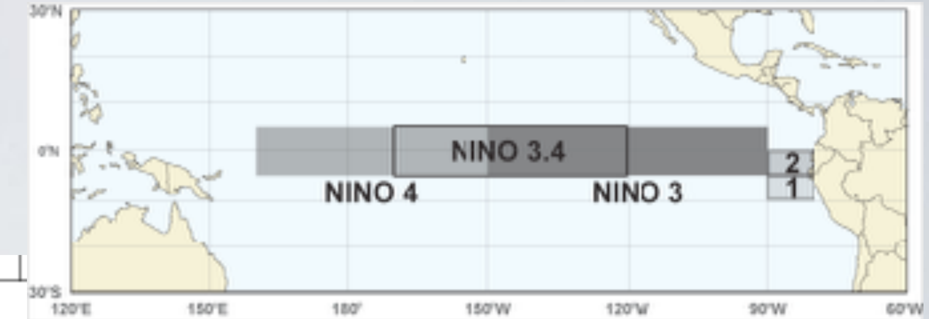
CESM Last Millennium Ensemble (CESM LME): Otto-Bliesner et al. 2016

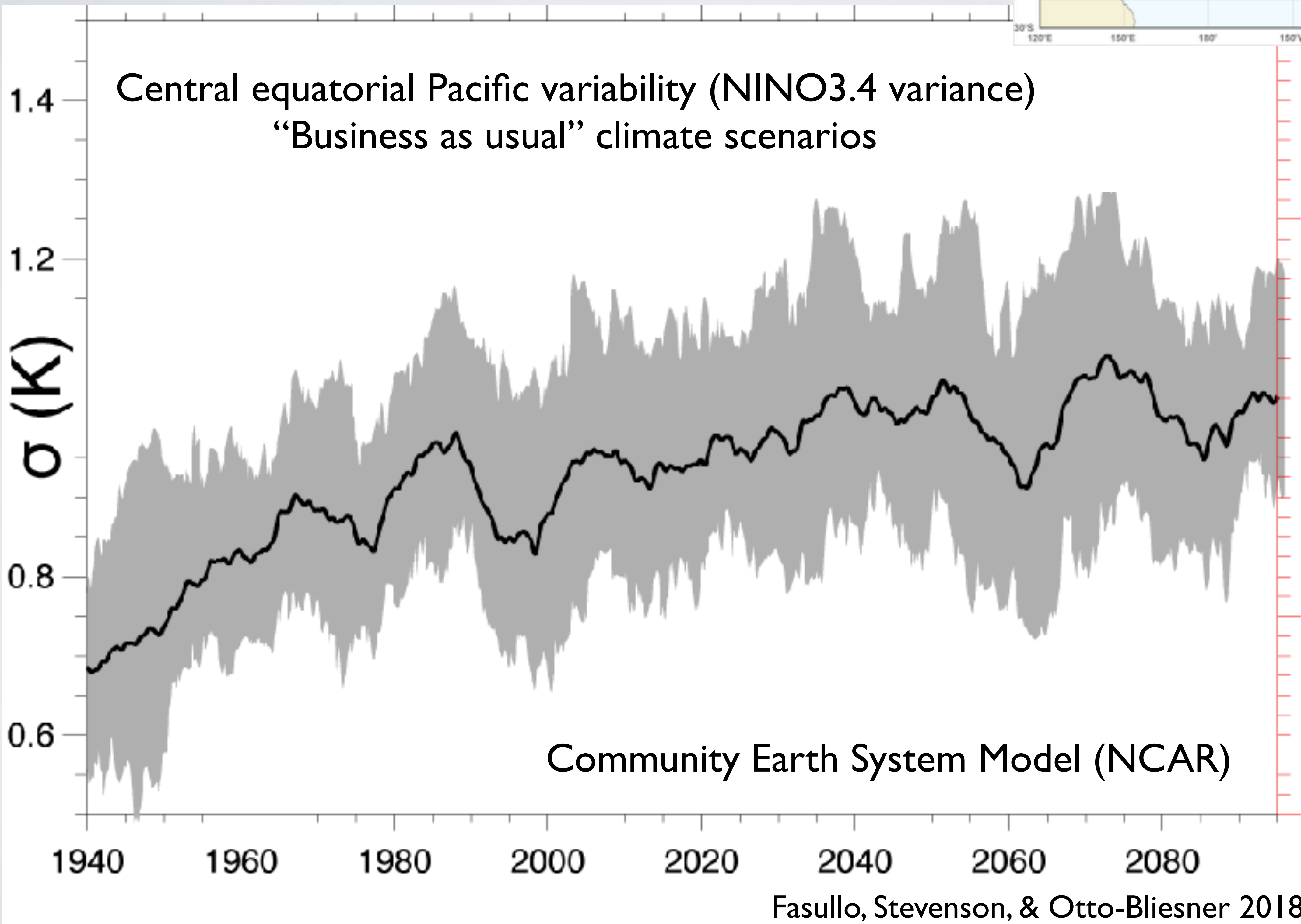
Multiple ensembles, varying sizes: different combinations of climate forcings 850-2005 (Orbital, solar, volcanic, GHG, ozone/aerosol, land use/land cover, all of the above)

CESM Large Ensemble: Kay et al. (2016)

30+ members, 20th century: 1920-2005; 21st century: 2006-2100 (RCP8.5)

CESM: El Nino, La Nina events both strengthen under climate change



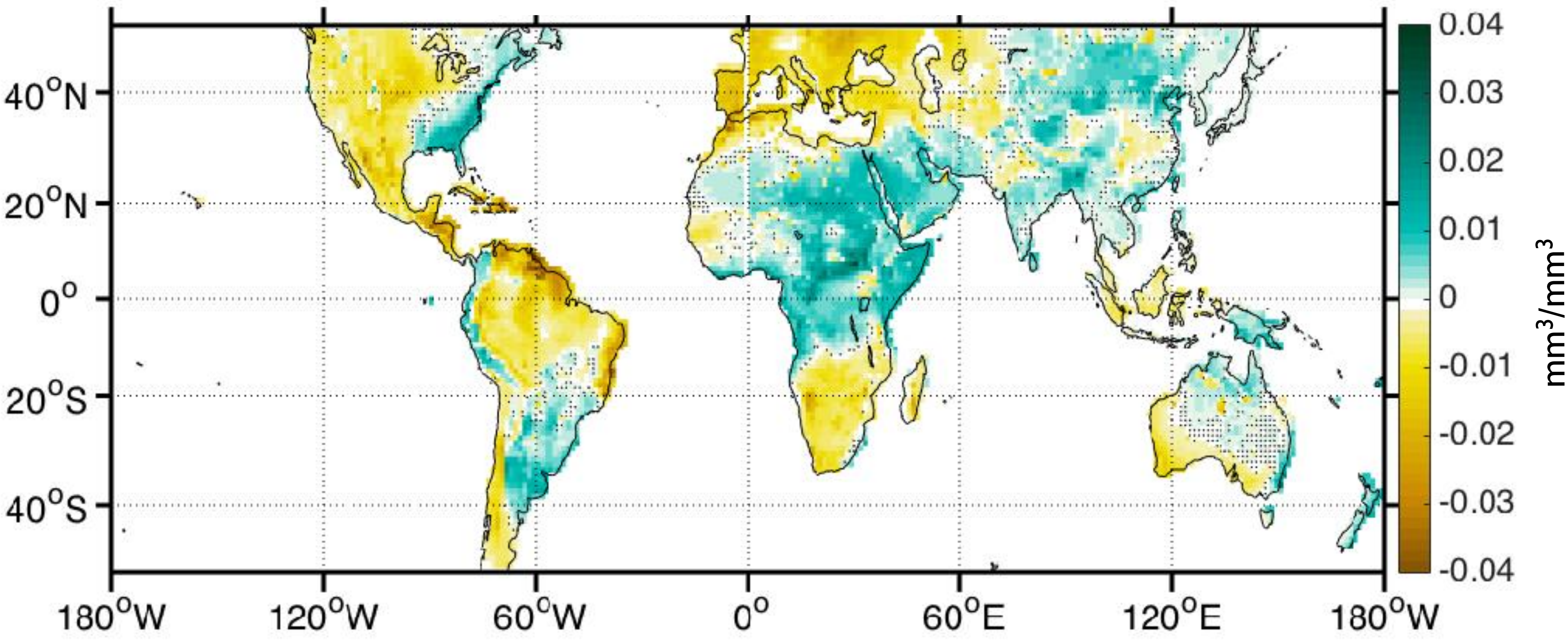


Stronger ENSO

Weaker ENSO

21st century: drying projected for western N. America, Amazon

Difference in 0-30cm soil moisture: (2006-2100) - (1920-2005), CESM Large Ensemble



Stevenson et al. (2019), in prep

Megadrought risk increases in regions experiencing drying trends

15-year drought (0.5σ threshold)

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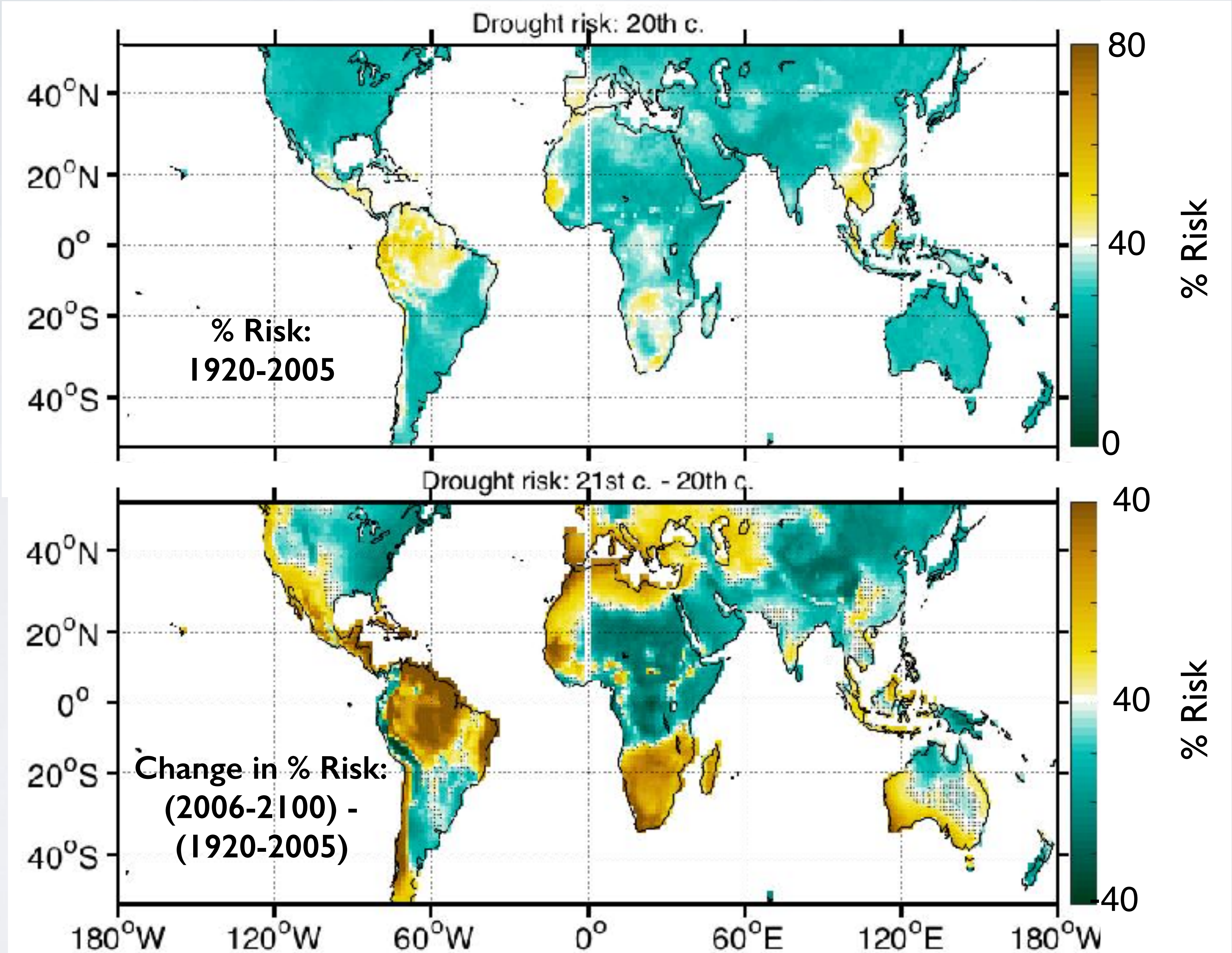
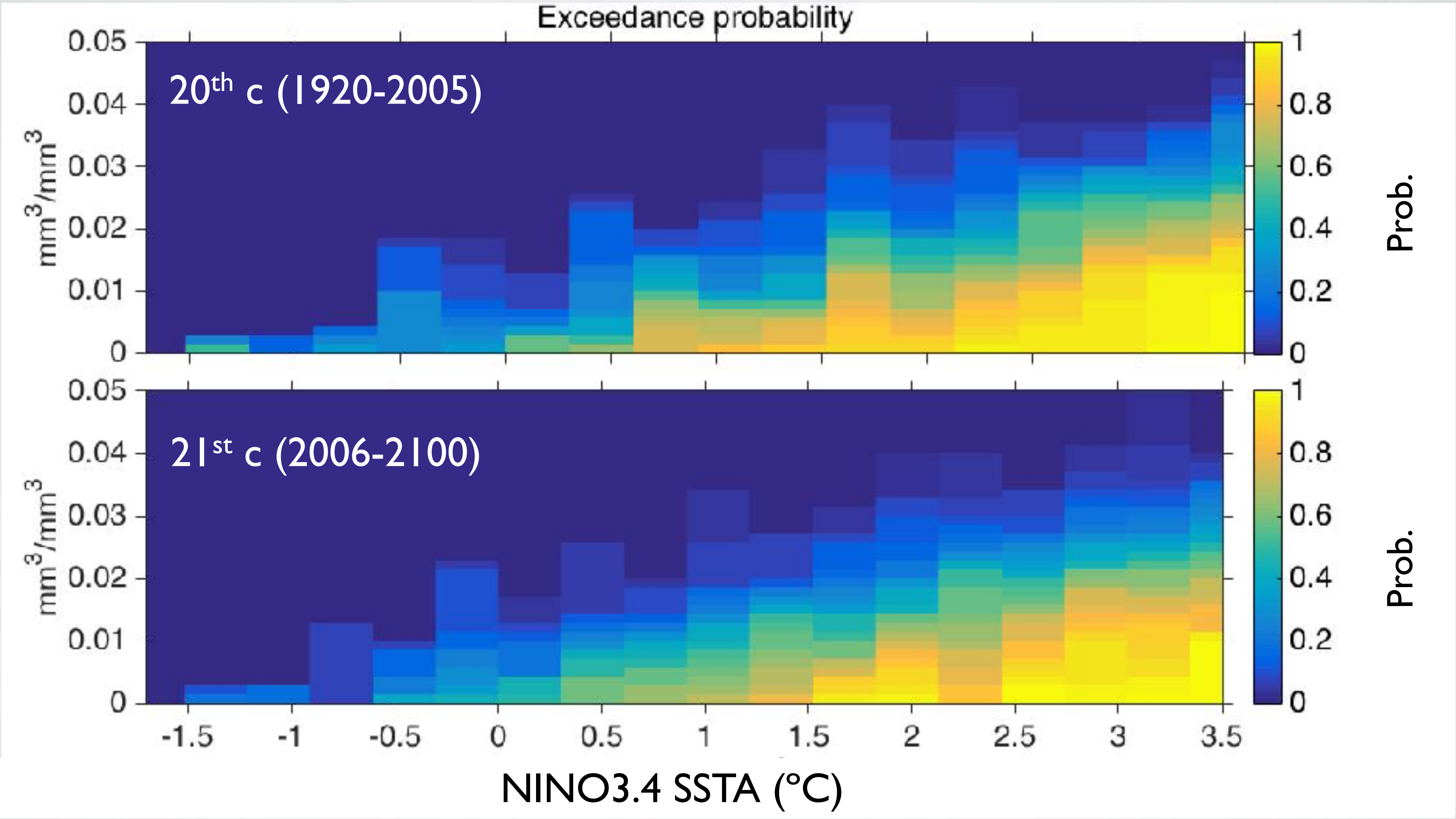


Stevenson et al. (2019), in prep

Warming reduces El Niño-induced drought termination in the western US

North American Southwest (30-45°N, 95-115°W) 0-30cm soil moisture

Exceedance probability = likelihood of JJA threshold exceedance given DJF NINO3.4 SSTA



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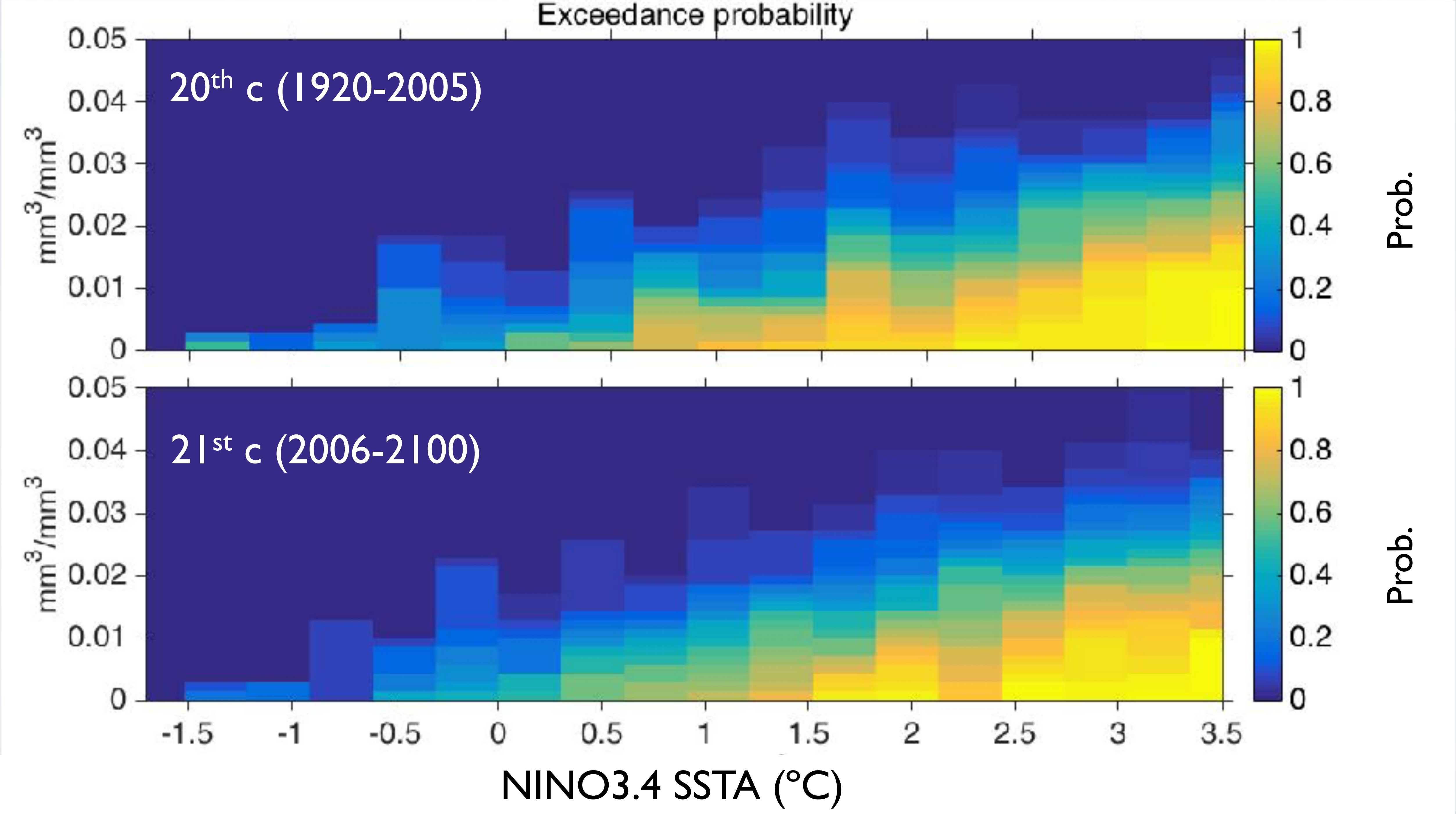

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Warming *increases* La Niña-induced drought termination in Australia

Australia (20-40°S, 120-160°E) 0-30cm soil moisture
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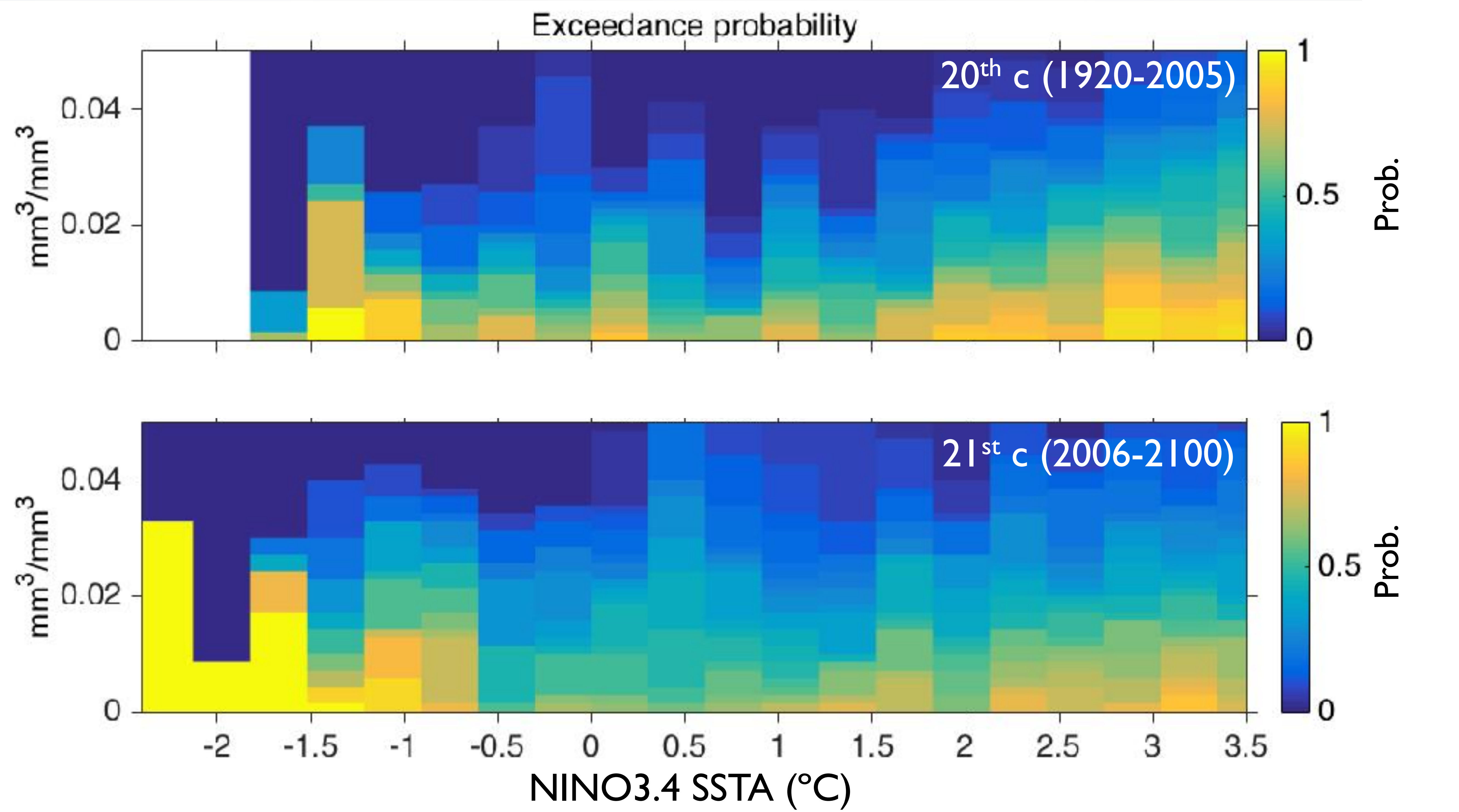

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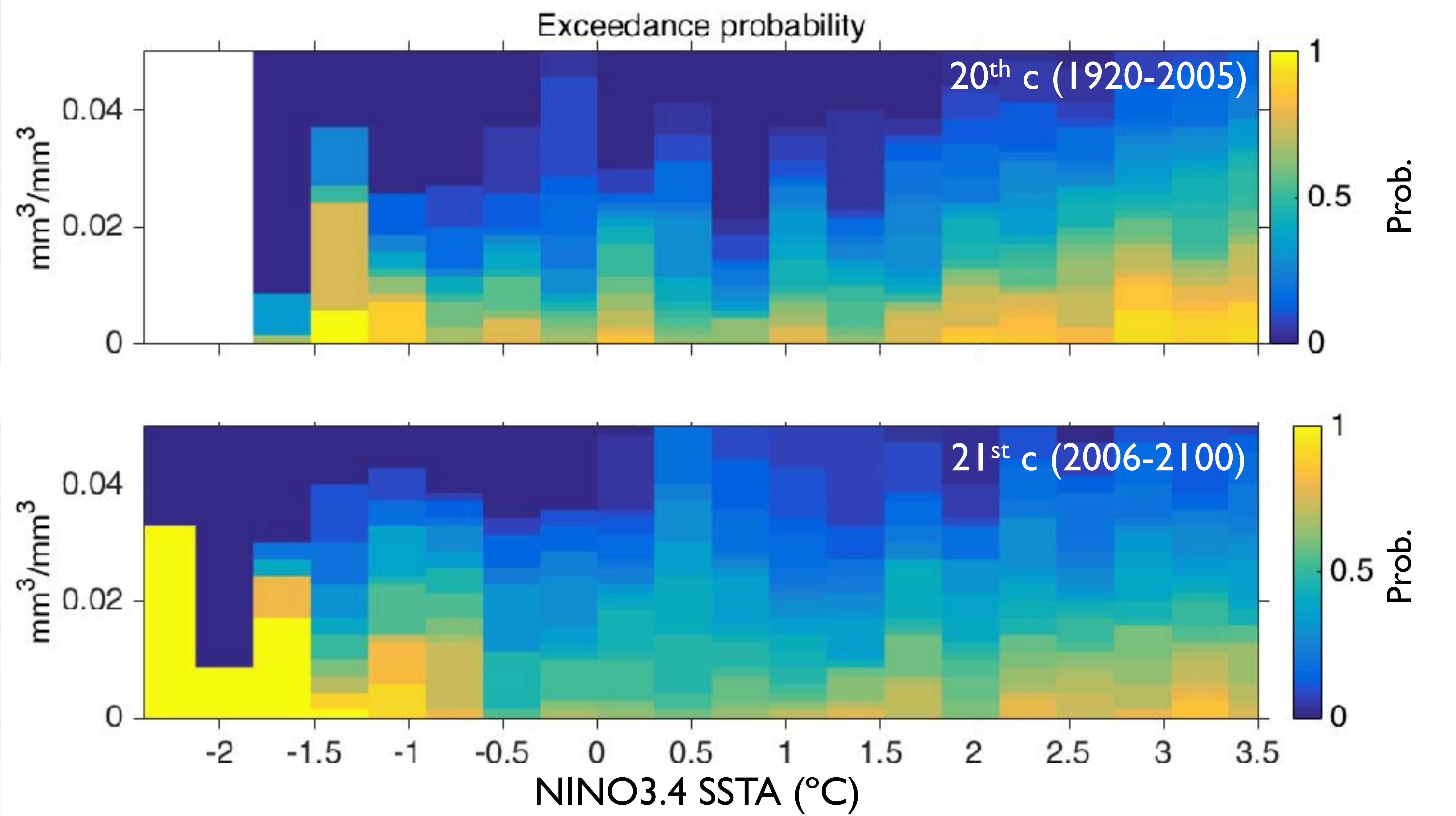

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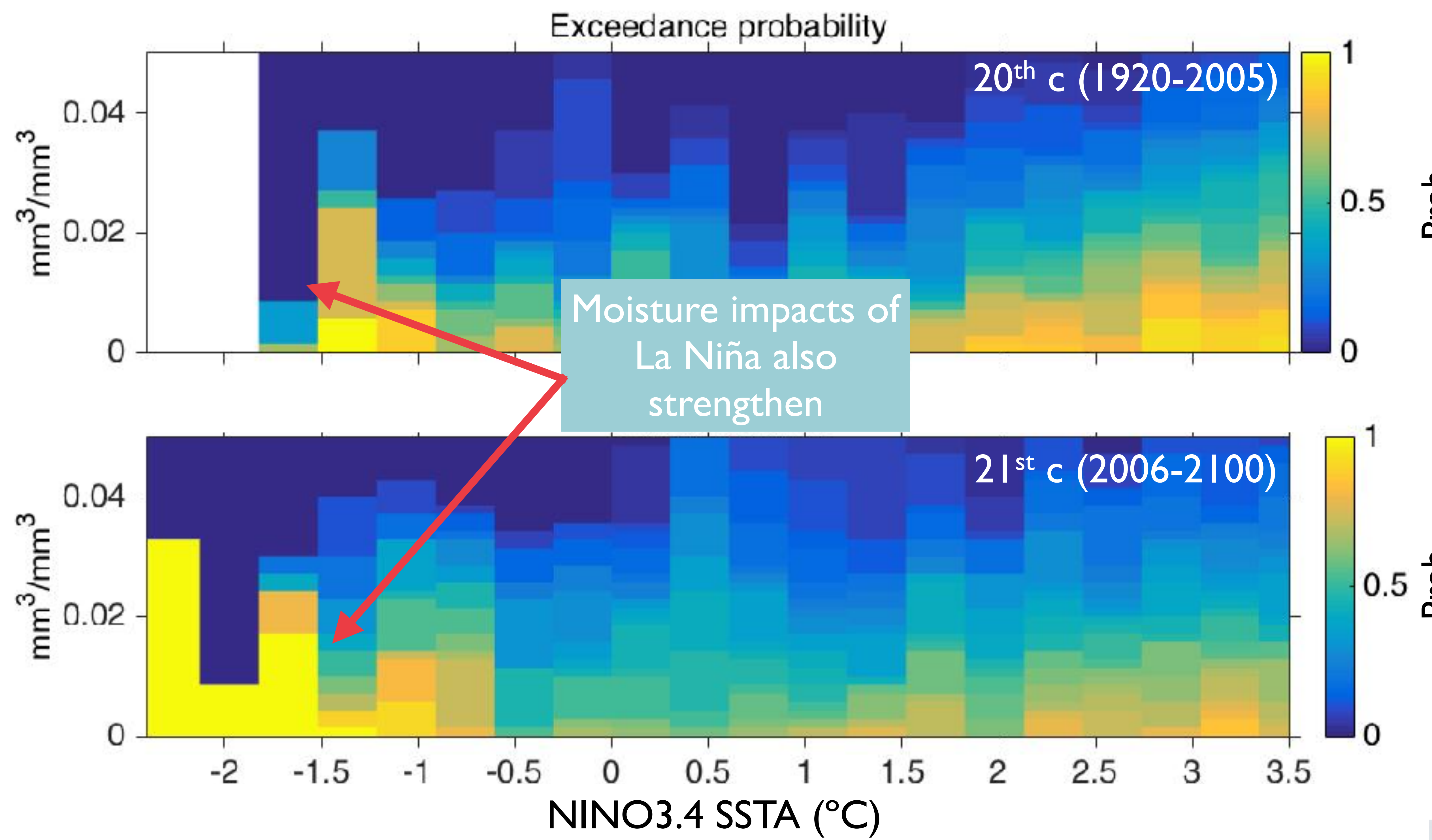

Stevenson et al. (2019), in prep

Conclusions

Megadroughts arise from internal atmospheric variability, coupled atmosphere/ocean/land processes, and impacts from external climate change

- Stronger tropical Pacific variability (ENSO) tends to reduce persistence of megadrought in the Southwest US, Australia, monsoon Asia

- Effects on persistence largely due to tendency for El Niño/La Niña to favor transitions between drought/pluvial states

- Changes to future ENSO are uncertain, but impacts of El Niño/La Niña likely to strengthen

- El Niño-induced megadrought termination in the US SW will still likely decrease due to overall 21st century warming trend

- La Niña-related megadrought termination in Australia likely to increase: trends not as large

Potential for changes to the predictability of "megadrought" start/end times due to tropical Pacific conditions; understanding future changes to ENSO and its teleconnections is key