Past, Present, and Future Impacts of Drought on Forests in the Southwestern USA

Park Williams, Craig D. Allen, Alison K. Macalady, Connie Woodhouse, David Meko, Tom Swetnam, Ed Cook, Daniel Griffin, Sara Rauscher, Richard Seager, Jeff Dean, Henri Grissino-Mayer, Xiaoyan Jiang, Michael Cai, Nate G. McDowell

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Photo: Craig D. Allen

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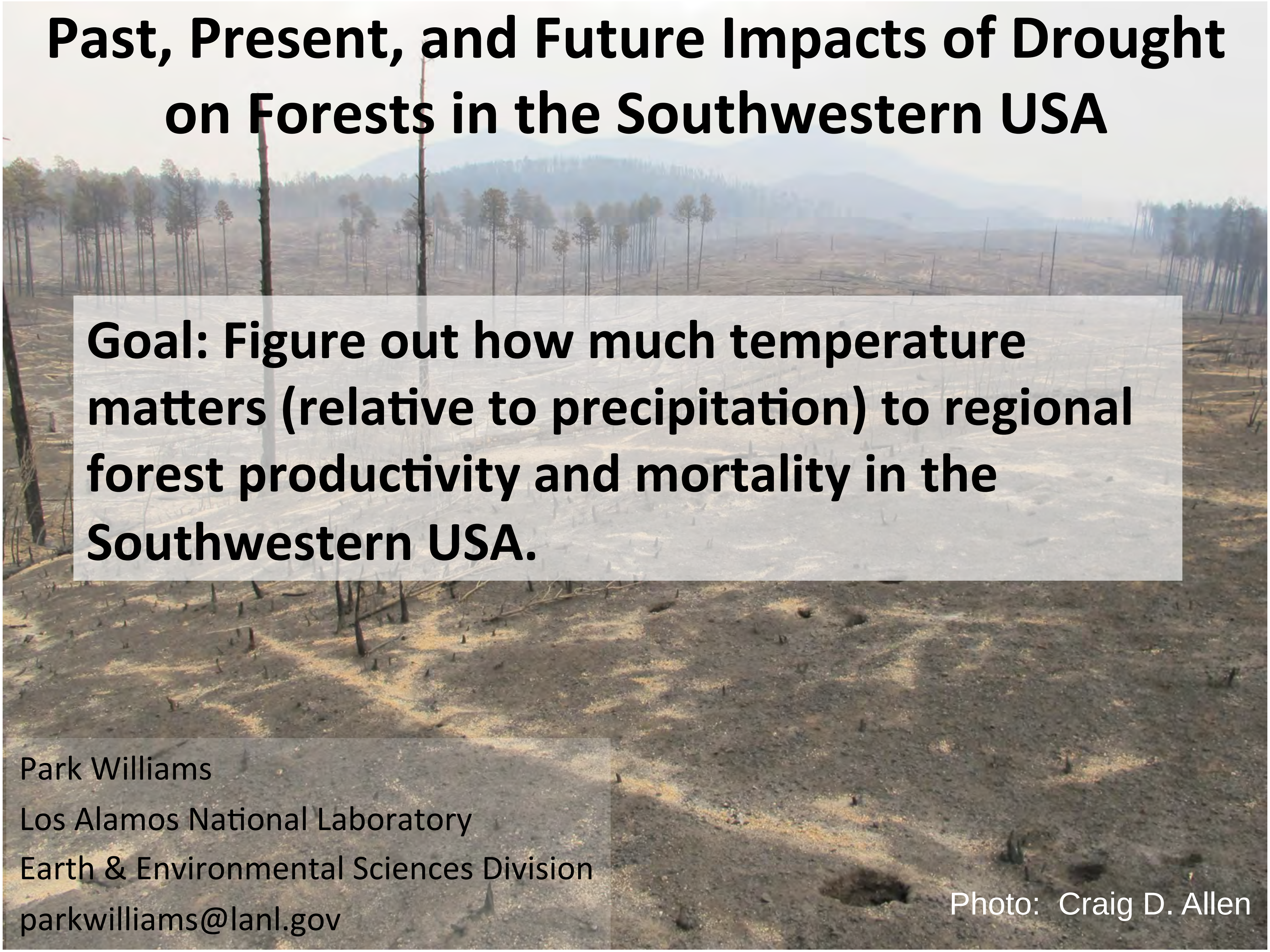

Goal: Figure out how much temperature matters (relative to precipitation) to regional forest productivity and mortality in the Southwestern USA.

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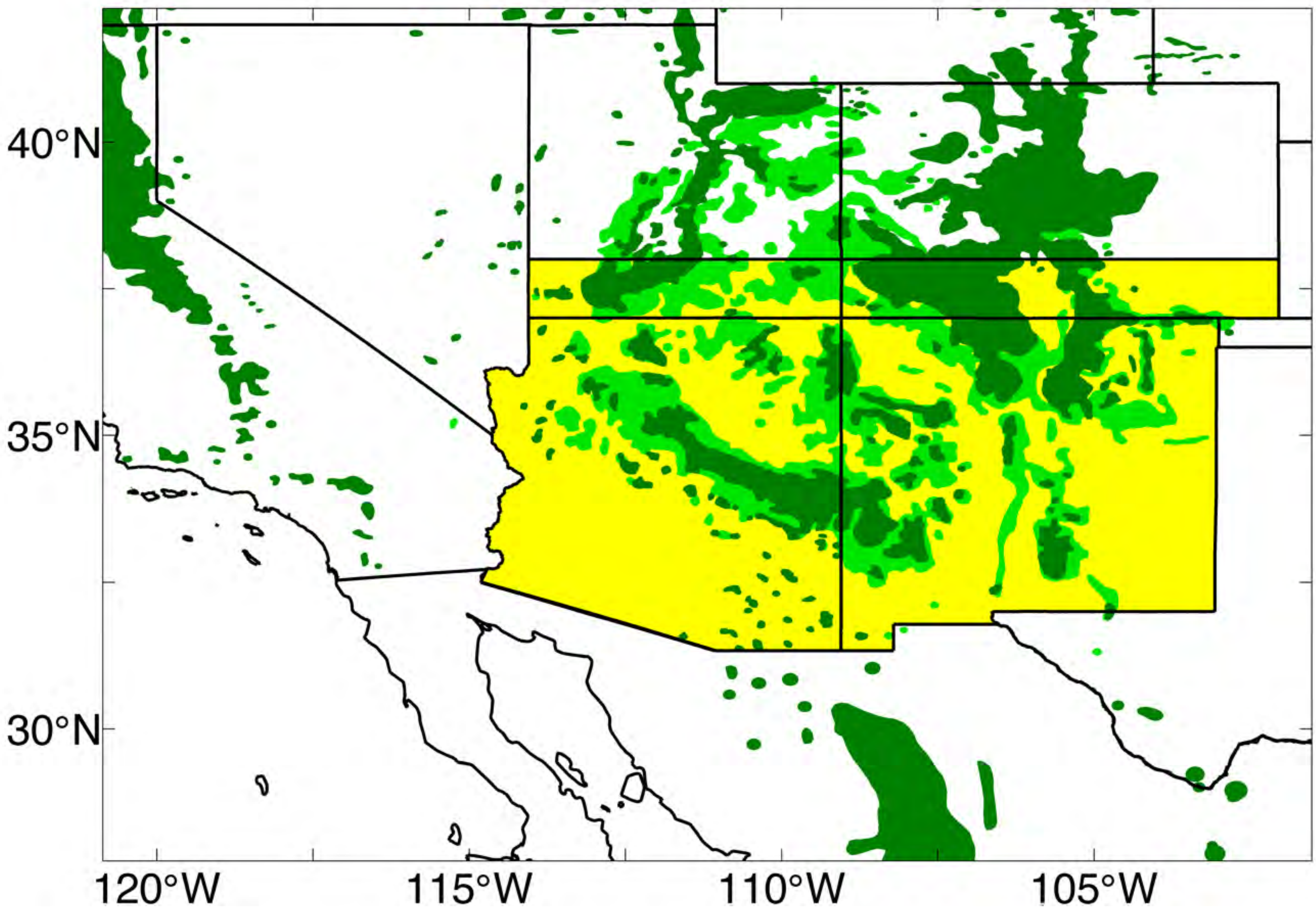
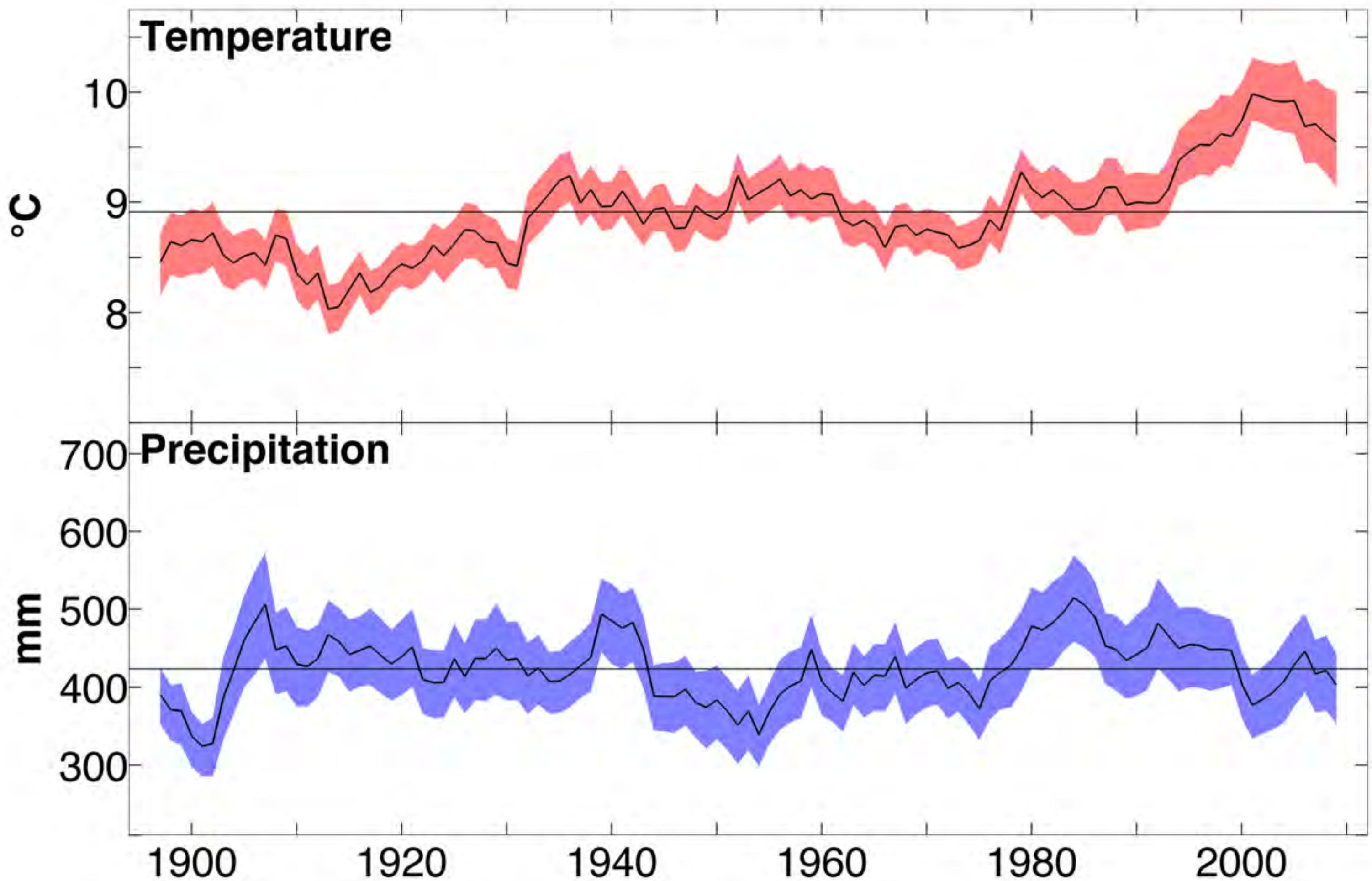
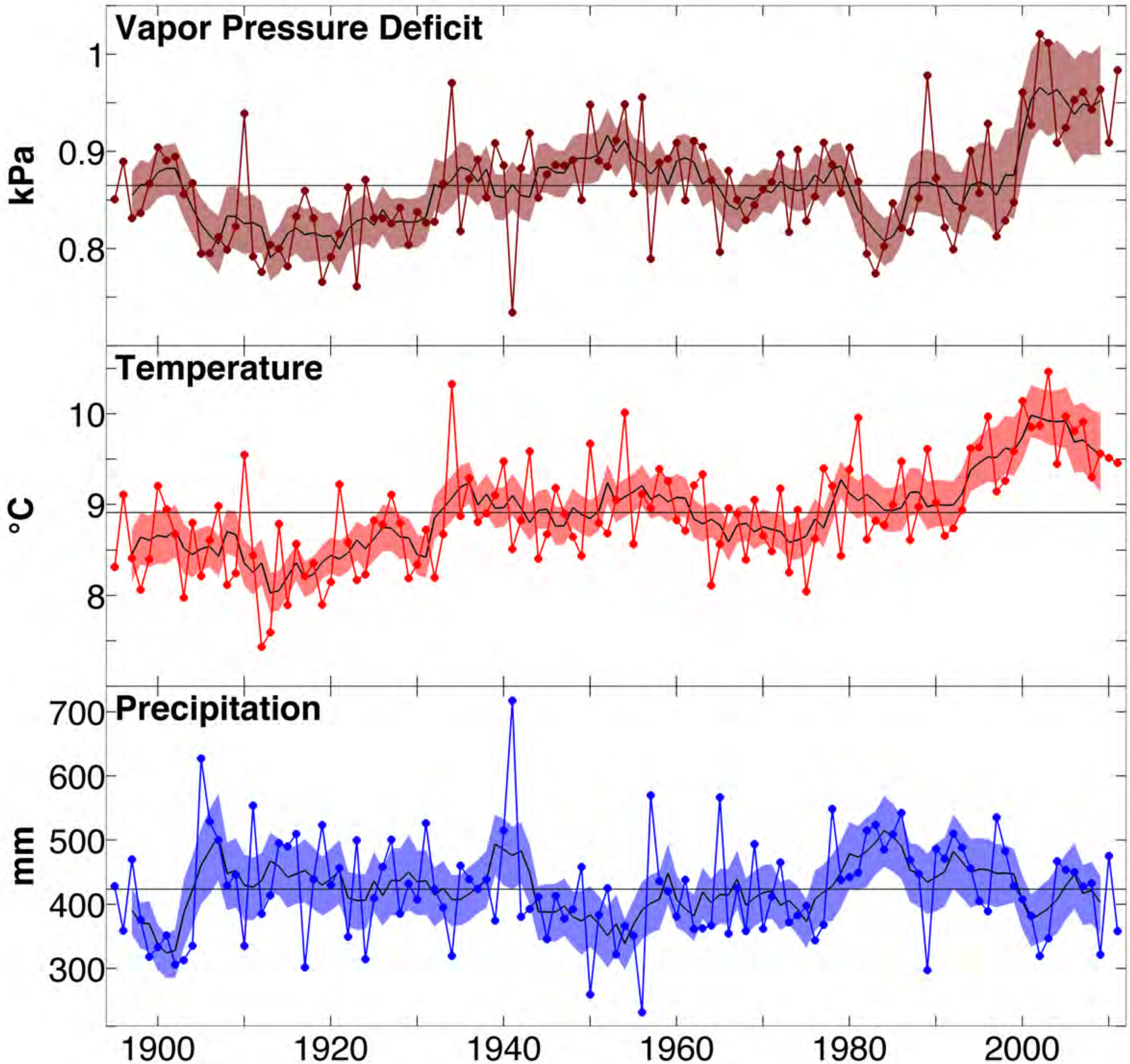
Southwest United States



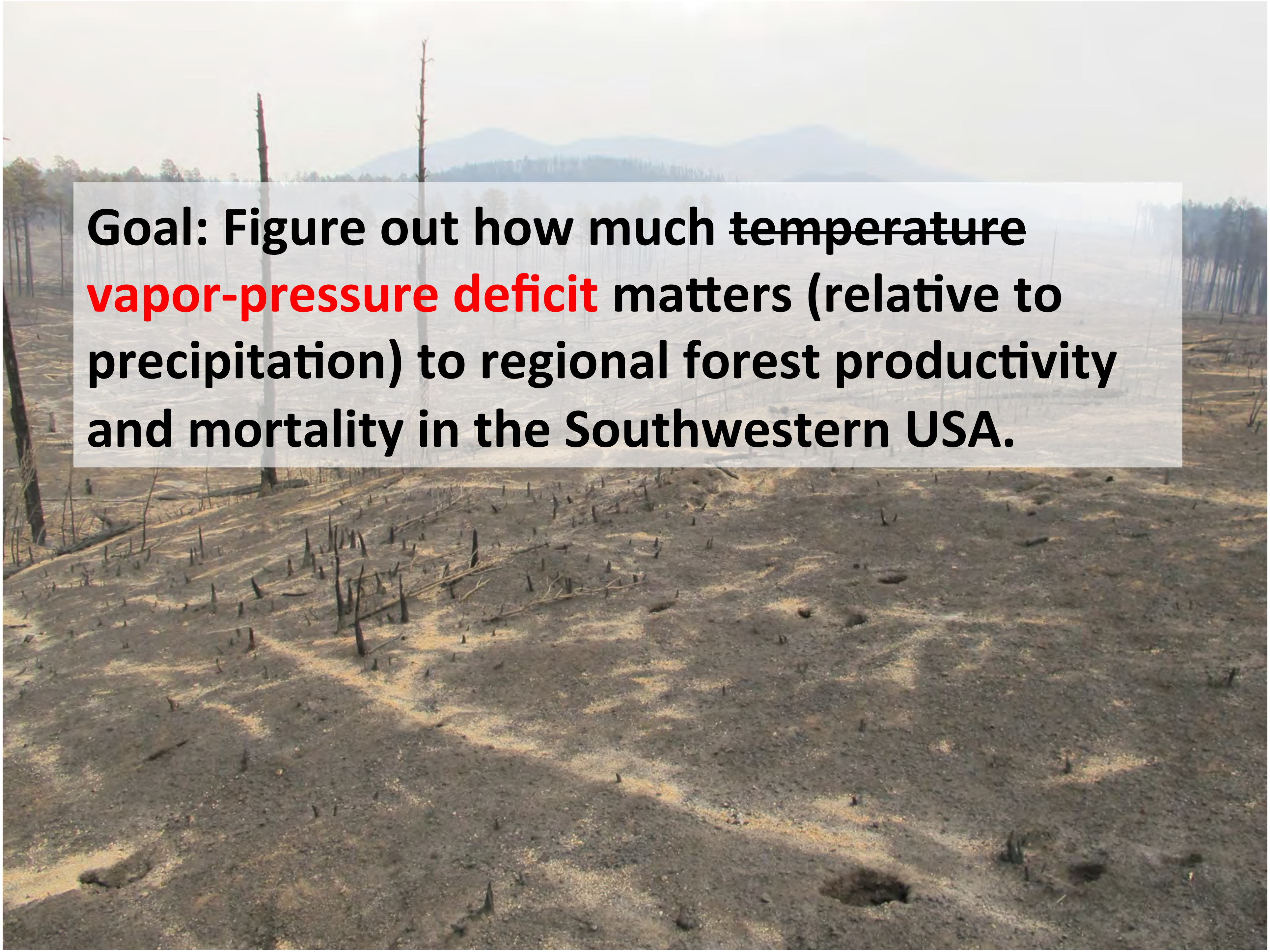
Last 117 Years of Climate in the Southwest

5-Year Running Average





Vapor Pressure Deficit
kPa
1
0.9
0.8
Temperature
°C
10
9
8
Precipitation
mm
700
600
500
400
300
1900
1920
1940
1960
1980
2000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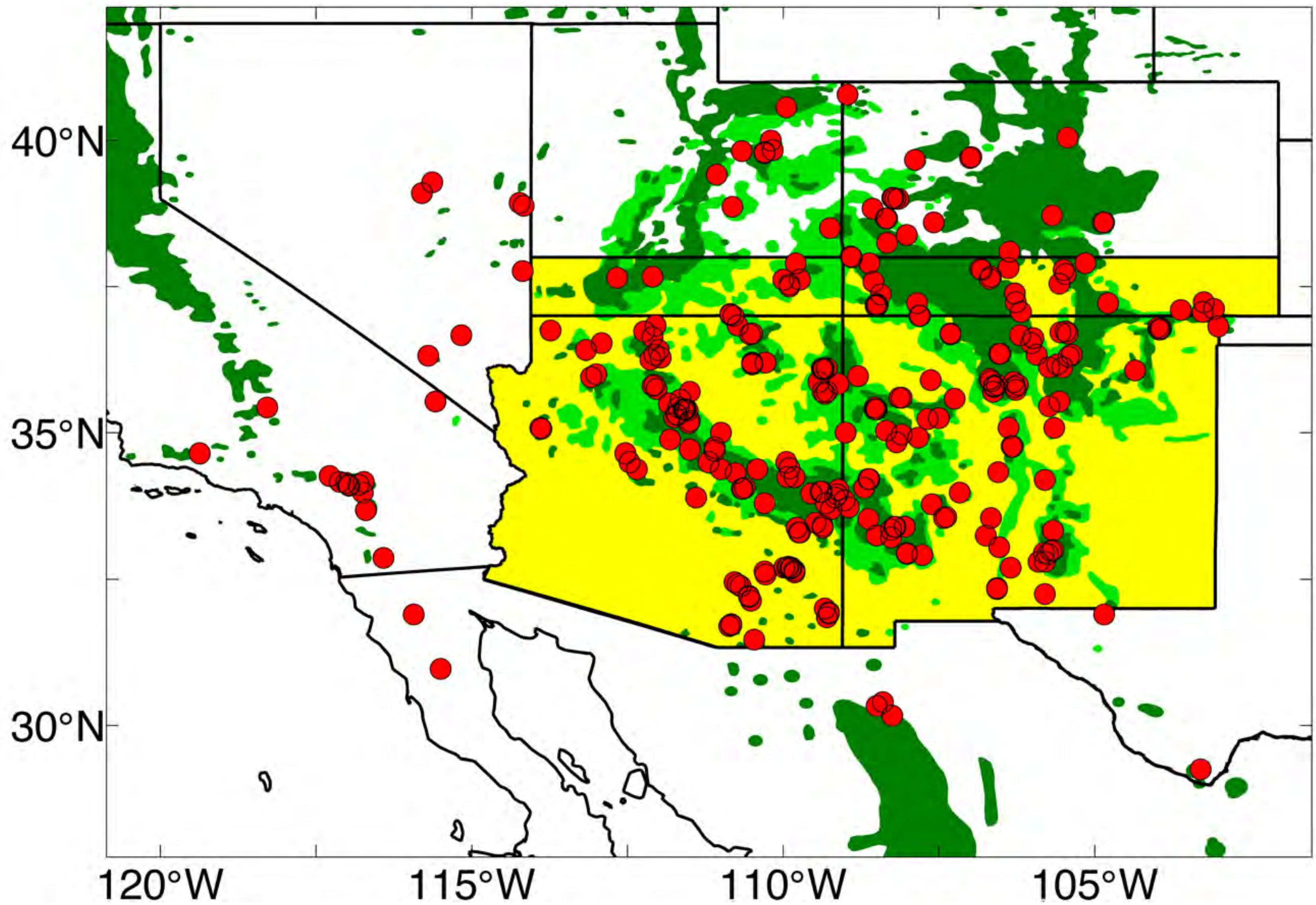
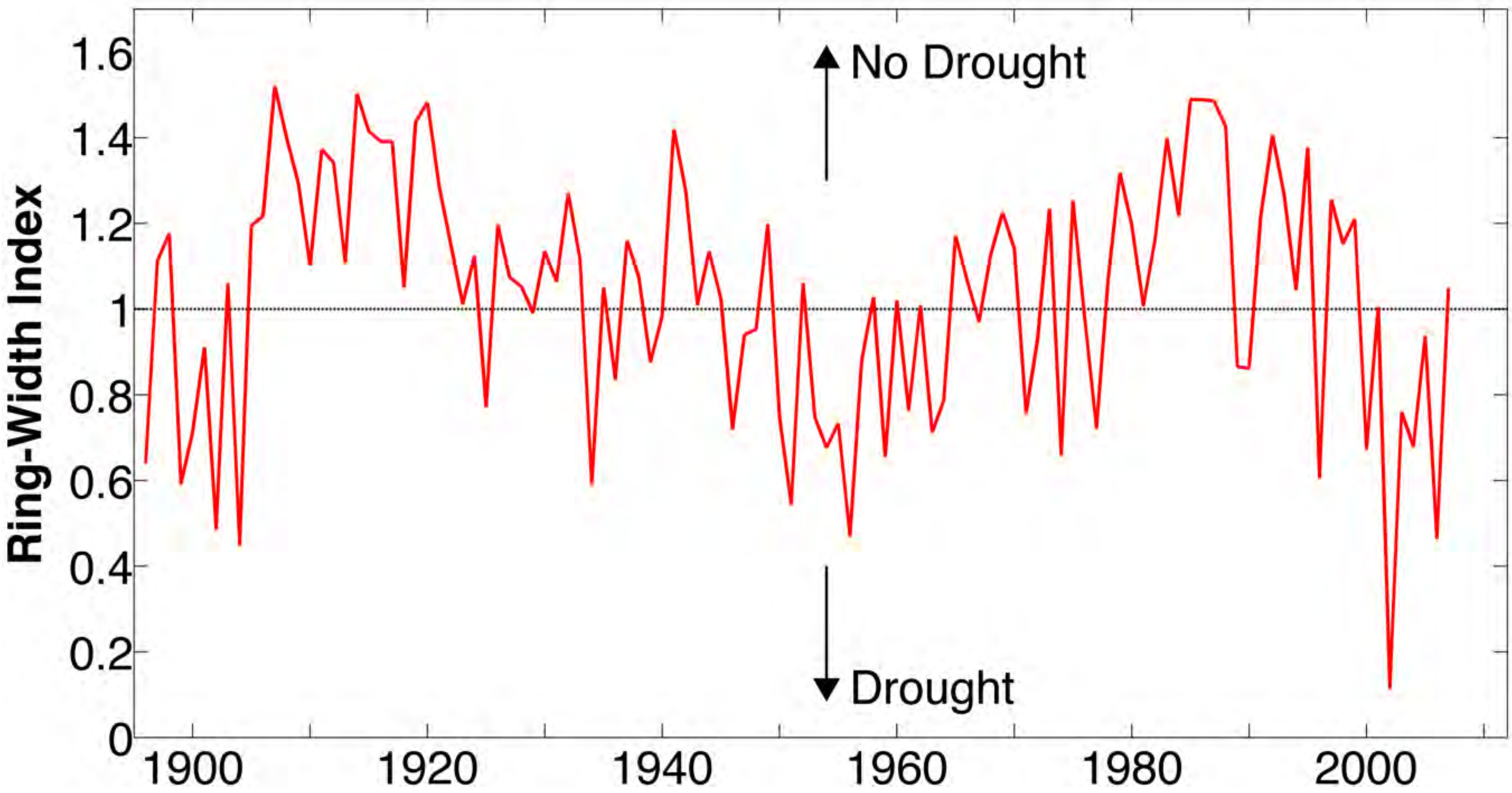
336 Tree-Ring Sites

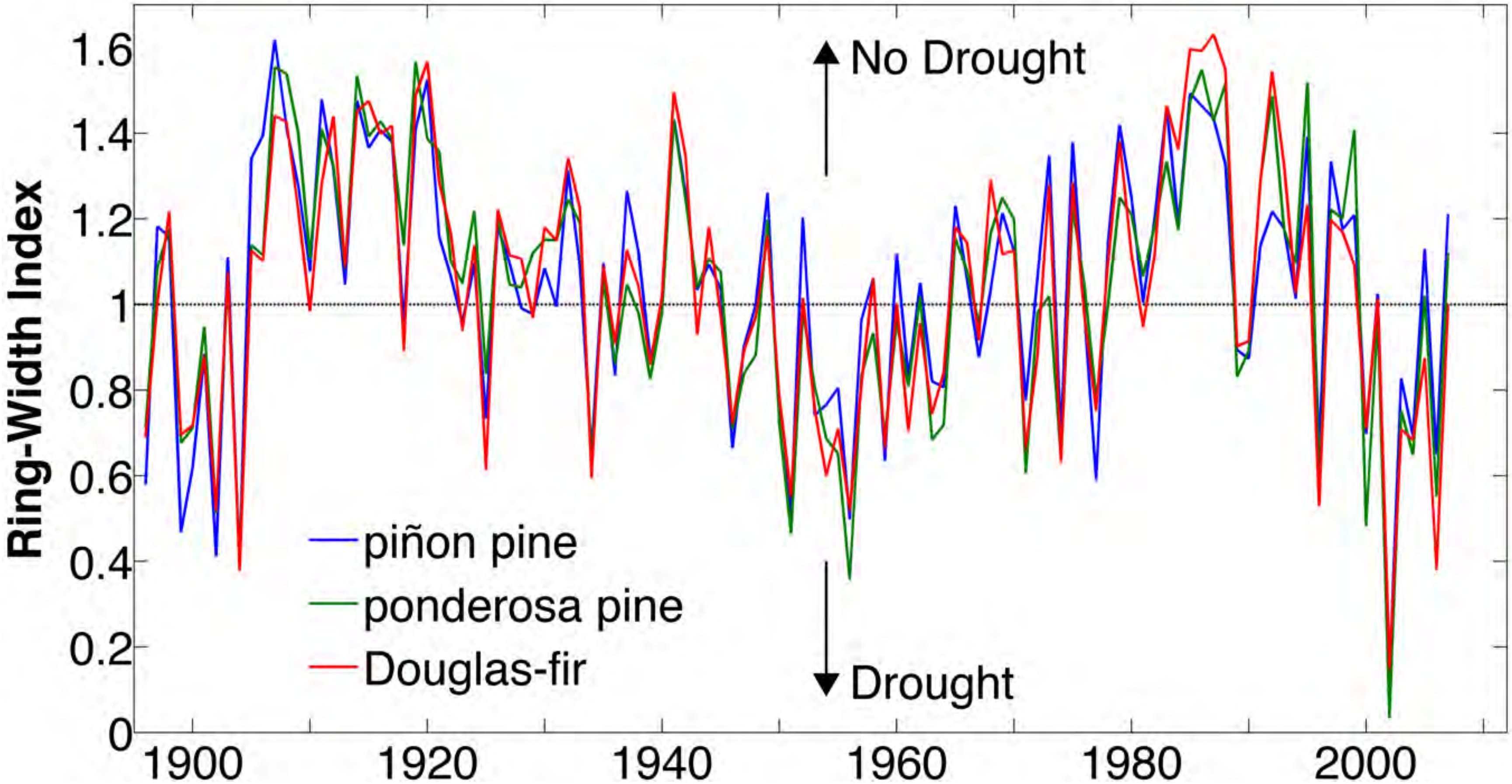


Regional Ring-Width Record



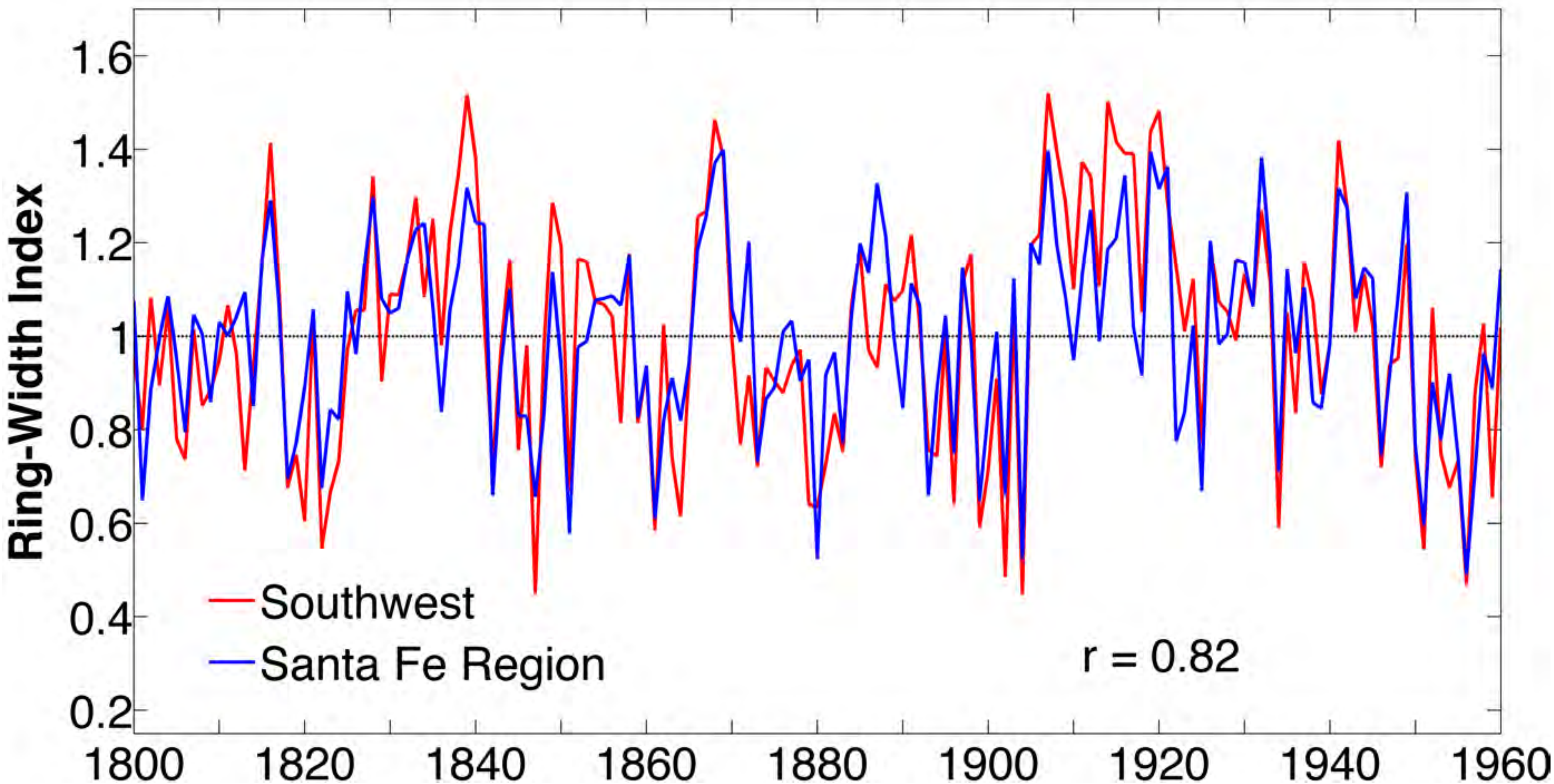
Regional Ring-Width Record

3 Primary Tree Species



Regional Ring-Width Record

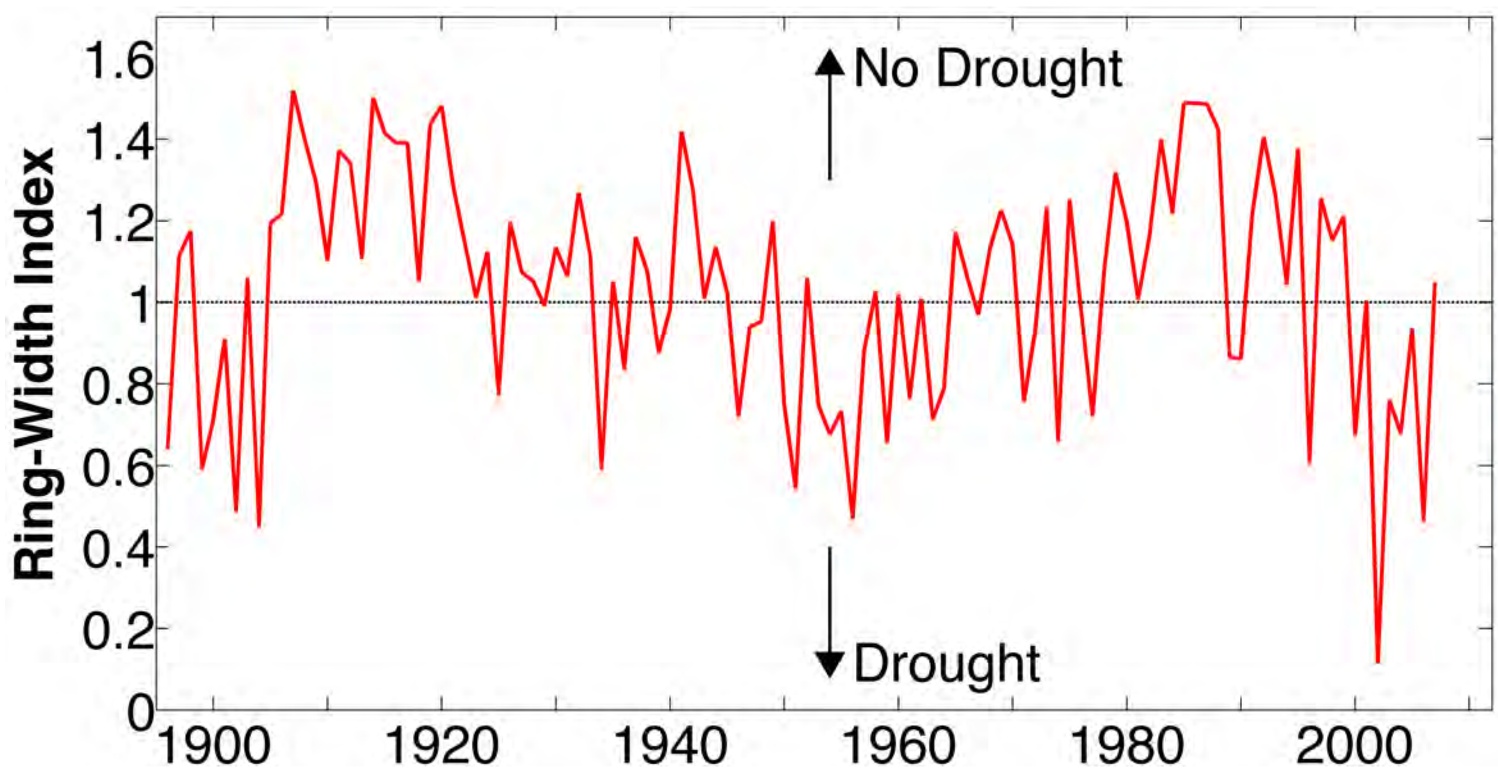
Southwest-wide record represents local region well



Ring-Widths Vs. Climate

During which seasons are precipitation and vapor-pressure deficit most influential on the regional ring-width record?

Previous year			Growth year		
May-July	Aug.-Oct.	Nov.-Jan.	Feb.-April	May-July	Aug.-Oct.



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				VPD	
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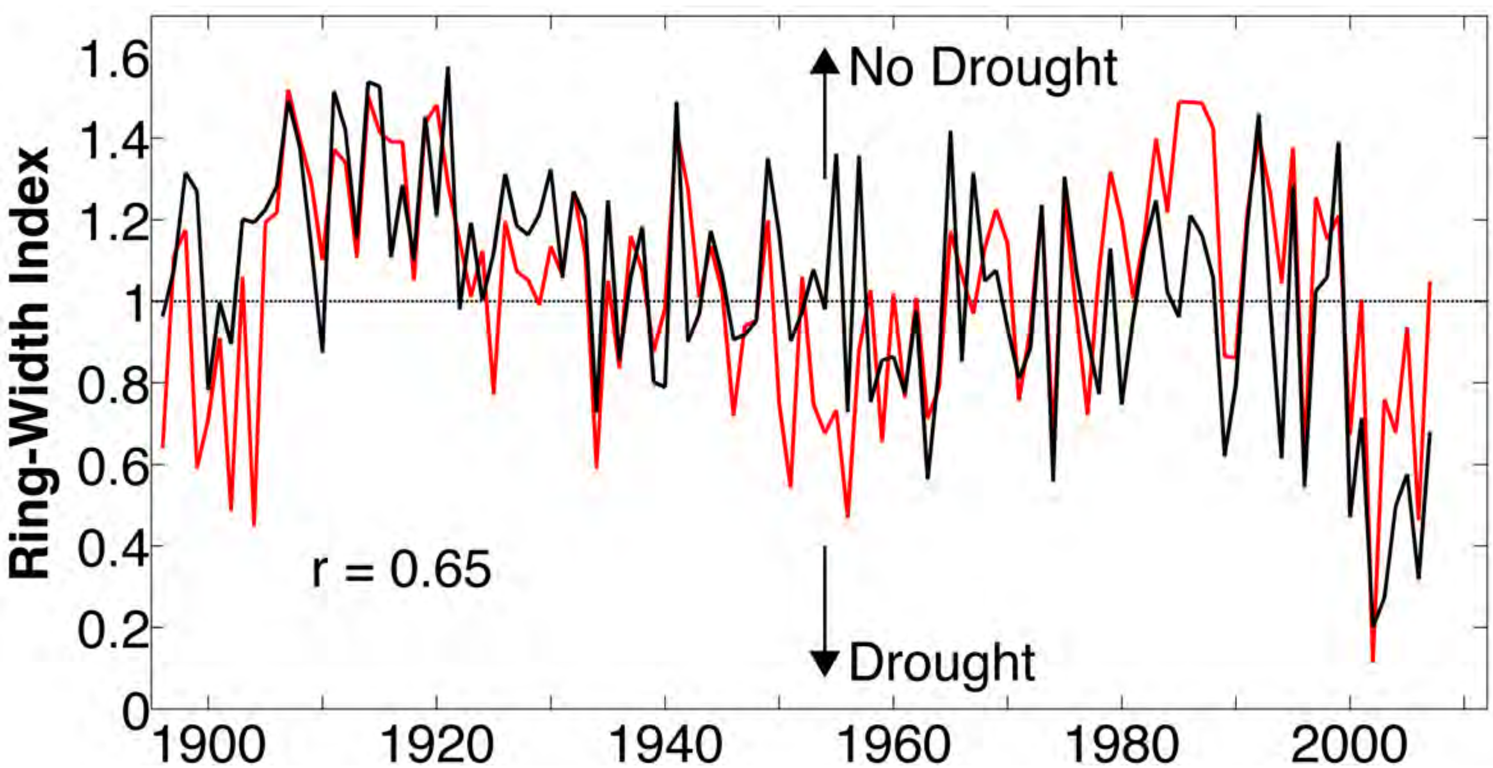

Ring-Widths Vs. Climate

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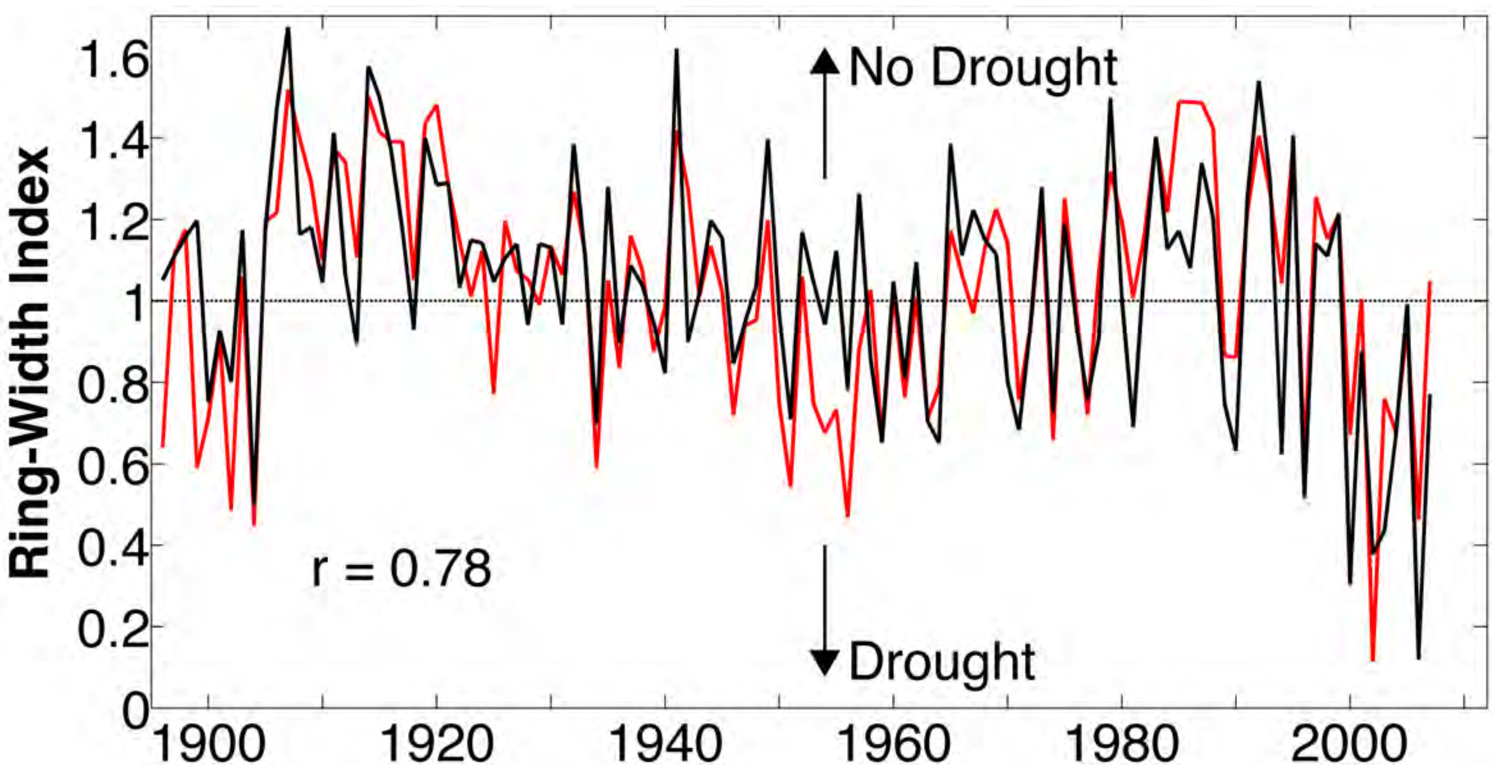

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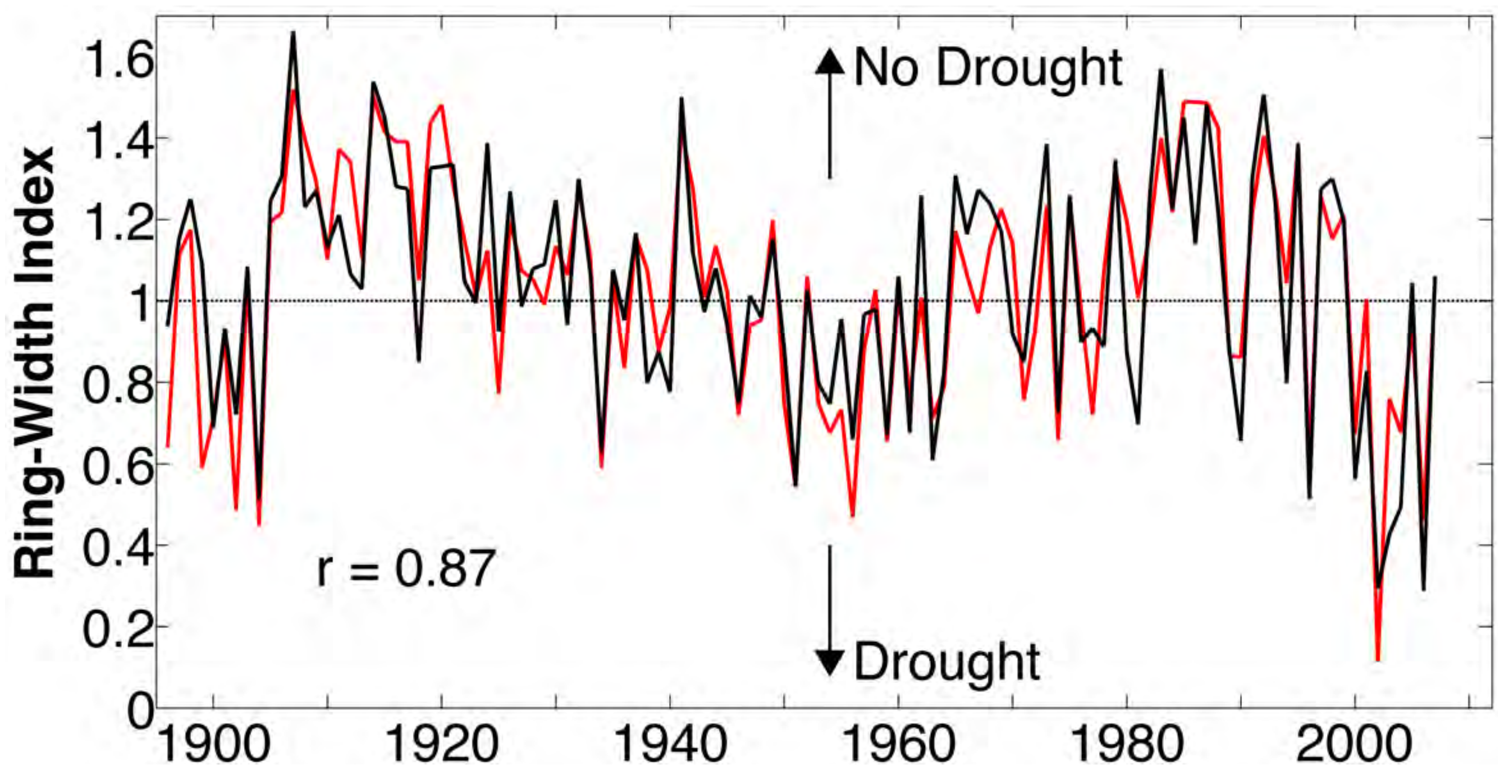

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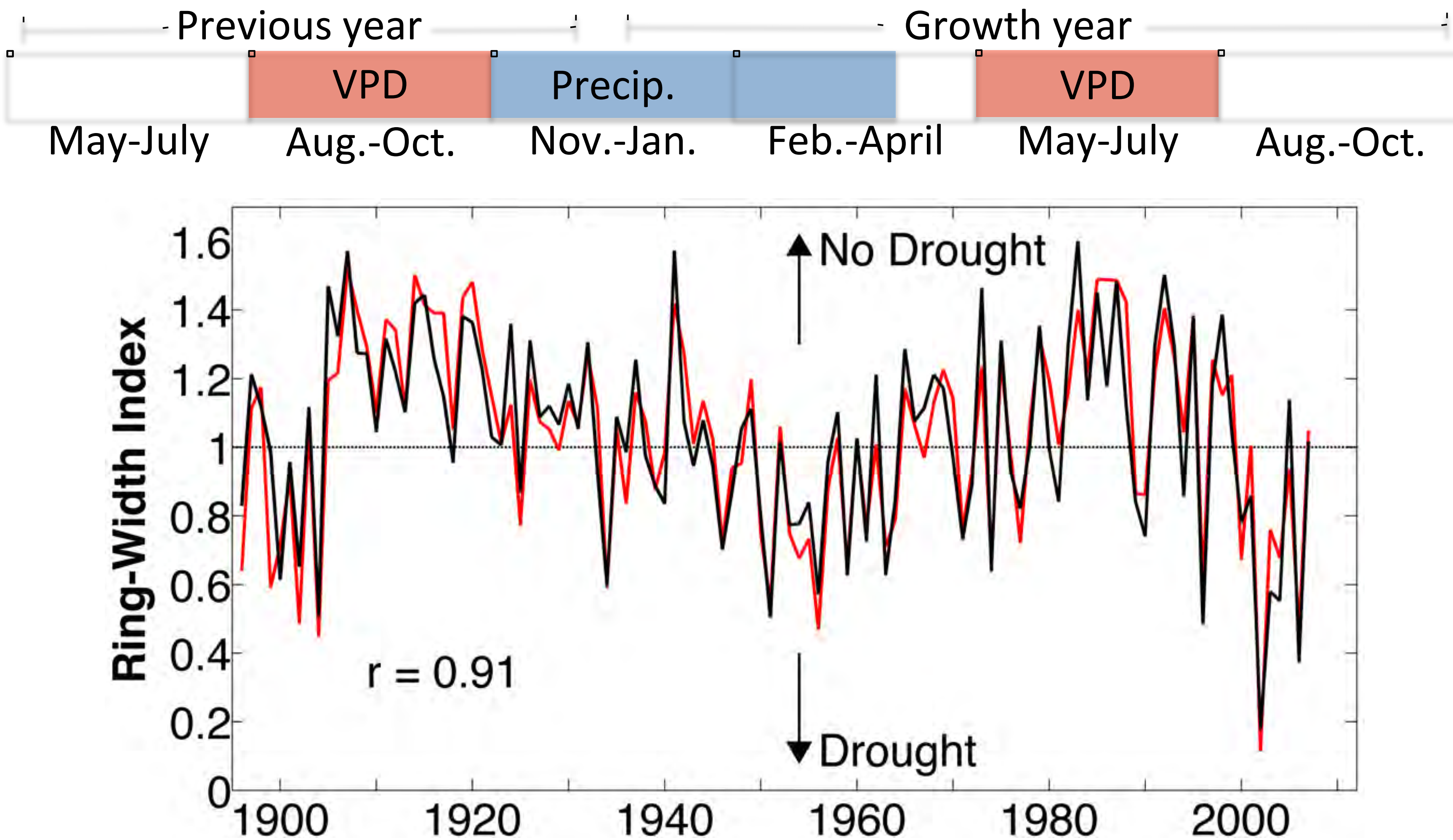

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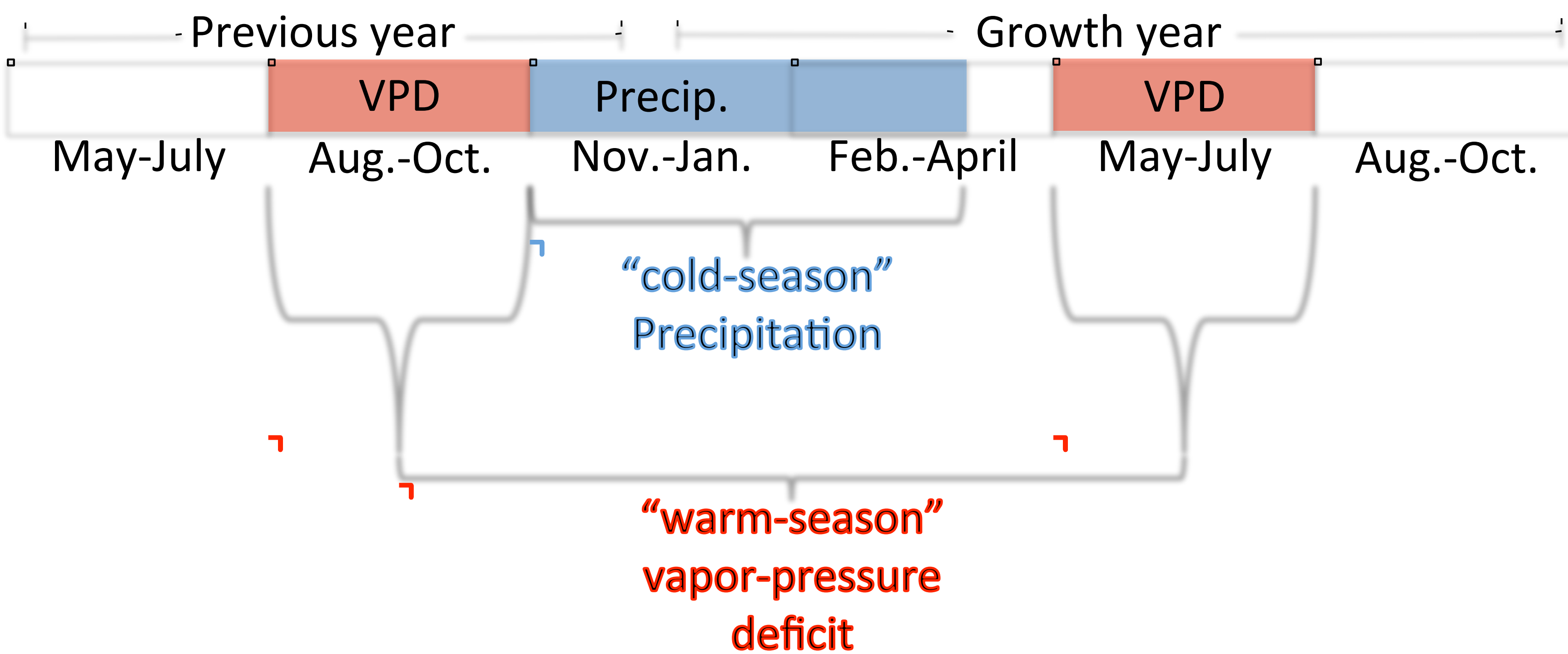

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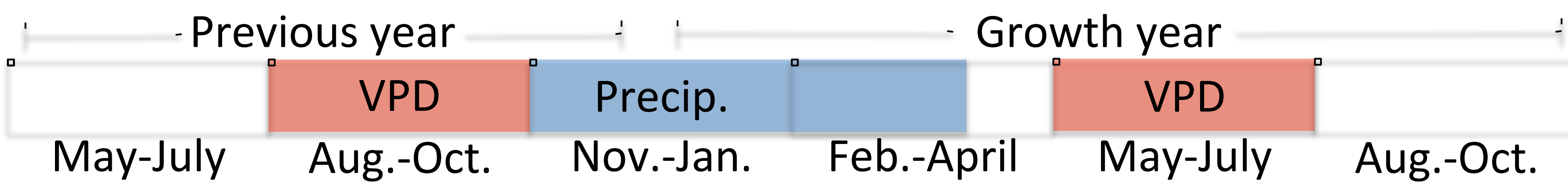
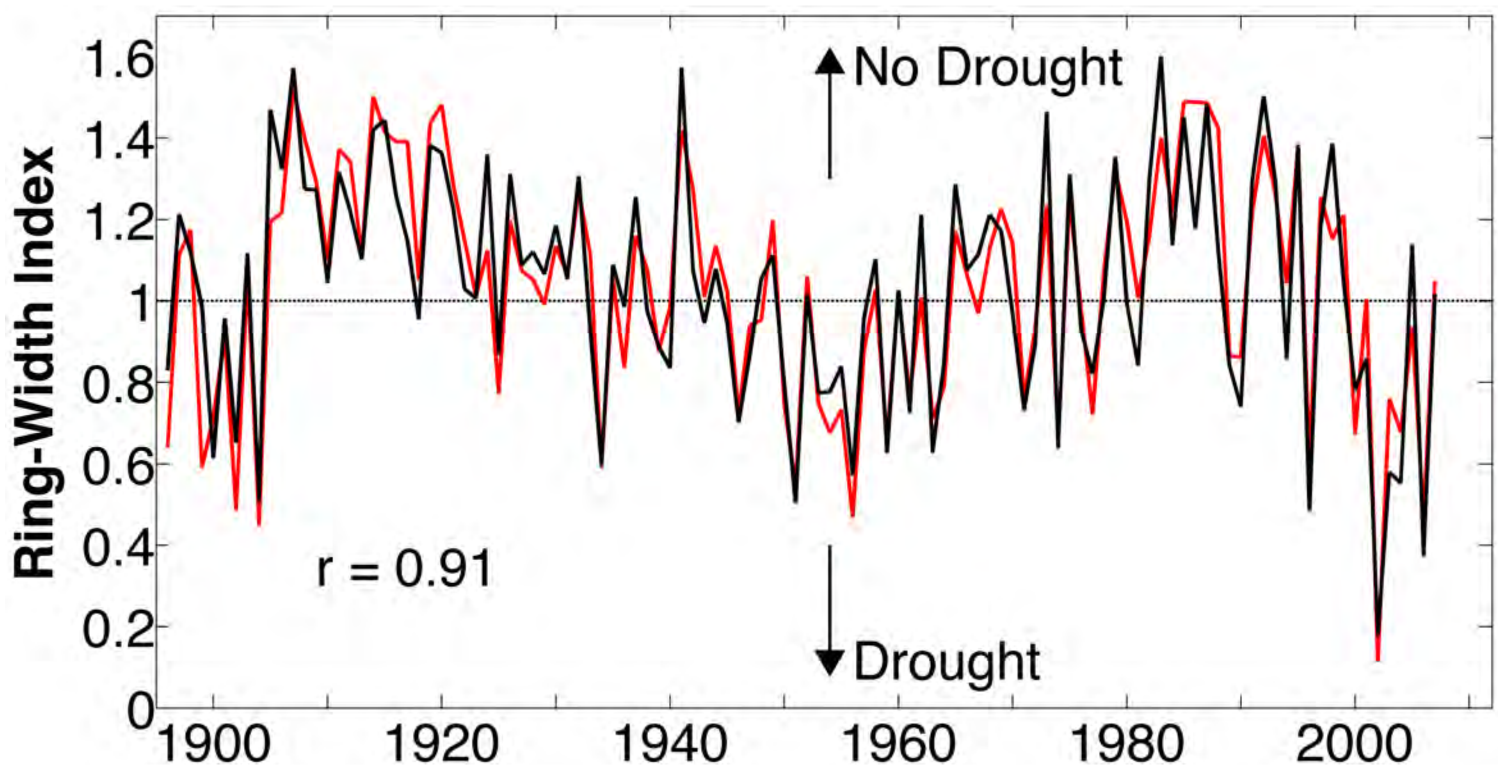
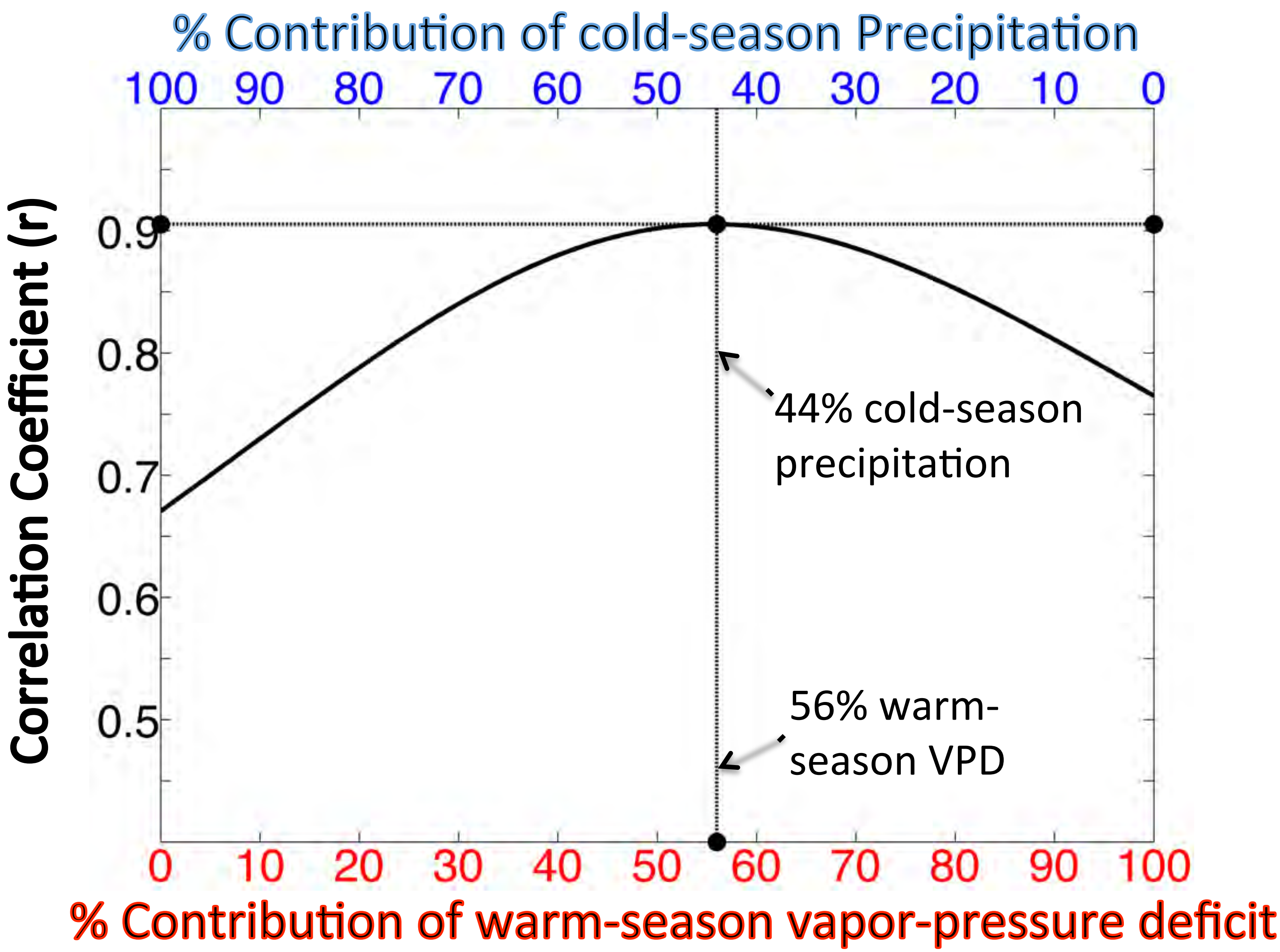


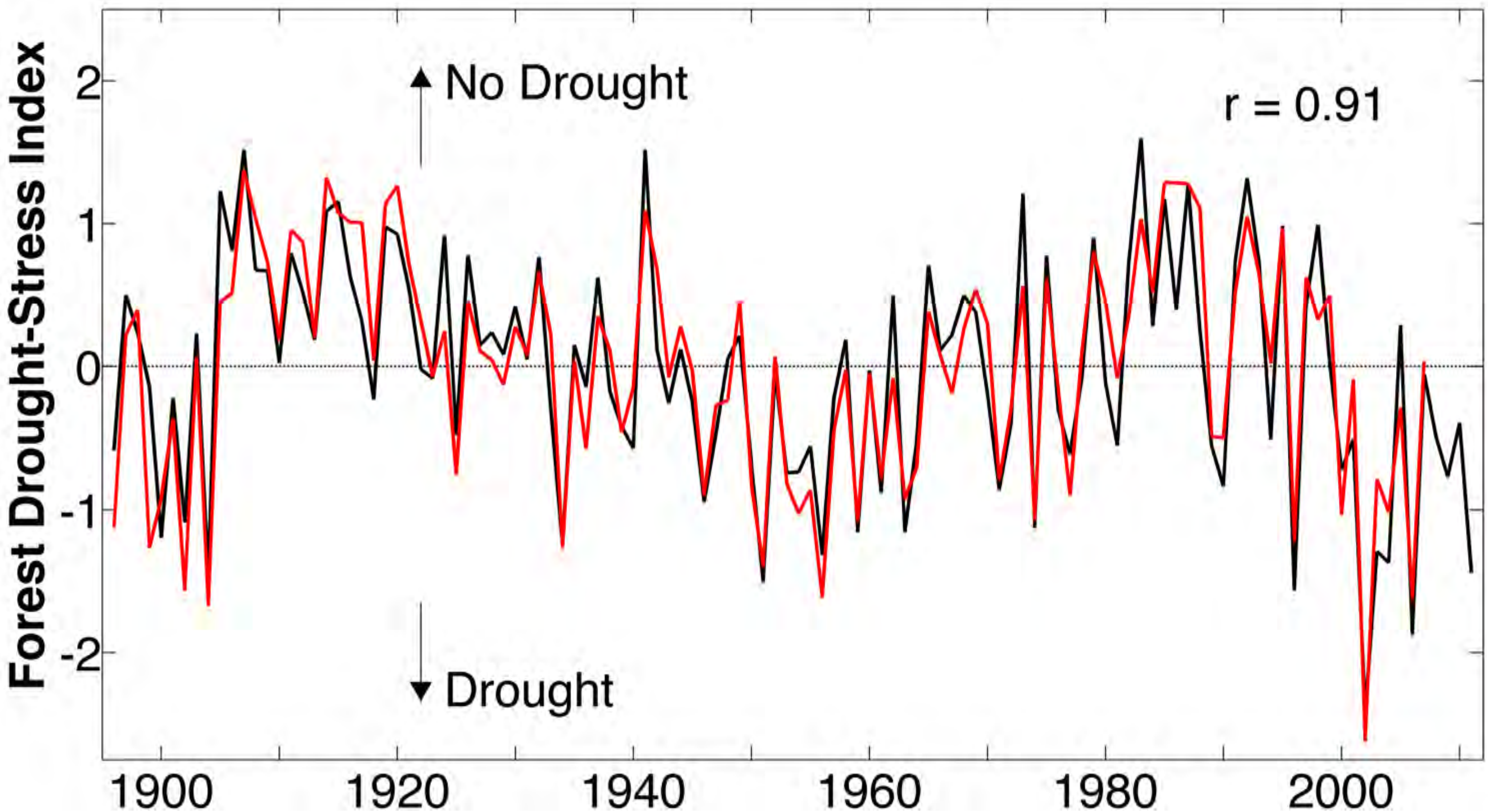


Warm-season Vapor-Pressure Deficit is **AT LEAST** as important as cold-season precipitation

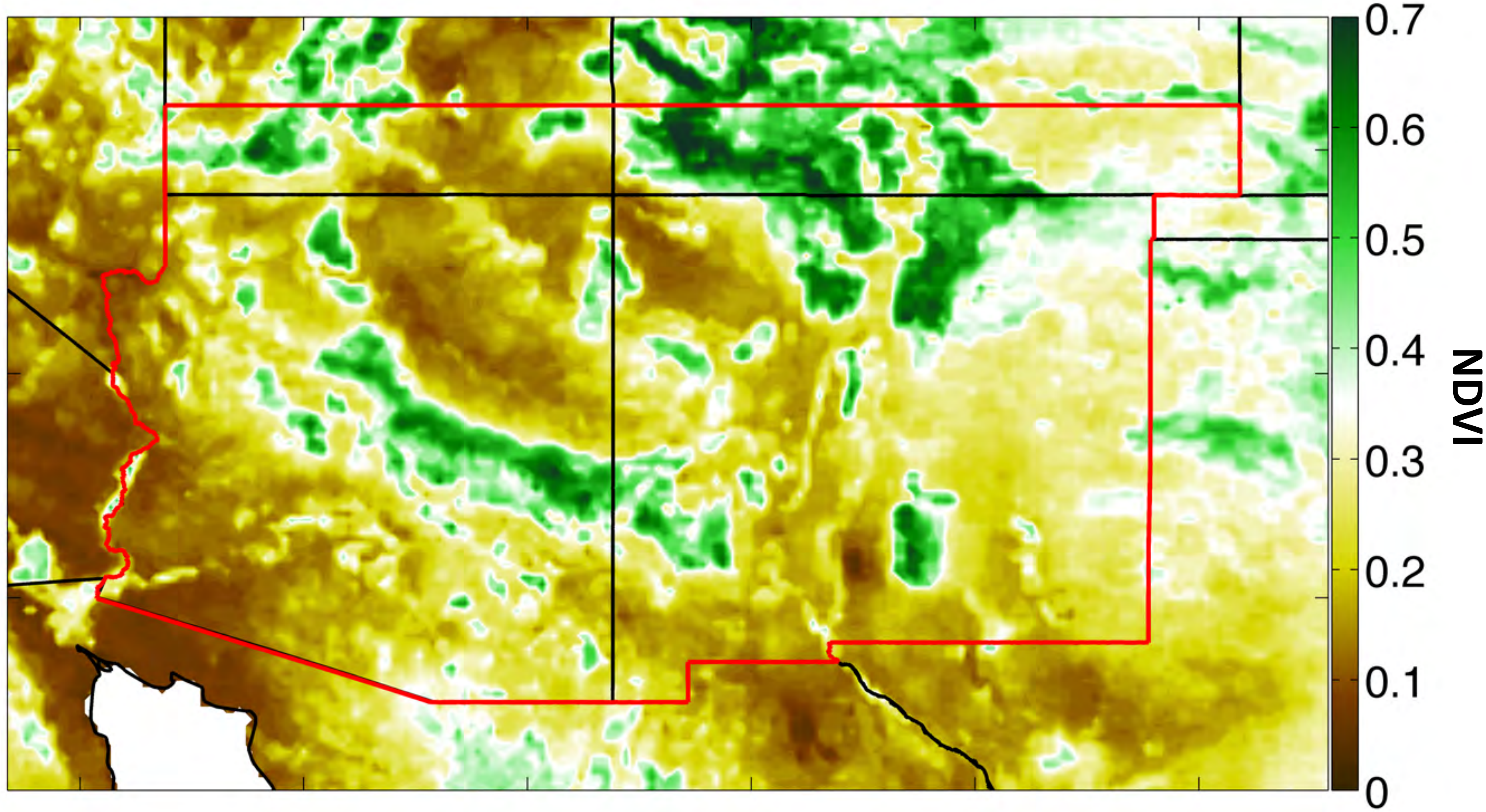


Forest Drought-Stress Index (FDSI)

$$FDSI = 0.44[\text{zscore}(\textit{cold-season Precip.})] - 0.56[\text{zscore}(\textit{warm-season VPD})]$$



Average Summer Vegetation Greenness



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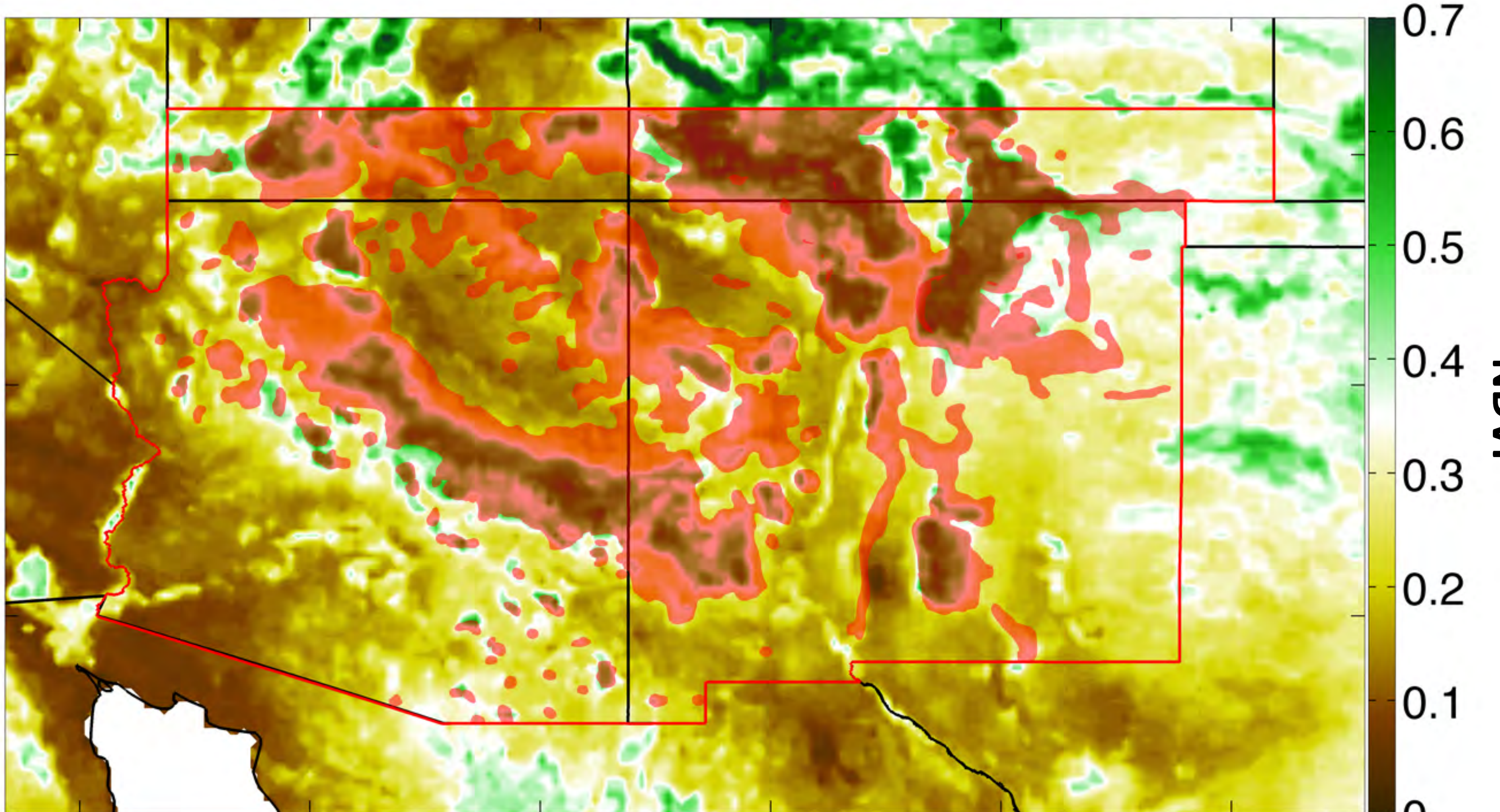
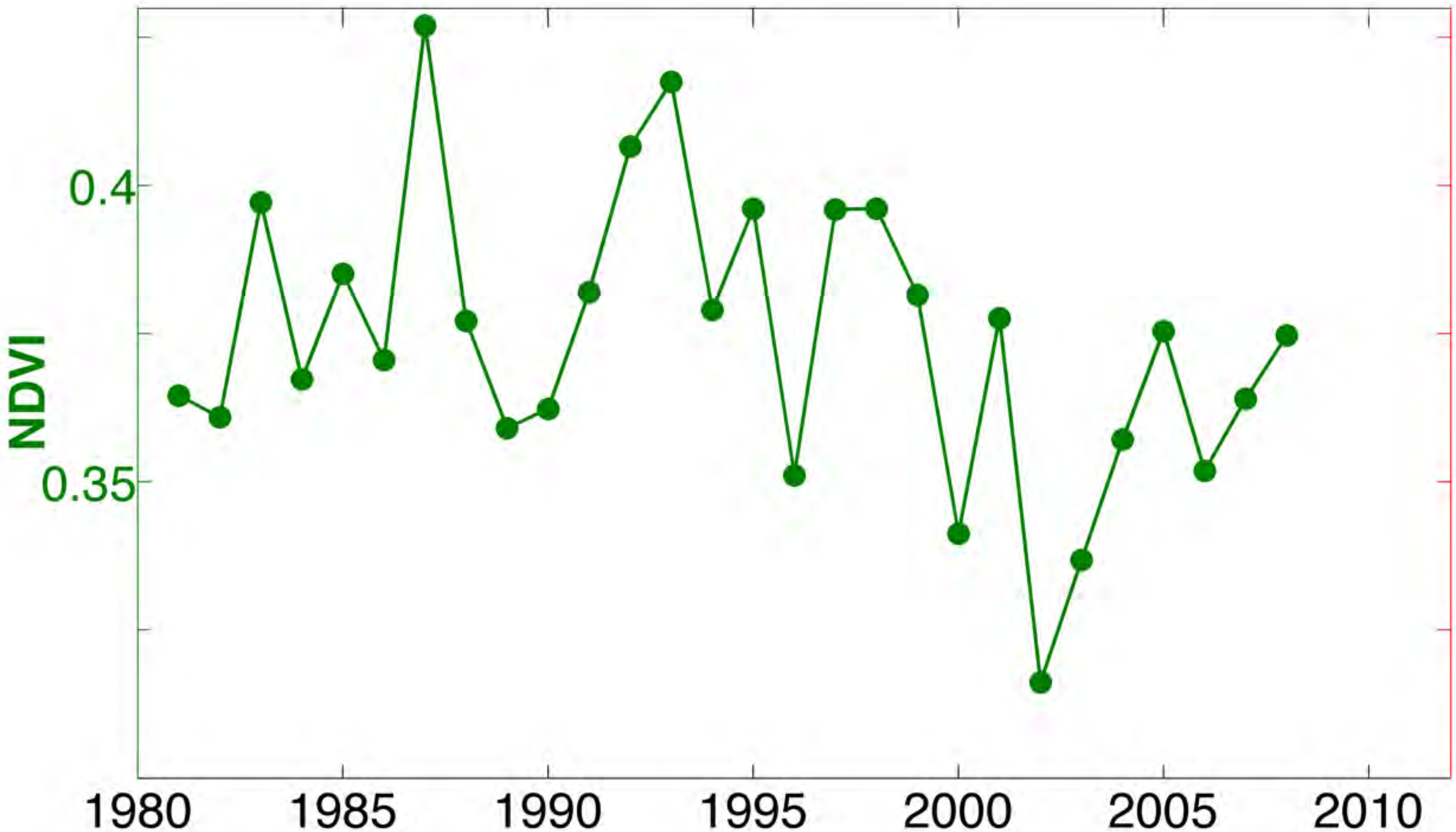
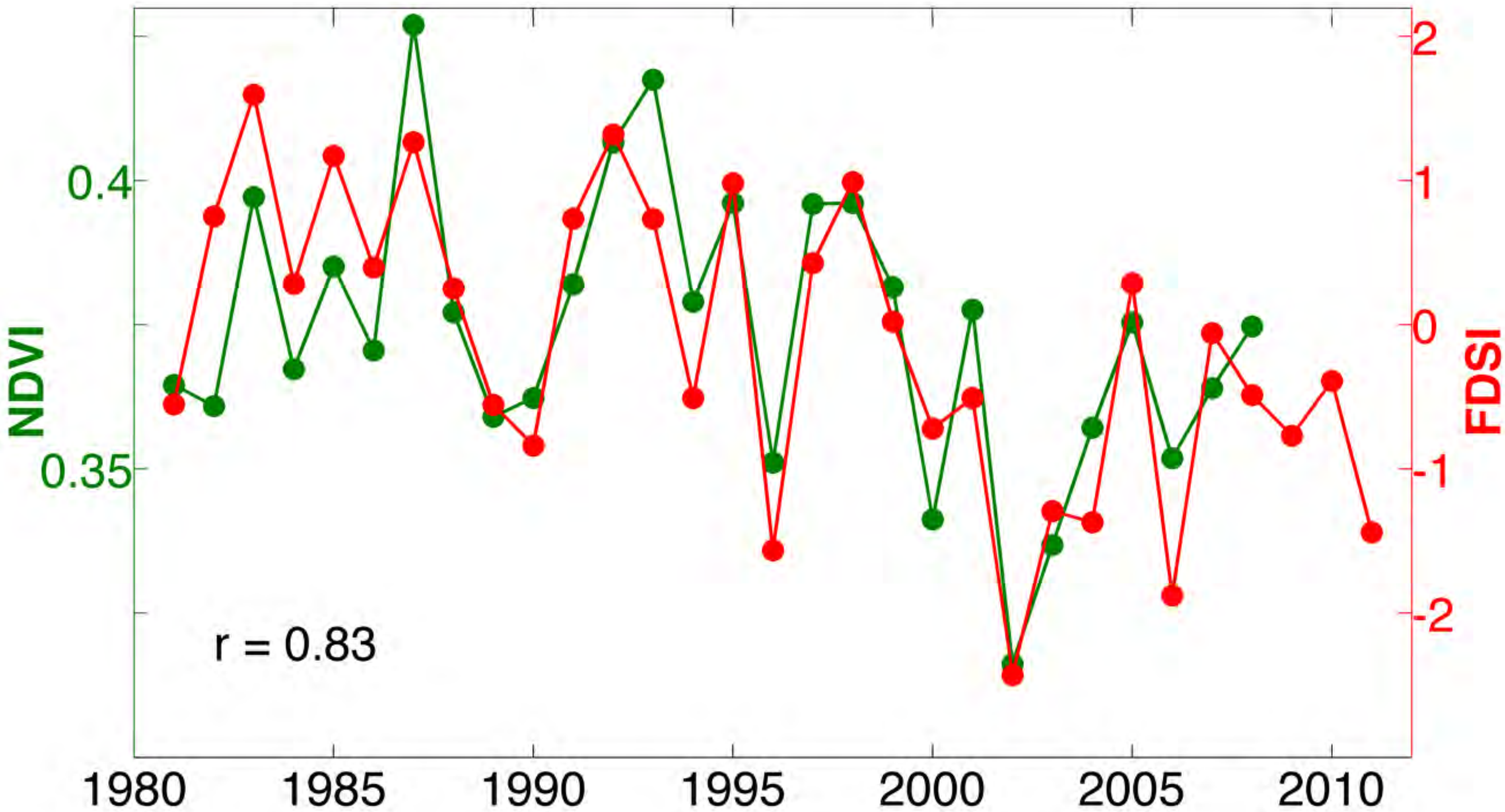


Summer Vegetation Greenness 1981–2008



NDVI data collected by the AVHRR satellite

Summer vegetation greenness agrees well with FDSI



NDVI data collected by the AVHRR satellite

Dying piñon pine, Jemez Mts. October 2002

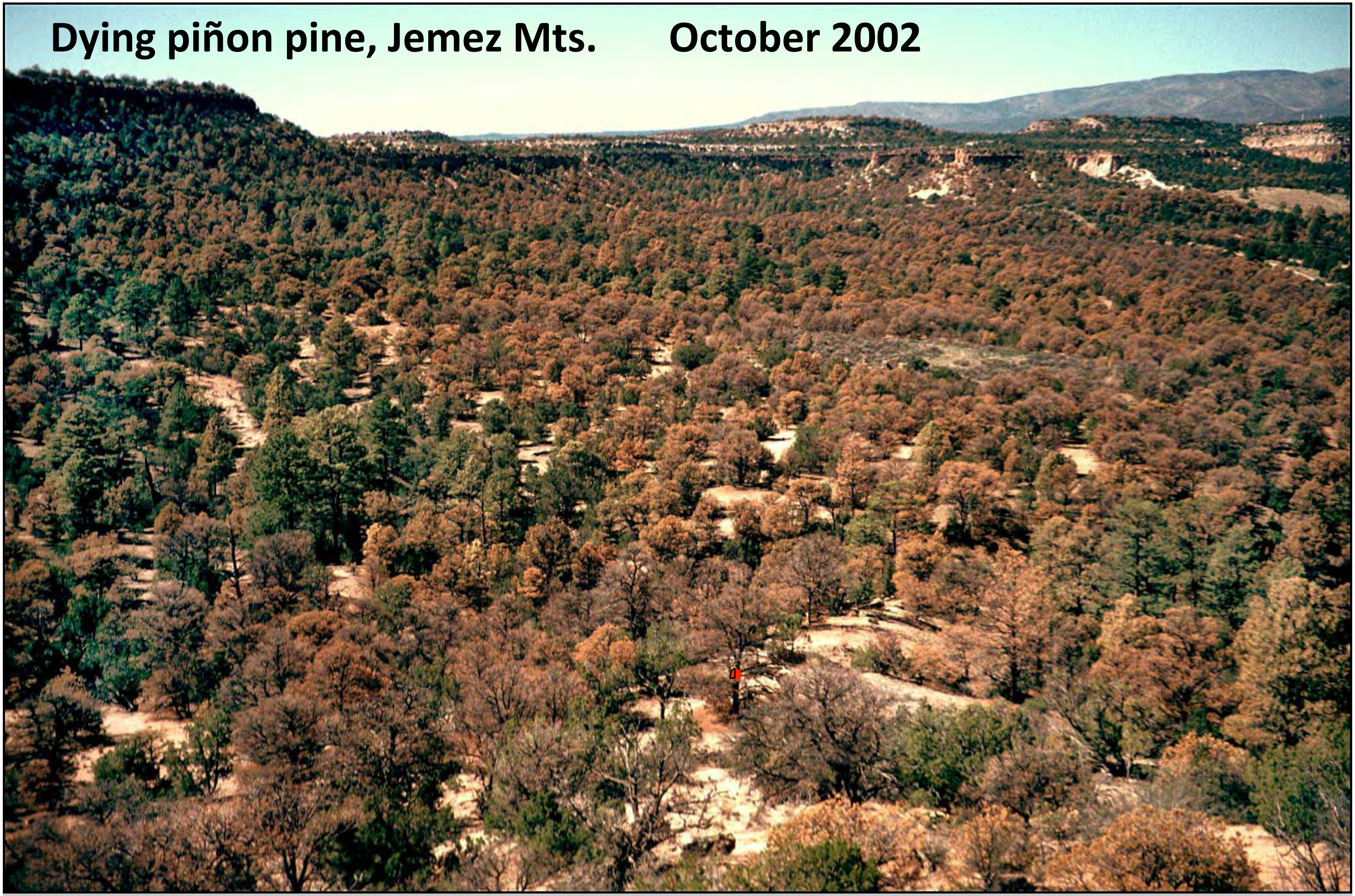
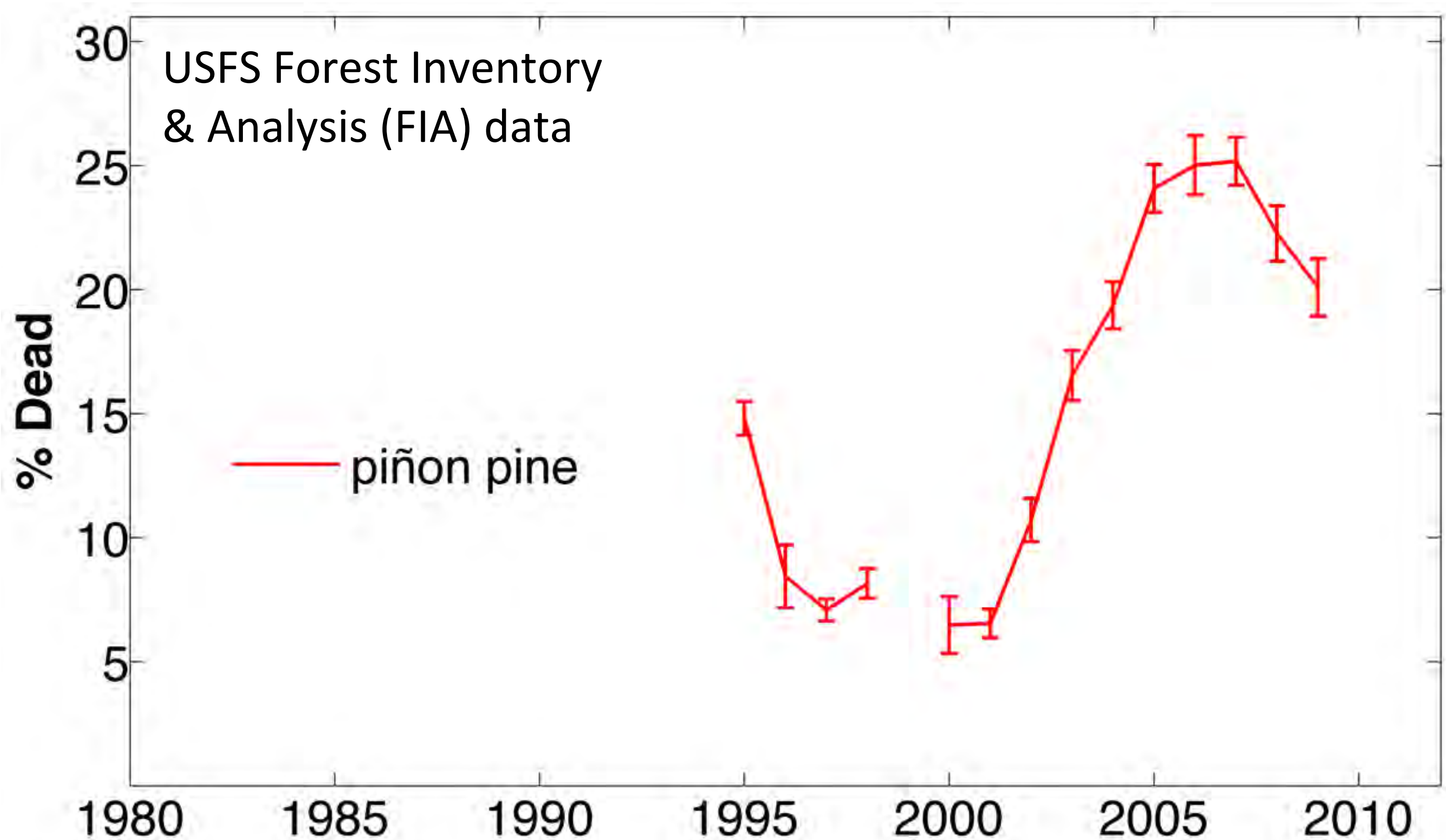


Photo: Craig D Allen

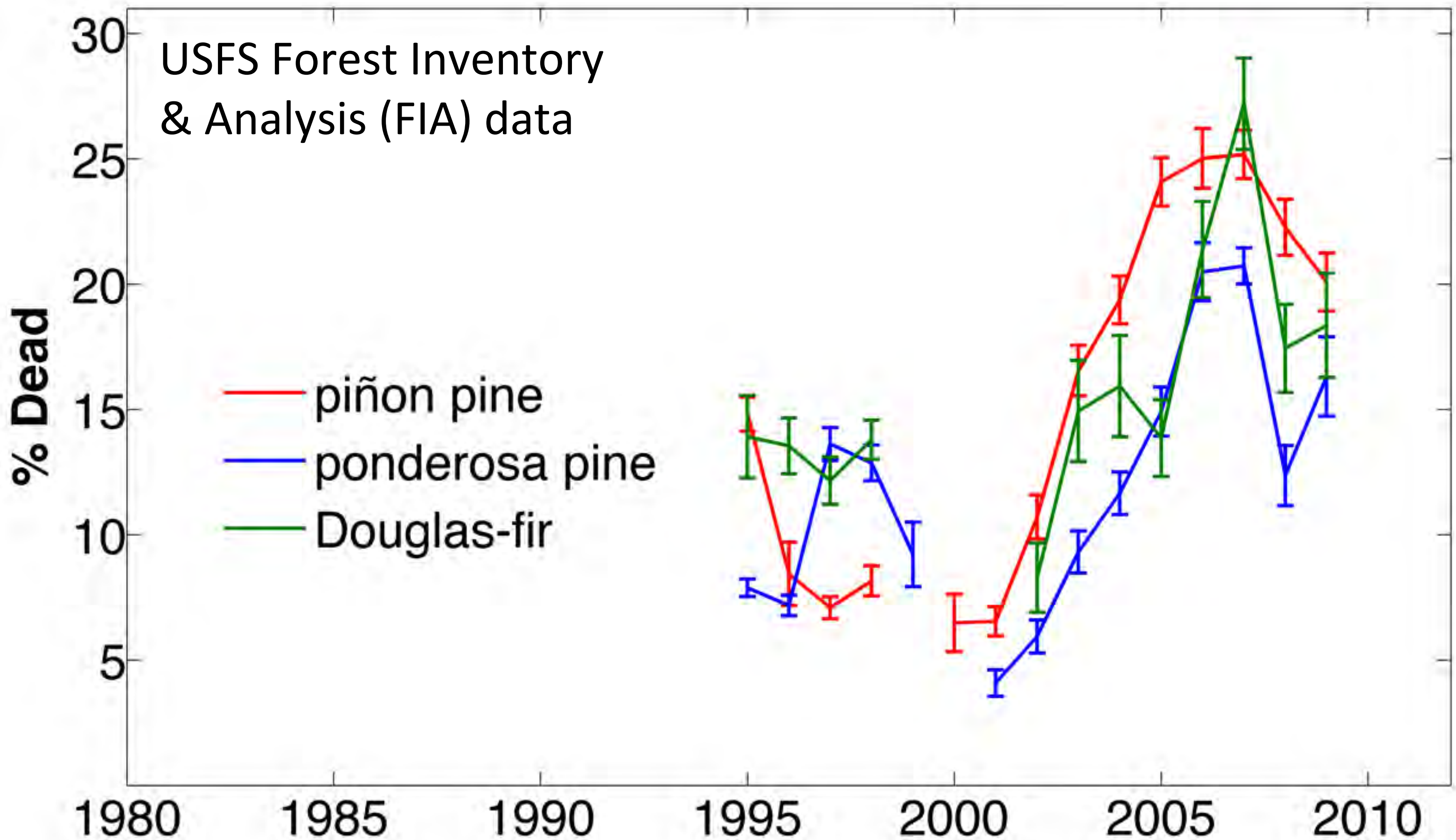
Pine skeletons, conversion to juniper woodlands, Jemez Mts. May 2004

Photo: Craig D Allen

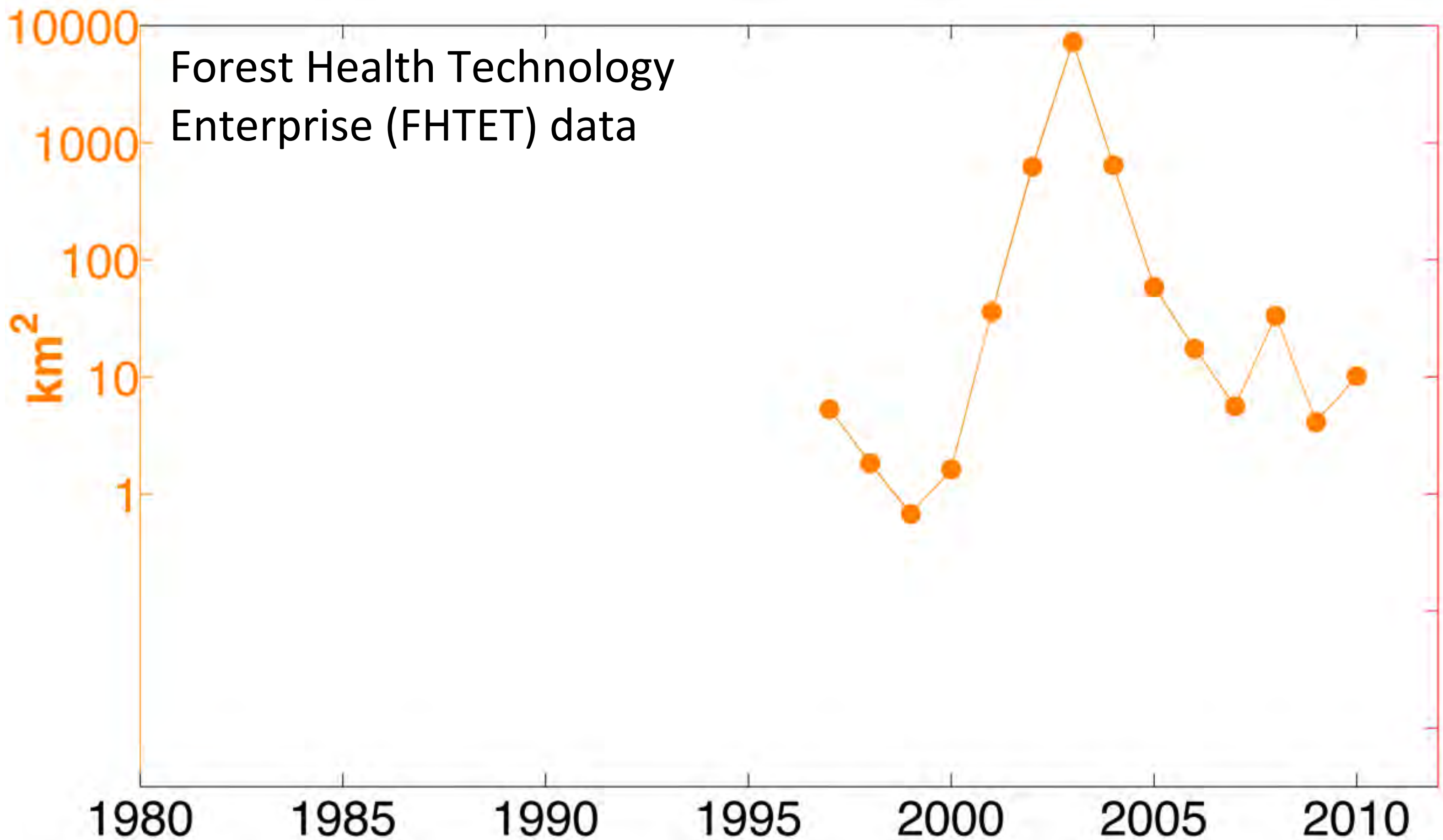
Number of dead piñon pines roughly doubled during 2001–2006

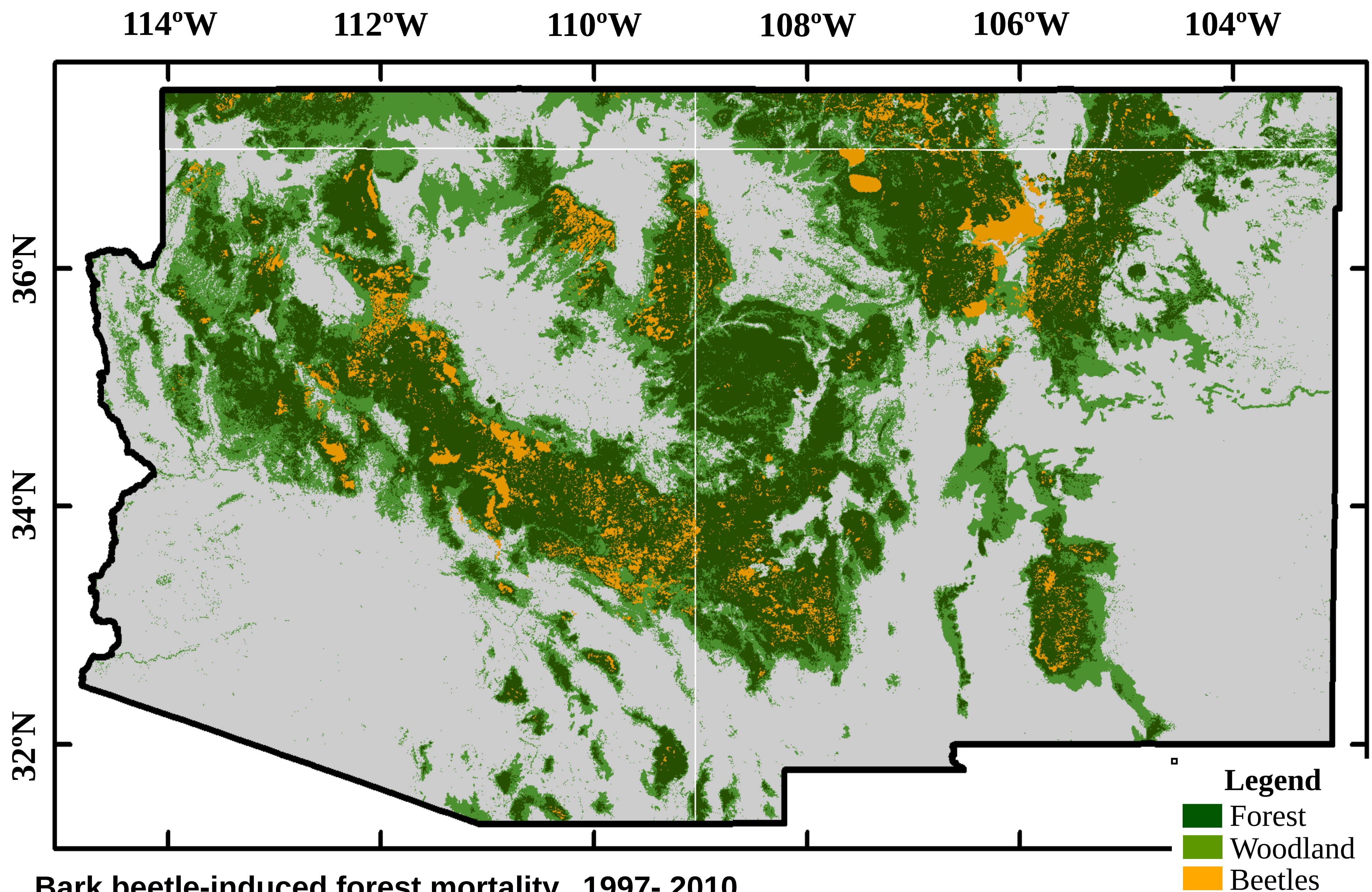


Same is true for ponderosa pine and Douglas-fir



How did all those trees die?
One cause was bark beetles



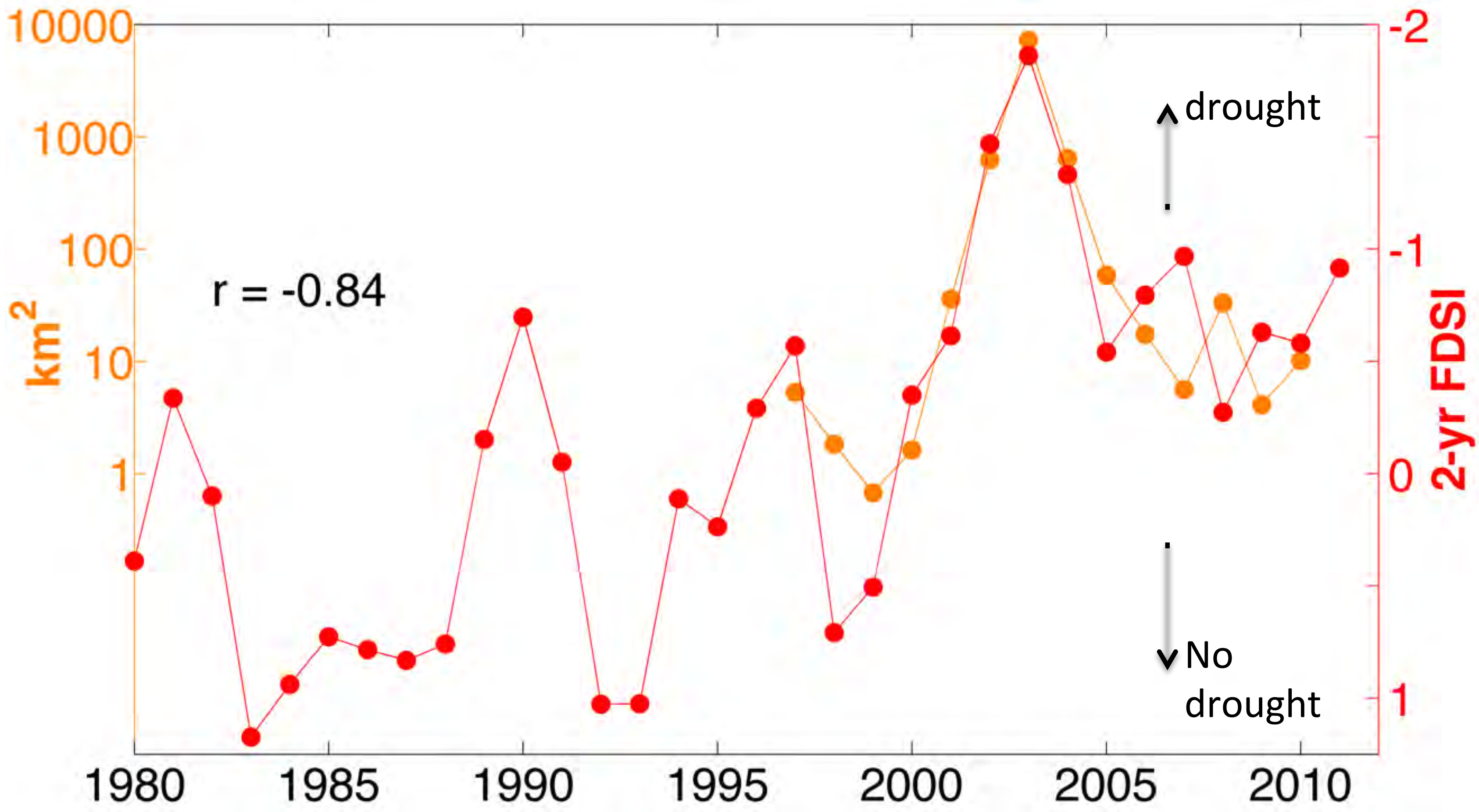


Bark beetle-induced forest mortality, 1997- 2010

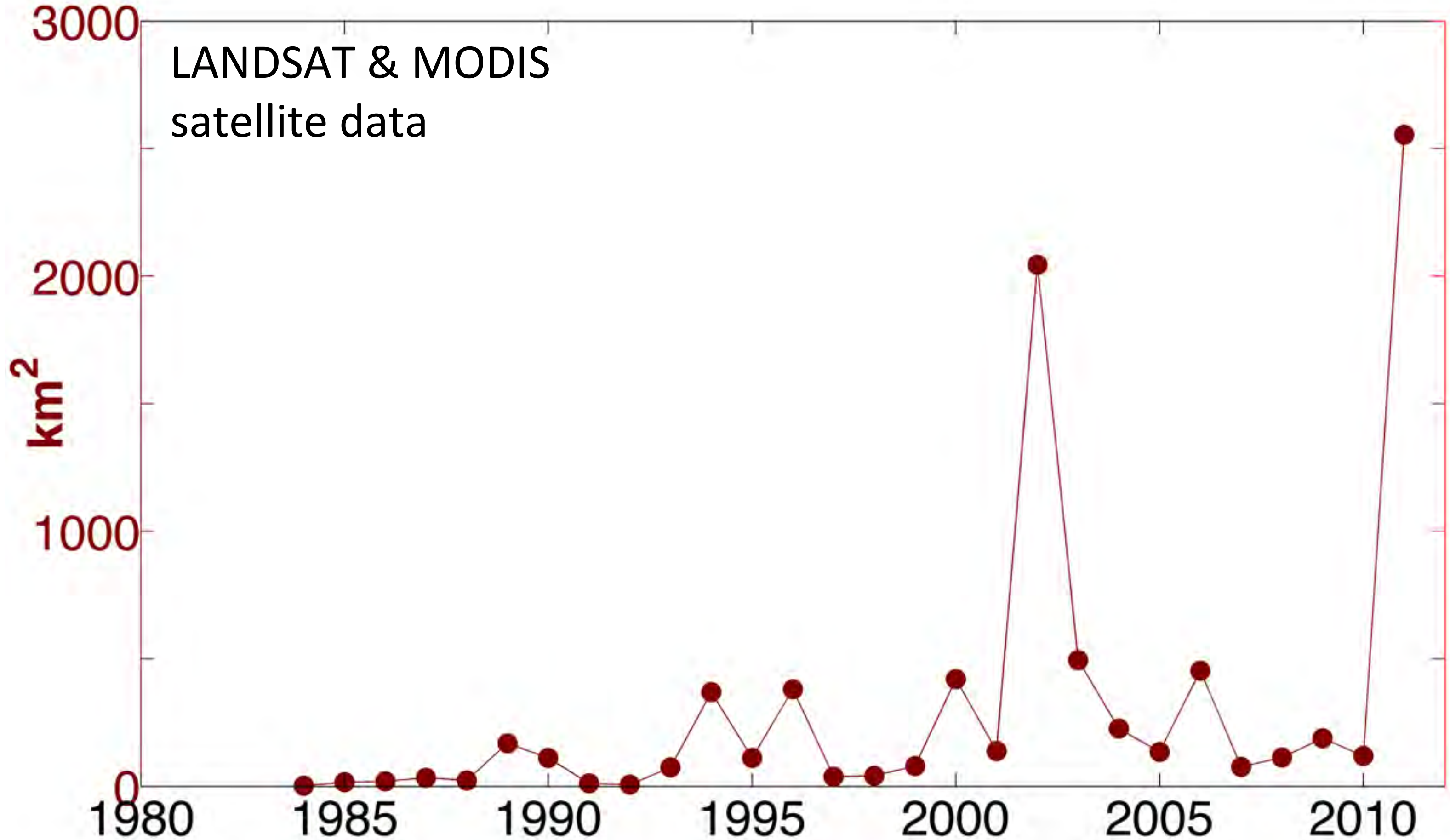
~ 8 % of forest and woodland was affected.

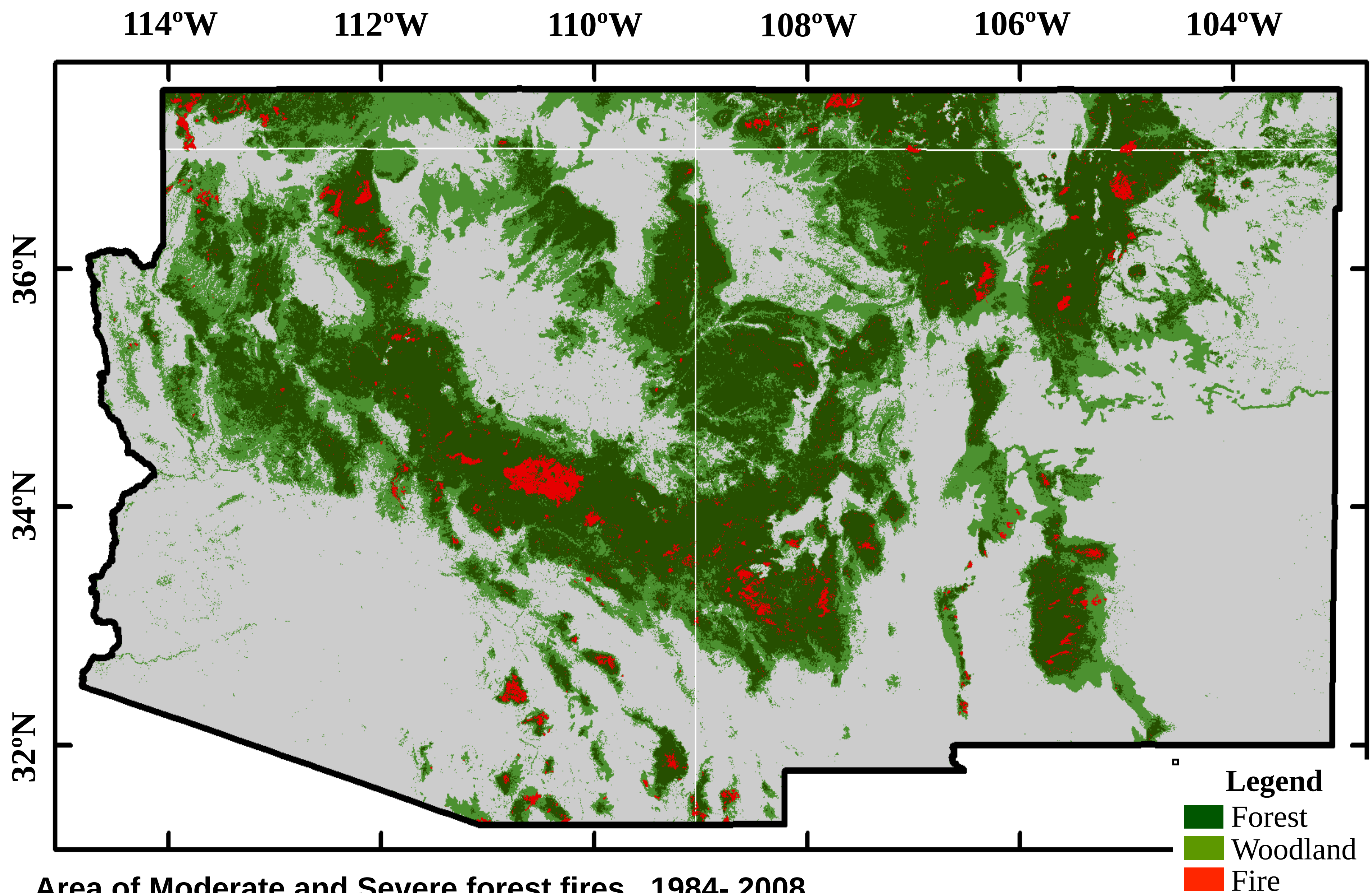
(Williams et al., 2010 *PNAS*)

Bark-beetle outbreak corresponded with major forest drought stress



How did all those trees die?
Another cause was wildfire

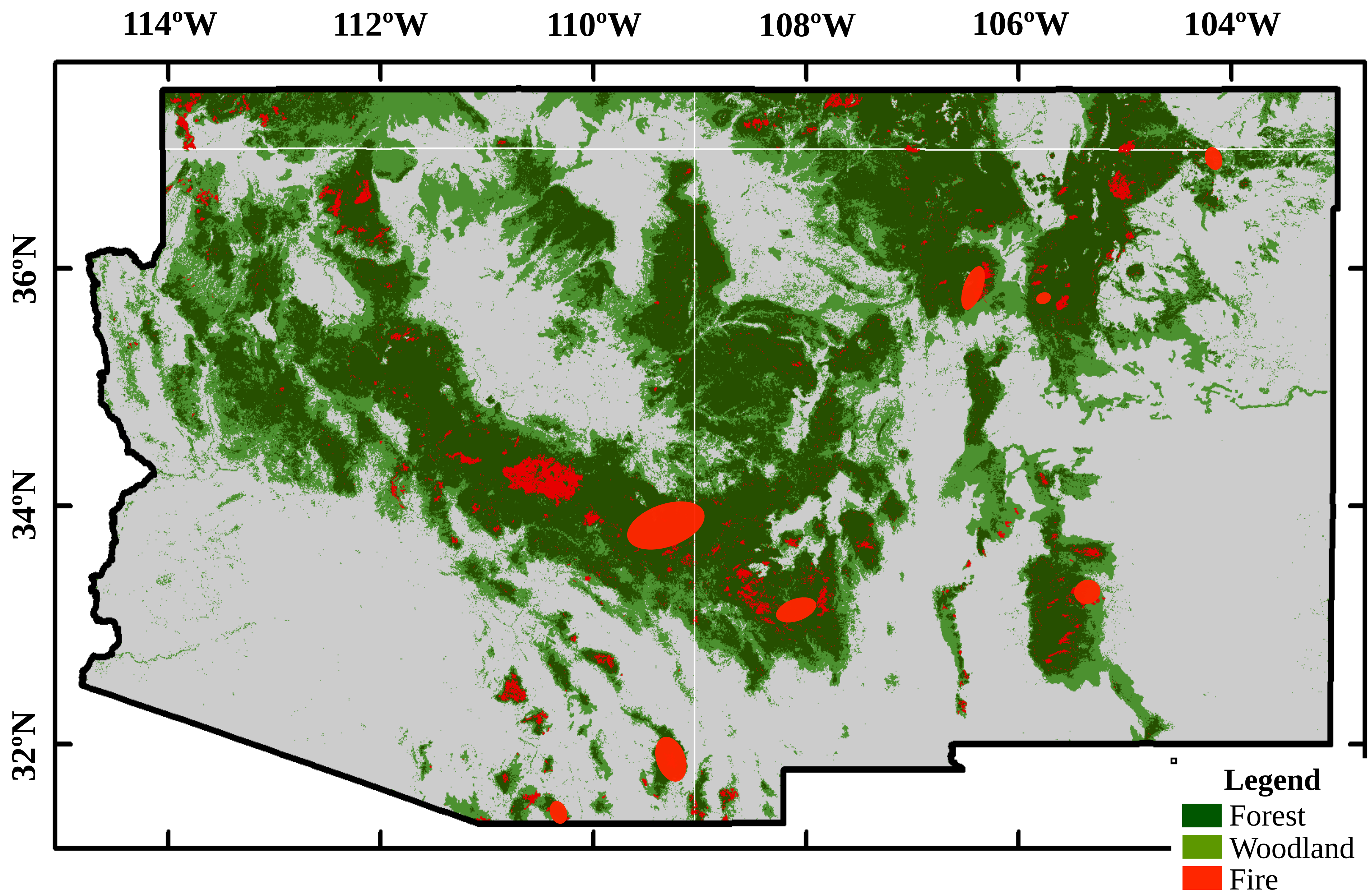




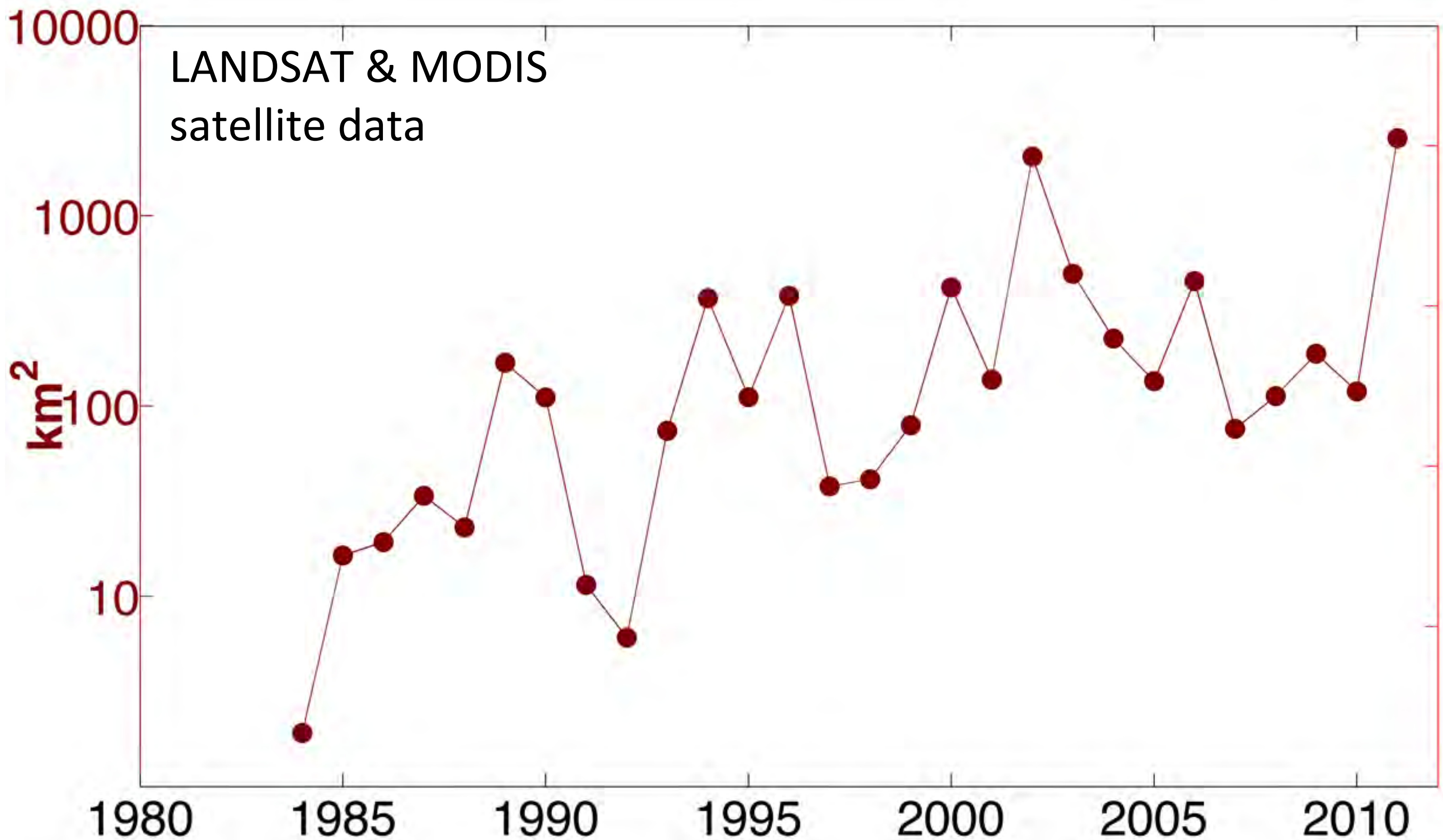
Area of Moderate and Severe forest fires, 1984- 2008

~ 3 % of forest and woodland was affected.

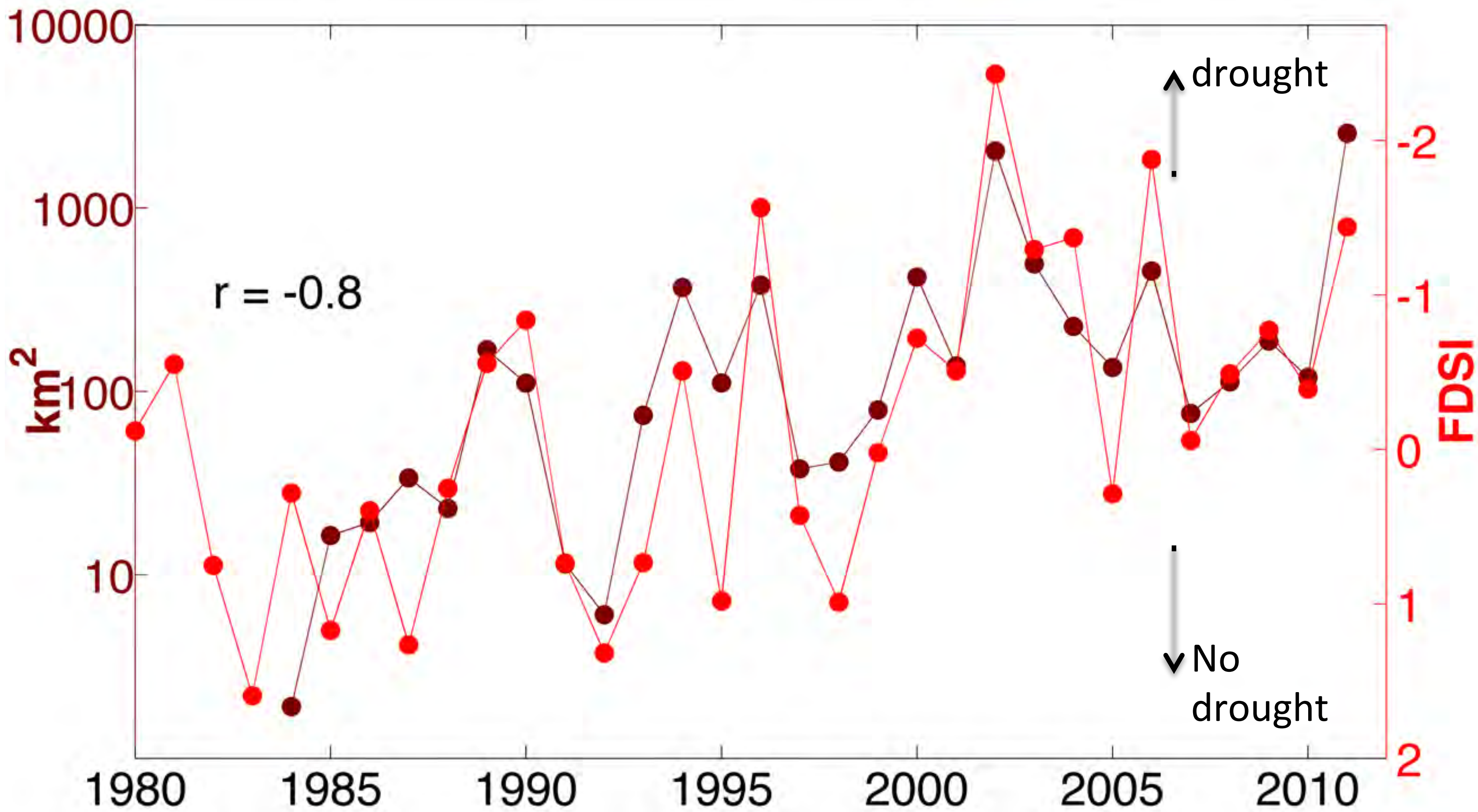
(Williams et al., 2010 *PNAS*)


114°W
112°W
110°W
108°W
106°W
104°W
36°N
34°N
32°N
Legend
Forest
Woodland
Fire

How did all those trees die?
Another cause was wildfire



Burned area correlates well with forest drought stress



2011 Vapor-Pressure Deficit: 2 to 6 standard deviations above average from east AZ through west TX compared to top 20% of drought years since 1895

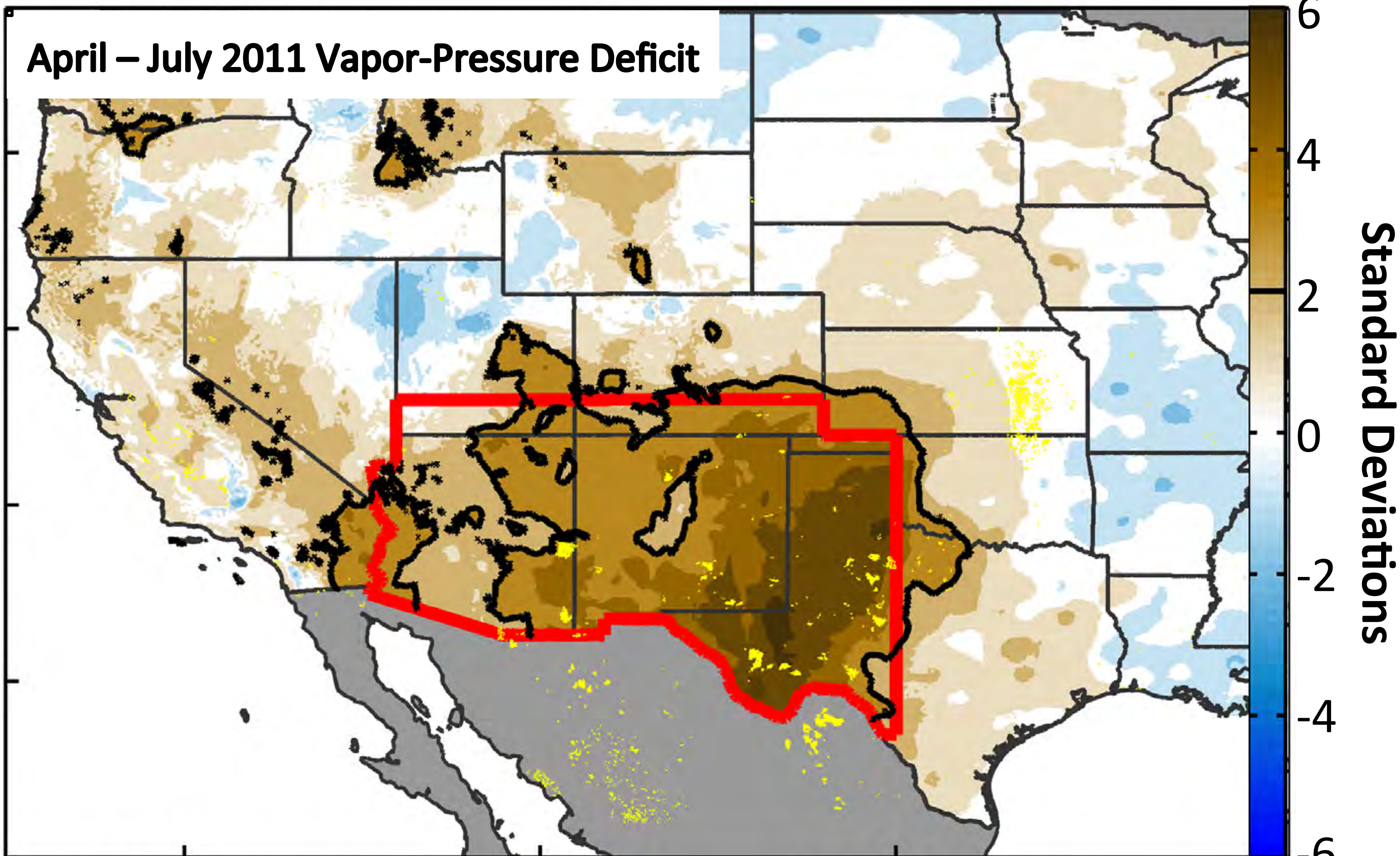



Photo: Craig D. Allen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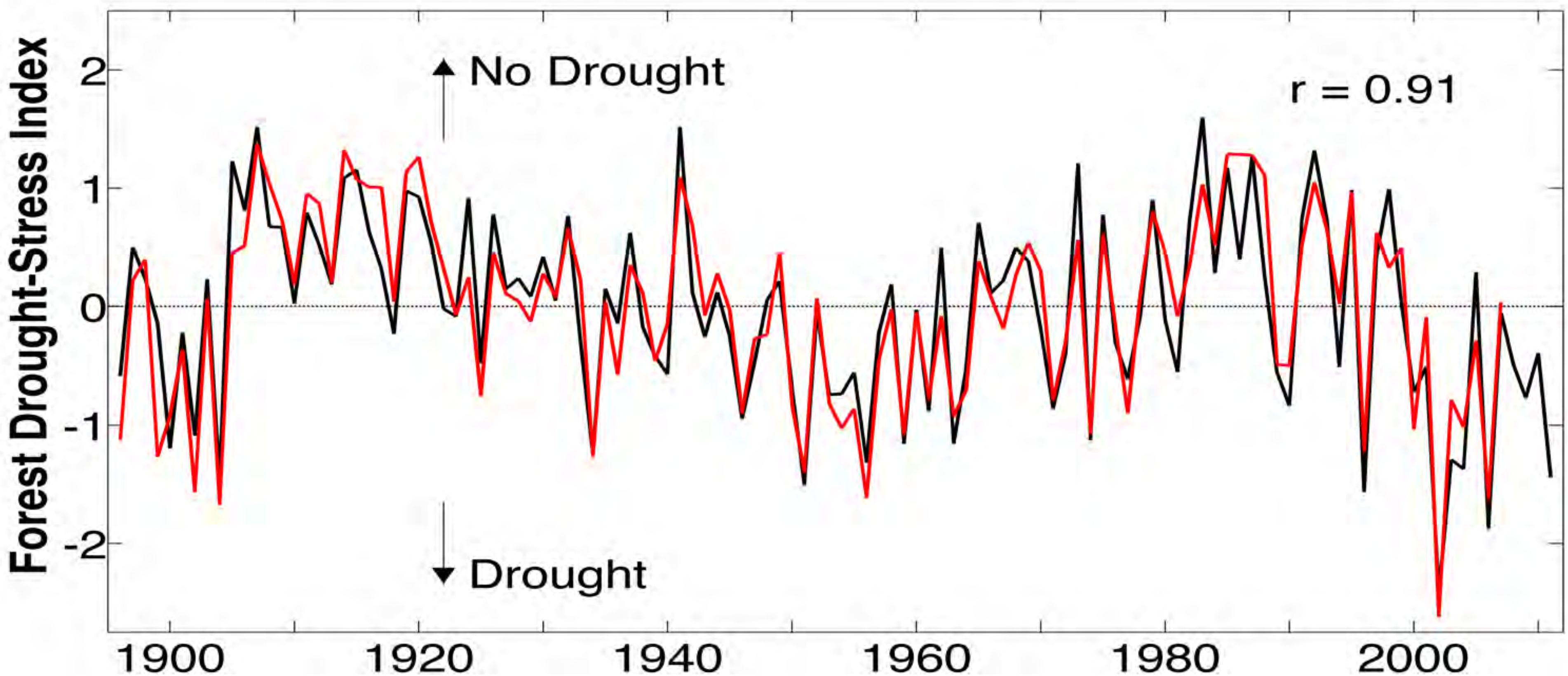
Importantly, drought-induced forest mortality is normal in the Southwest



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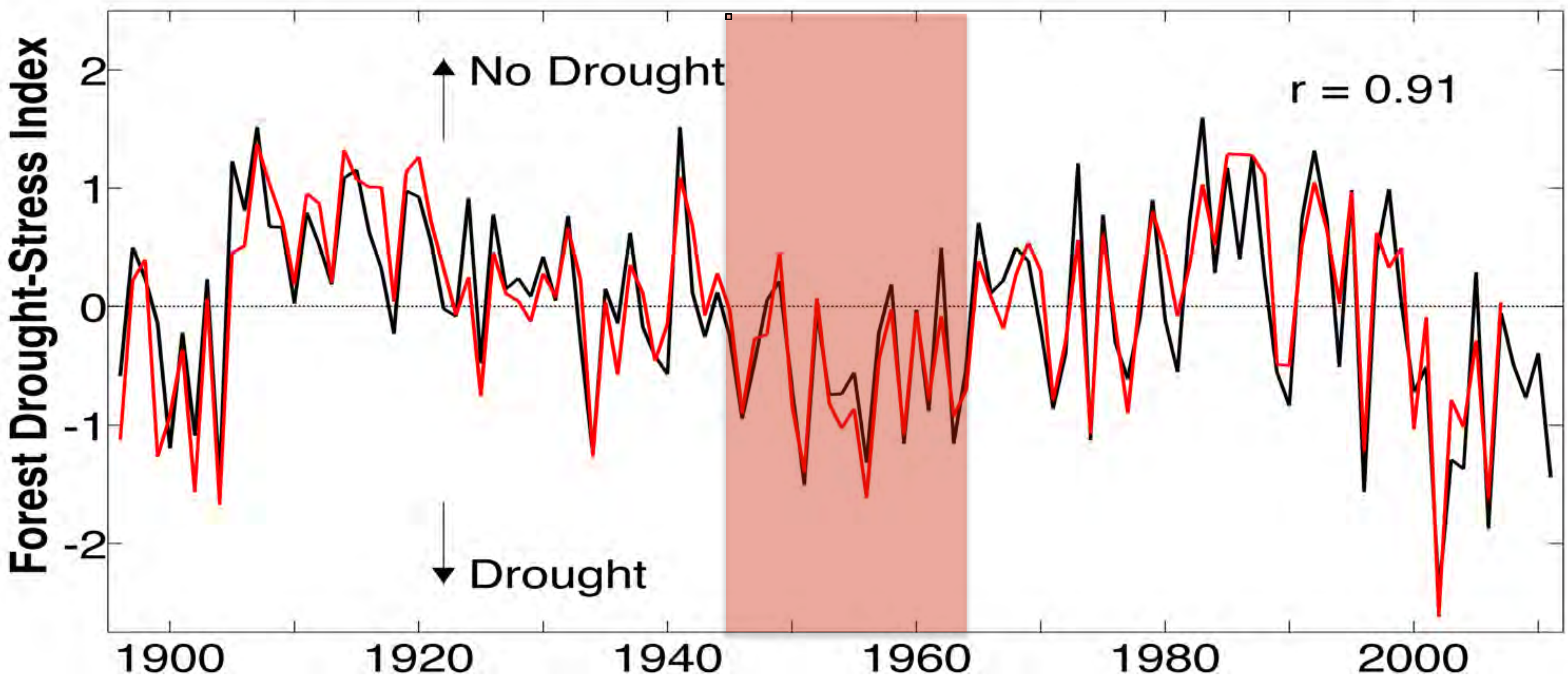
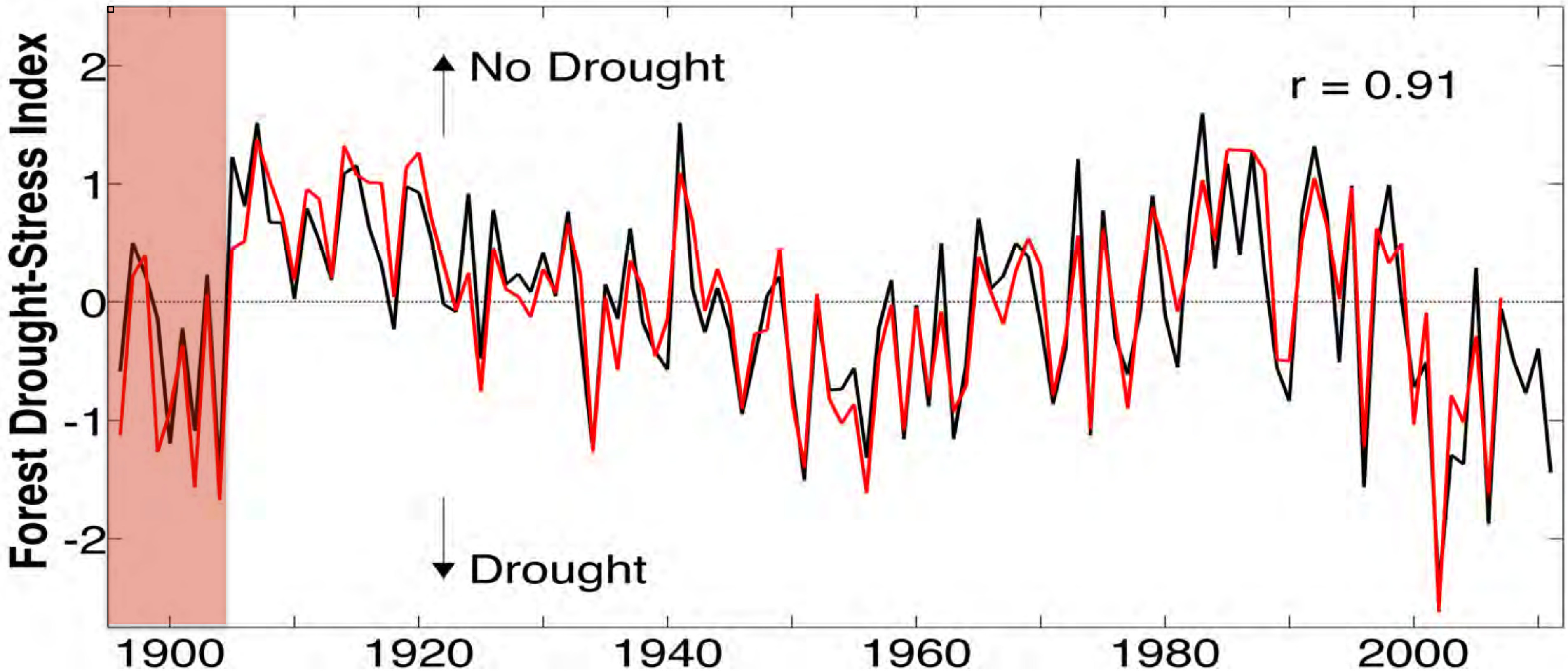


The mid-20th century drought extended from 1945–1964 and caused widespread tree mortality and some large wildfires.

Importantly, drought-induced forest mortality is normal in the Southwest

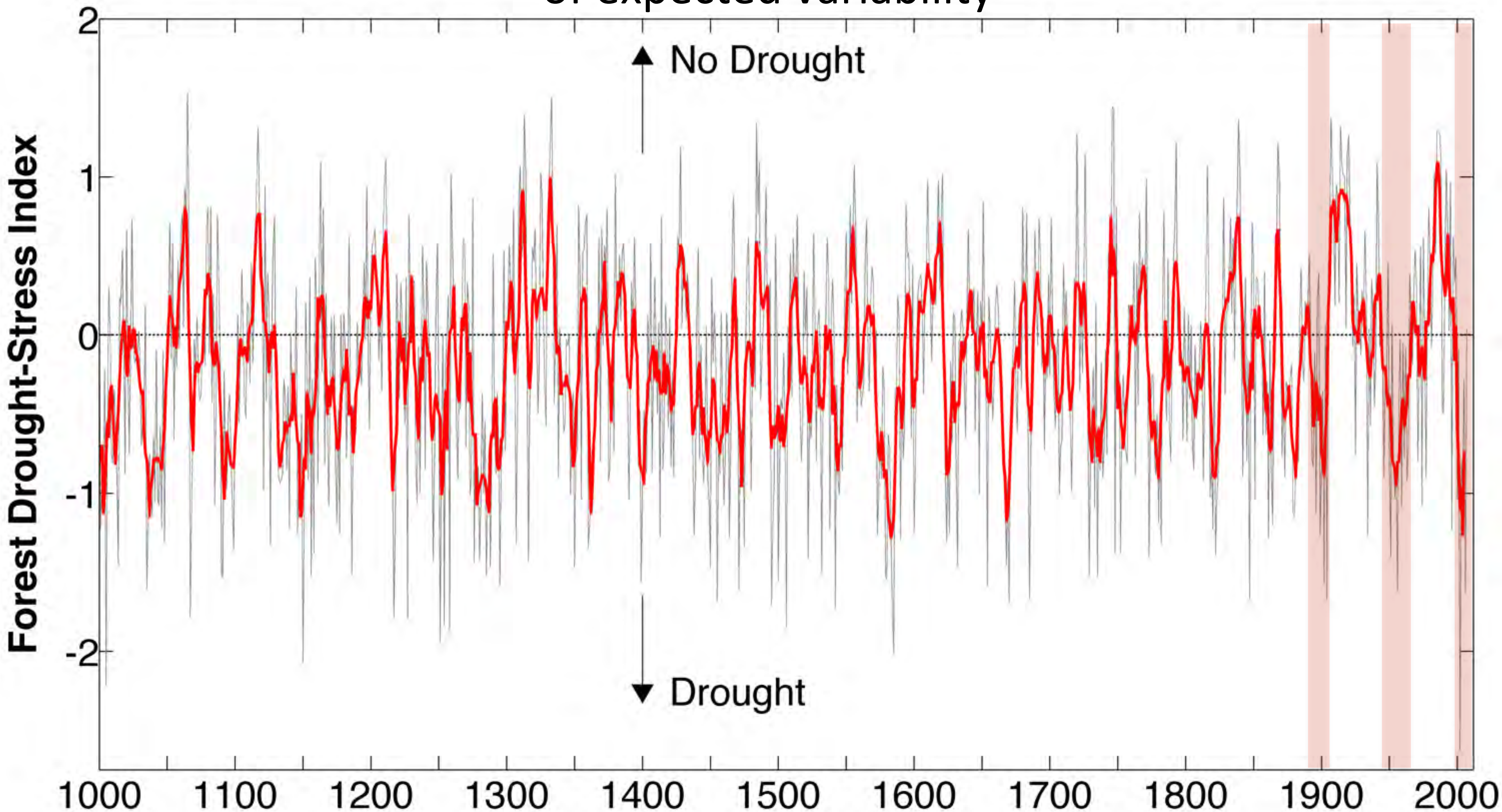


The 1899–1904 and was also may have caused widespread tree mortality.

From Plummer et al. 1904: "The scarcity of precipitation [that] has afflicted this region is shown by the condition of yellow pine, alligator juniper, and Arizona cypress, which, as a rule, stand an extreme drought… Yellow pine is rapidly being killed, as the whole of them are dead or so far diseased as to be beyond resuscitation."

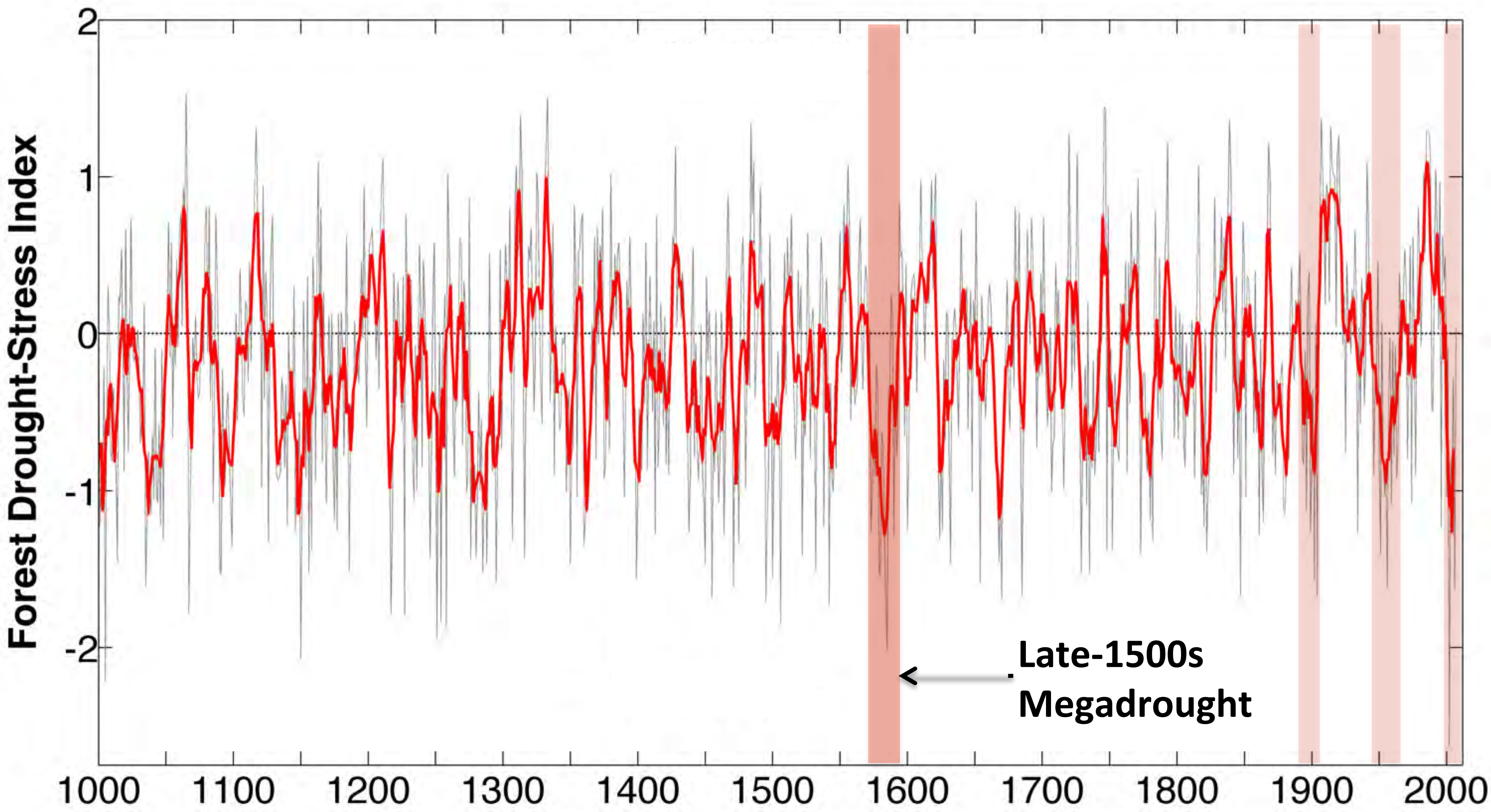
Drought variability over the past 1000 years

Drought intensity during the past century appears within the range of expected variability

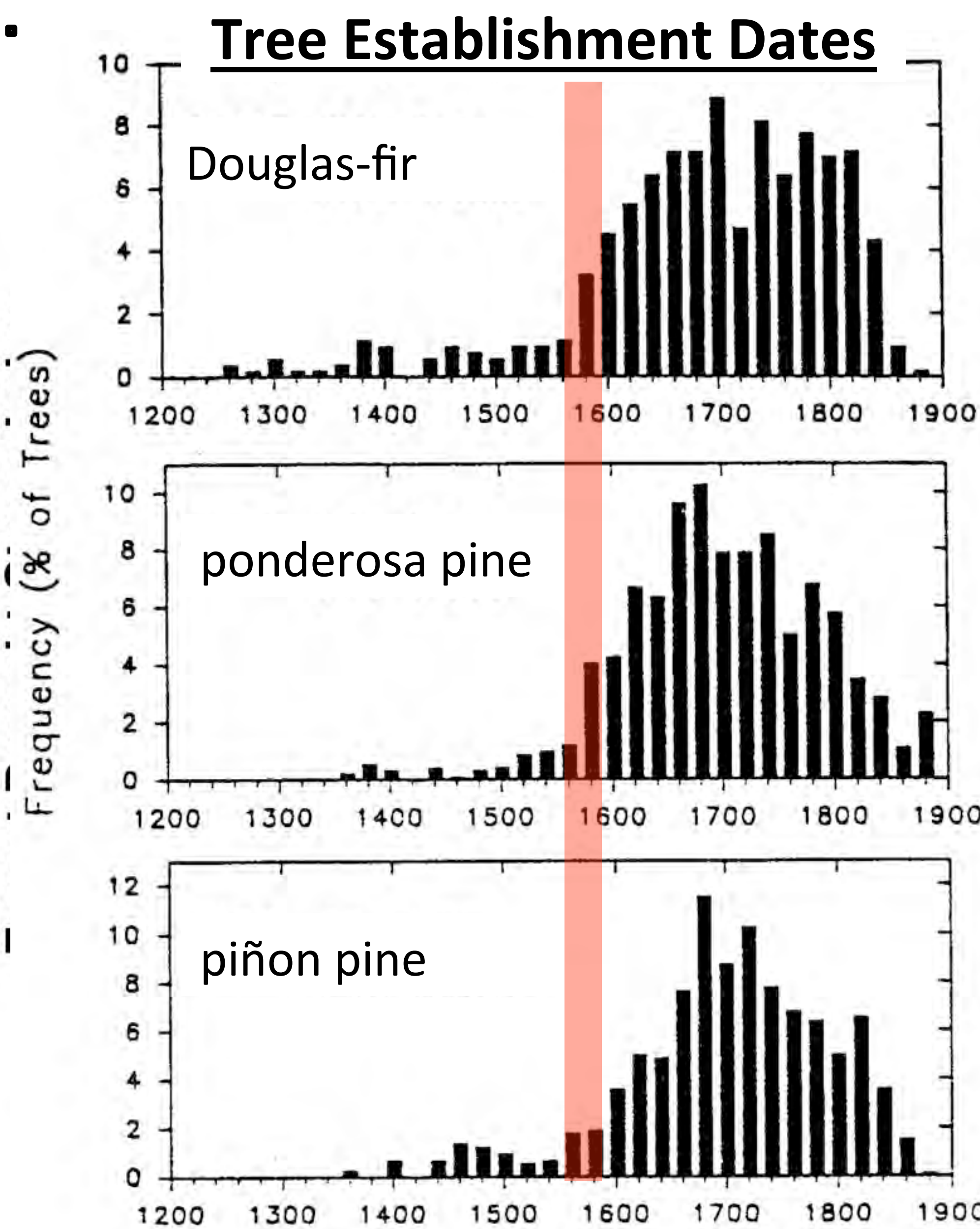


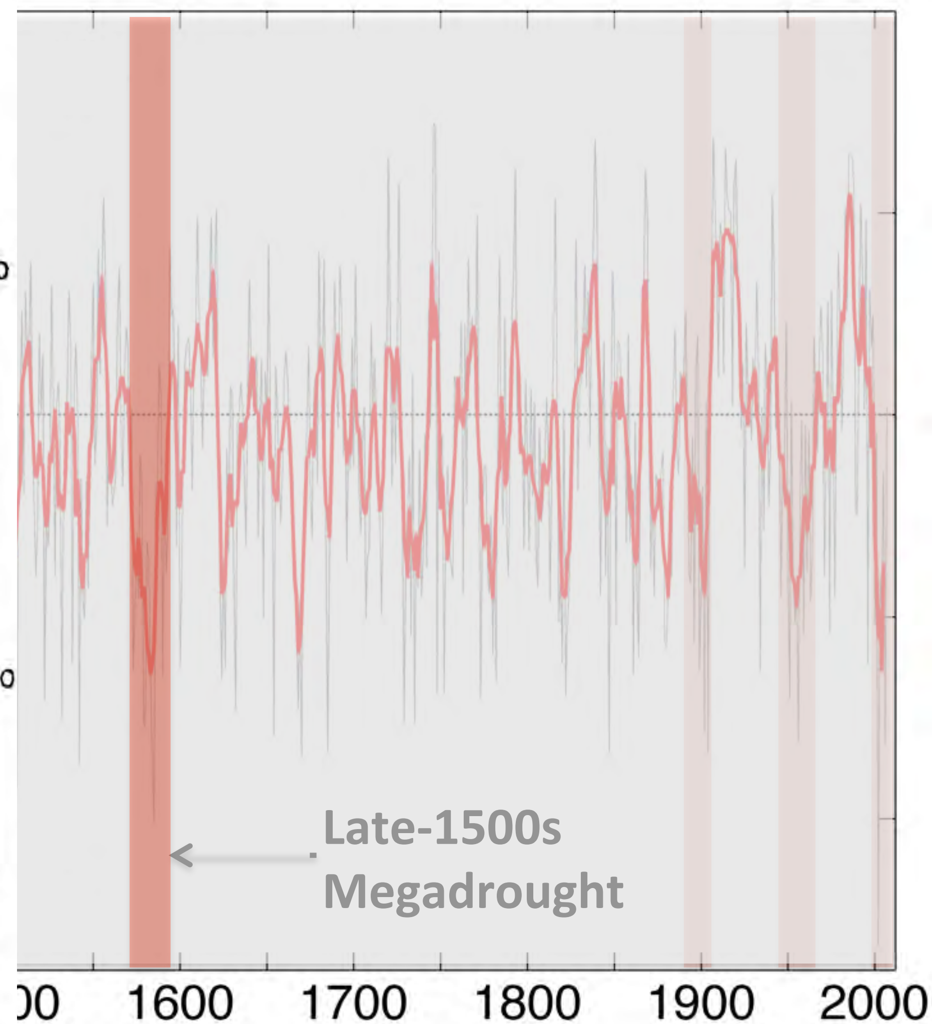
Drought variability over the past 1000 years

Historic droughts also caused widespread mortality



Drought variability over the past 1000 years





Swetnam & Brown 1992

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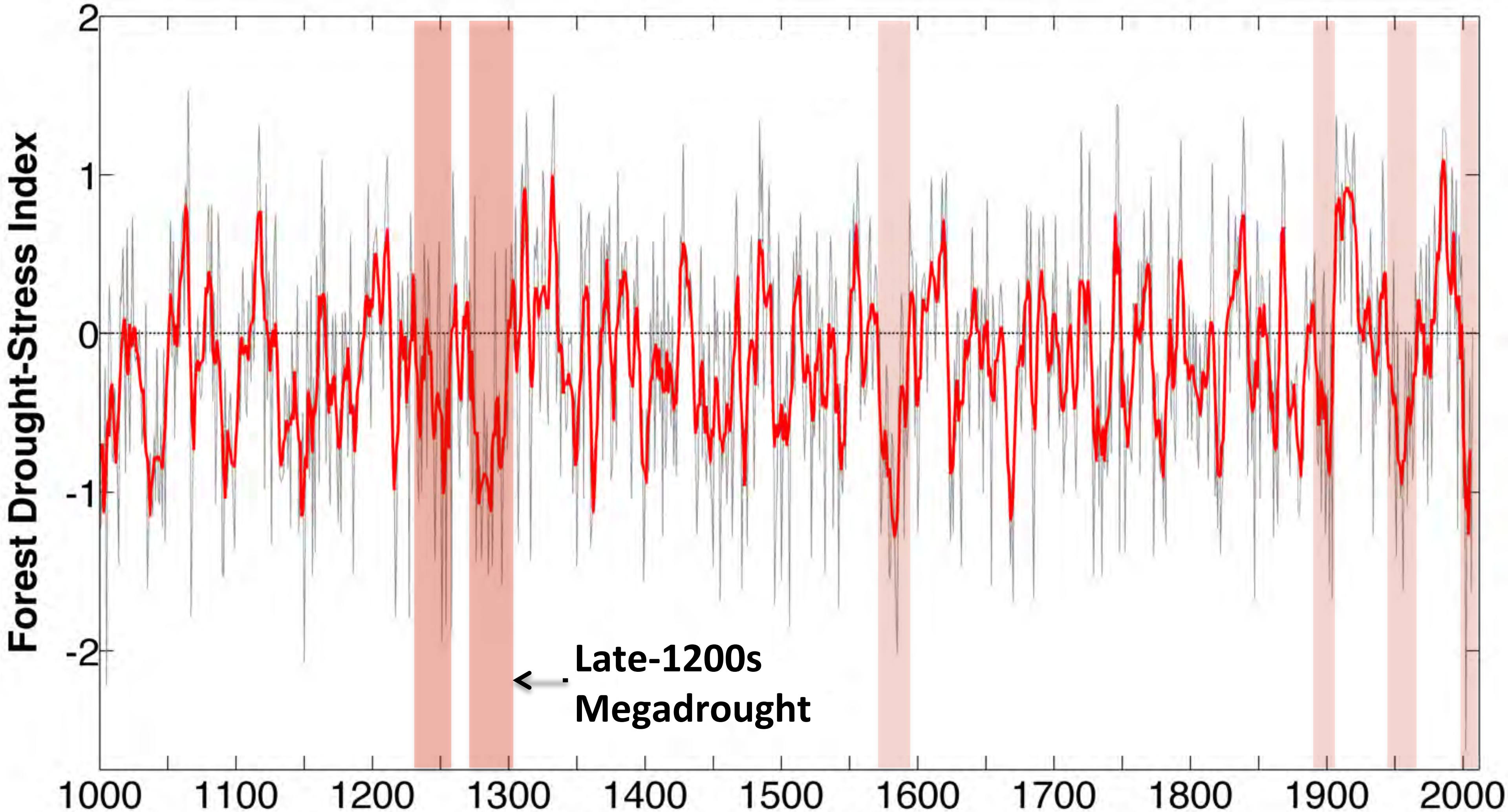

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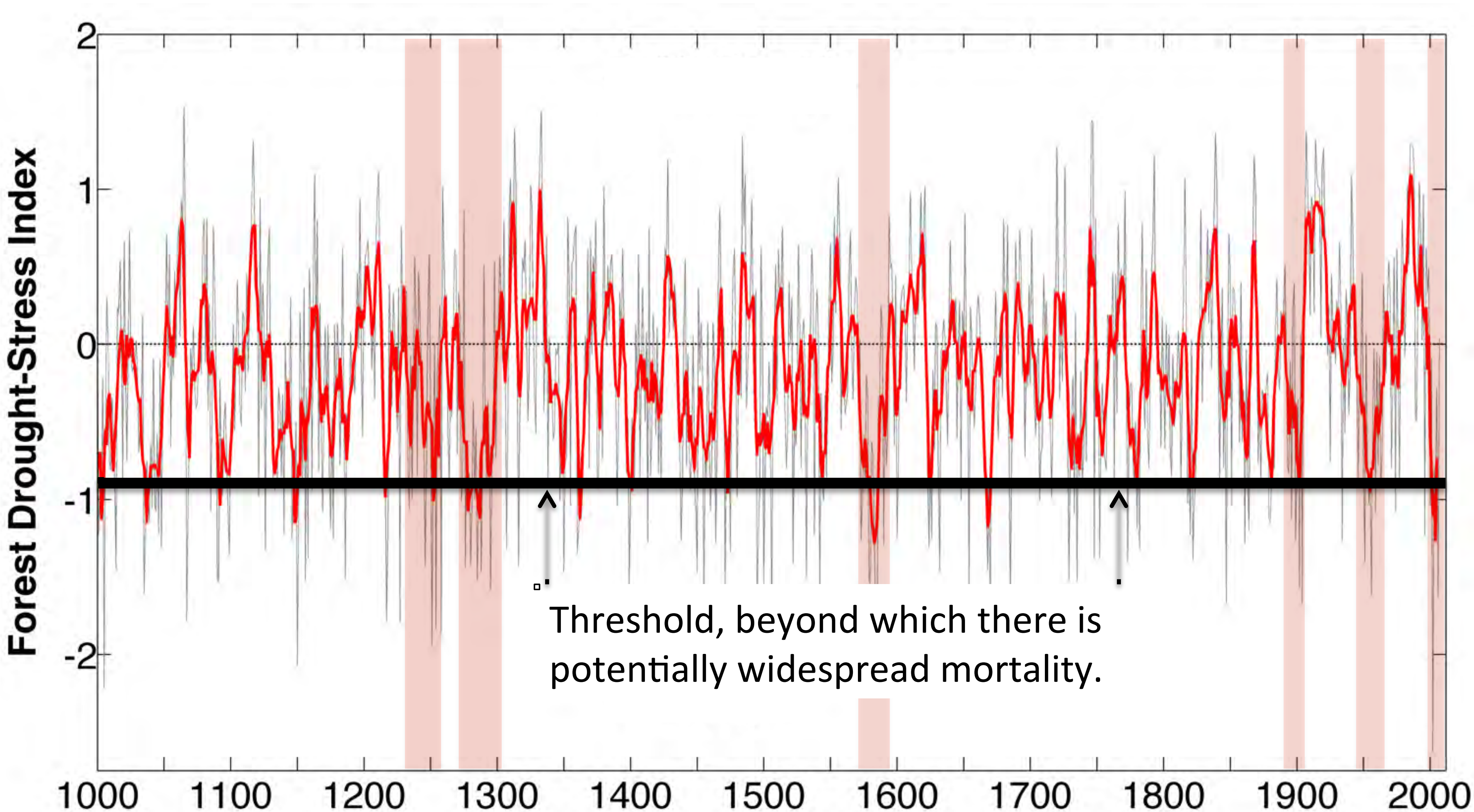
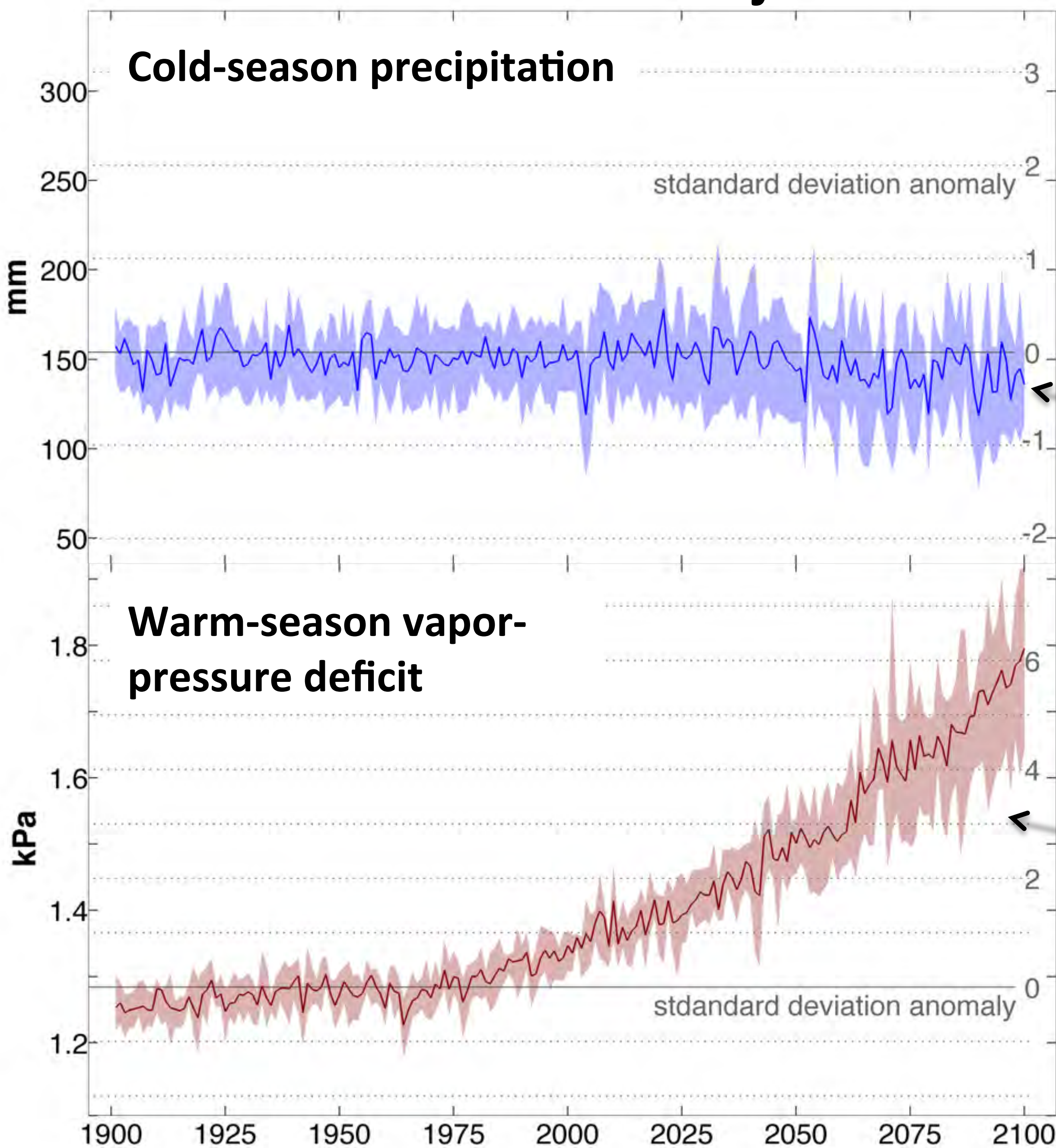


Climate Model Projections through 2100



5-15% decrease in cold-season precipitation by 2100

40% increase in warm-season VPD

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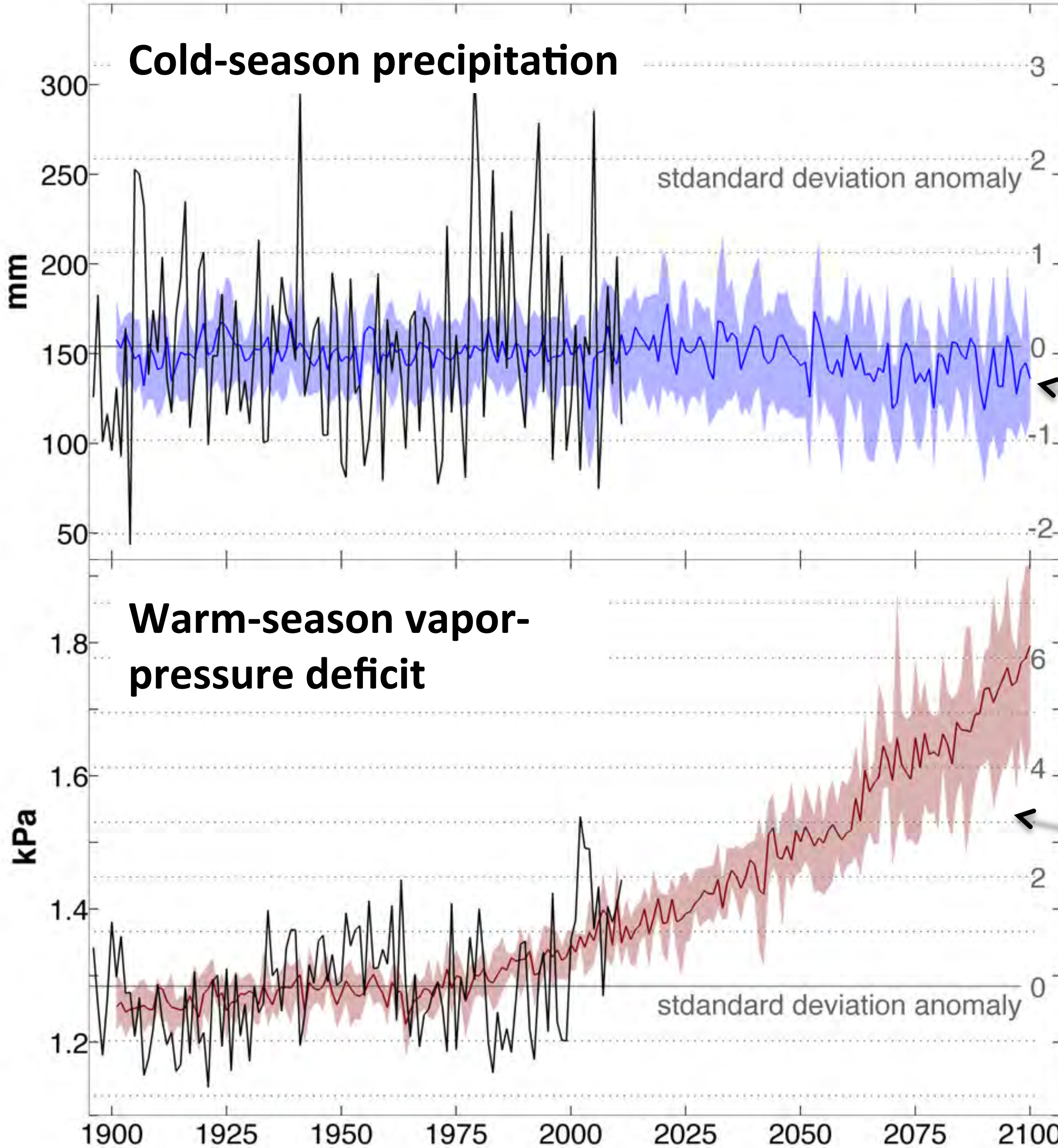
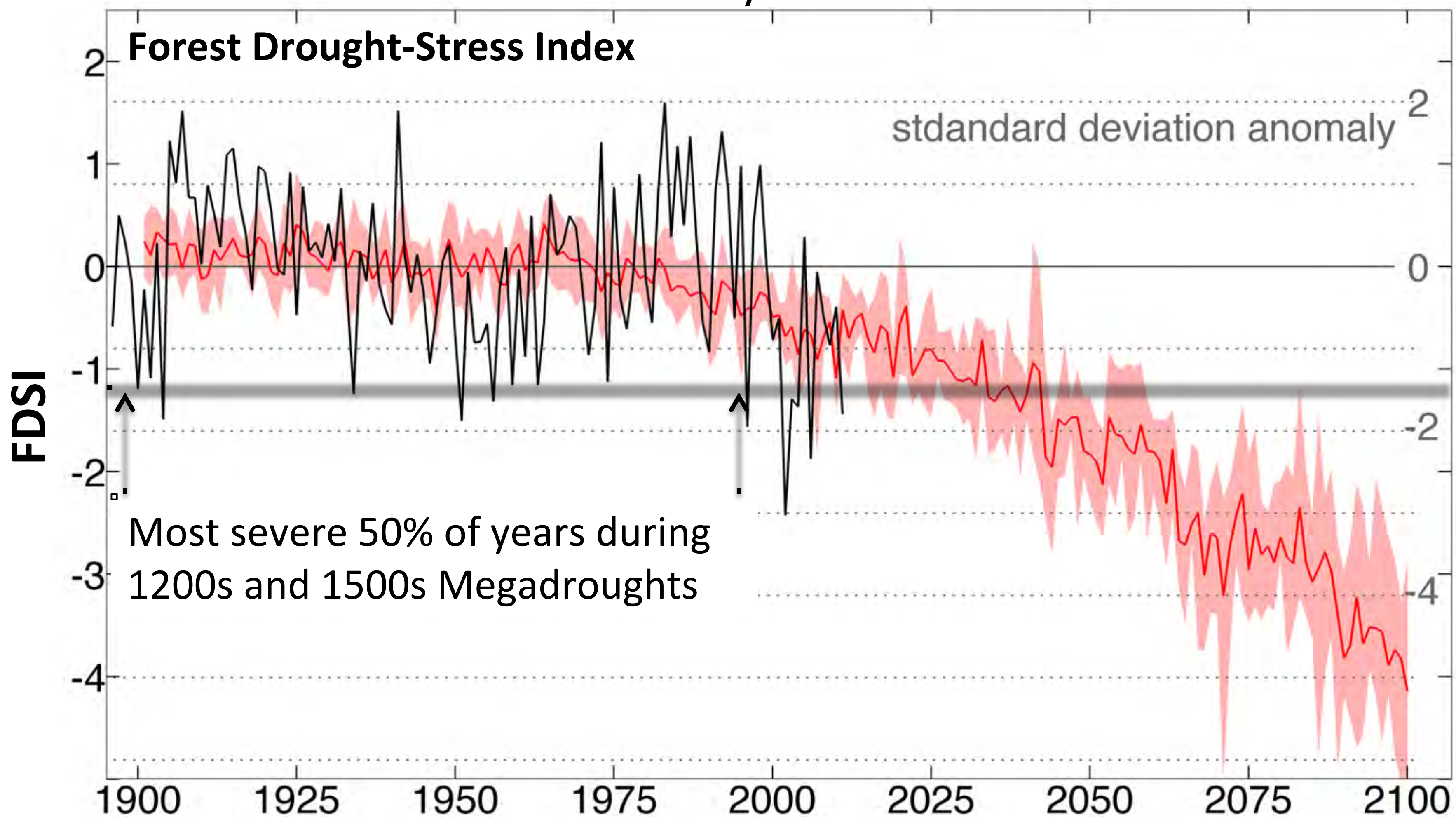


5-15% decrease in cold-season precipitation by 2100

40% increase in warm-season VPD

Climate Model Projections of Forest Drought-Stress Index (FDSI) through 2100

Climate models project persistent "megadrought" conditions by the 2050s



Conclusions

- Southwestern tree-ring records indicate similar year-to-year growth response to drought stress regardless of species or location.
- Warm-season vapor-pressure deficit appears to at least as important as cold-season precipitation in dictating drought stress.
- Drought stress corresponds well with regional forest productivity, area killed by bark beetles, and area burned by wildfire.
- If climate models are correct, average drought stress by the 2050s will match that of the worst years during the largest megadroughts in at least 1000 years.