Wildfires and Climate Change

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Outline

Wildfires and Global Changes

- Drivers of wildfire activities
- Anthropogenic factors influences
- A threshold approach

Wildfires and decreasing precipitation

- Three climatic hypothesis
- Influence of decreasing fire season precipitation
- Path analysis

Southeastern Australia Pyrocumulonimbus (pyroCb) Wildfires

- Drivers of this extreme wildfires
- Future prediction

Wildfires and global change

- Authors: Juli G Pausas and Jon E Keeley
- Source: Frontiers In Ecology and Envir, 2021

Types of wildfires

- Crown fire
- Surface fire
- Pyrocumulonimbus fire

Drivers of Wildfire Activity

- Four primary factors (AT.1a):

- The relationship between wildfires drivers and wildfire activity is _____(linear/non-linear)?

Drivers of Wildfire Activity

Table 1. Main effects of different global change drivers on fire-regime parameters in ecosystems with different types of fire regimes

	Crown-fire ecosystems	Surface-fire ecosystems	
Global change driver	***Woody-fueled fires***	***Grass-fueled fires***	***Litter-fueled fires***
Drought	+flammability +FI, +FS, –FRI	–biomass –FI	+litter fall, –litter decomposition +FI
Urban population growth	+ignitions –FRI	+fire exclusion +FRI, +FI	+fire exclusion +FRI, +FI
Rural population growth	+fragmentation –FS, +FRI	+(over)grazing and +ignitions	+fragmentation, +openings, +ignitions
Atmospheric CO_2	Minor effect	Encroachment +FI	+litter production, +C/N, –decomposition +FI
Invasive grasses	–FRI, –FI	+biomass +FI	+biomass +FI
Heatwaves	+flammability +FI, +FS	+flammability +FI, +FS	+flammability +FI, +FS
Unnatural fuel loads (fire exclusion, tree plantations)	+FI	+FI	+FI
Examples	*Mediterranean shrubland, boreal forests*	*Tropical grasslands, savannas, open woodlands*	*Pine woodlands, some closed forests*

Notes: + indicates positive effect of the global change driver; – indicates negative effect. FI: fire intensity; FS: fire size; FRI: fire return interval.

Same drive might have opposite effects on the fire activities!

Ignition Patterns

- Natural sources:

- Anthropogenic Factors:

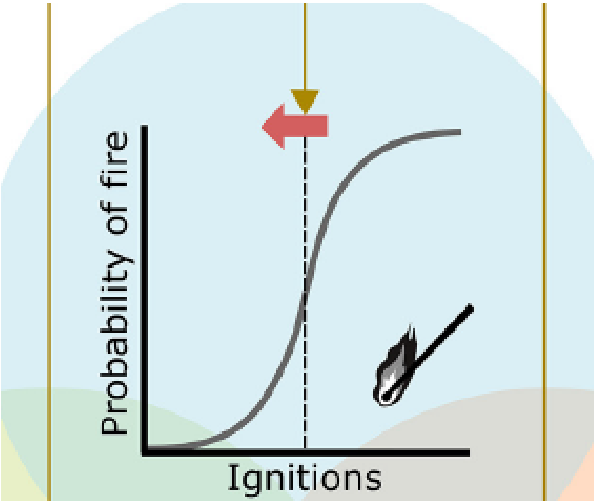
How anthropogenic factors influence ignition points?

- The number of people living in the wildland–urban WUI:
  - "California life-style" model
  - Highly developed landscapes (Eurasia)

Relations between the number of ignition and wildfires?

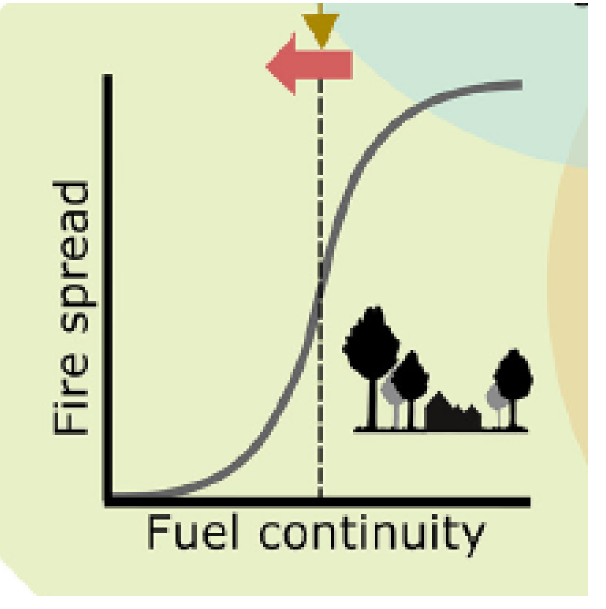
Ignitions and probability of fire follow a _________ curve:

- How probability of fire changes with ignitions?



Fuel continuity

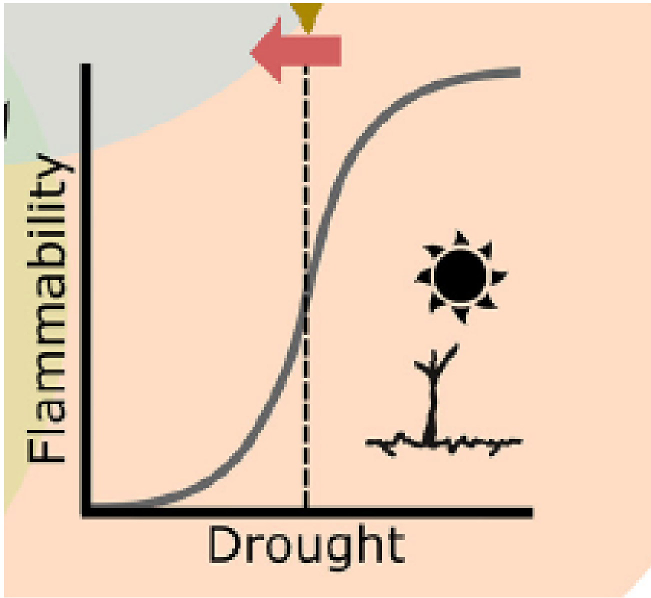
- Wildfire spread rate through plant communications depends on:
  - Structures
  - The flammability of neighboring plants



How human activities influence fuel continuity?

Drought: Woody vs. Grassy ecosystems

- Woody-dominated ecosystems:
  - Drought ______ fire seasons and increases the fire weather frequency.
- Seasonal grassy communities:
  - Drought ______ fire activity by __________.
  - Fire depends on previous rainfall.



Drought: Woody vs. Grassy ecosystems

- Example: Sever 2019 drought in Australia
  - increased areal extent burned in forests.
  - decreased areal extent burned in savannas.

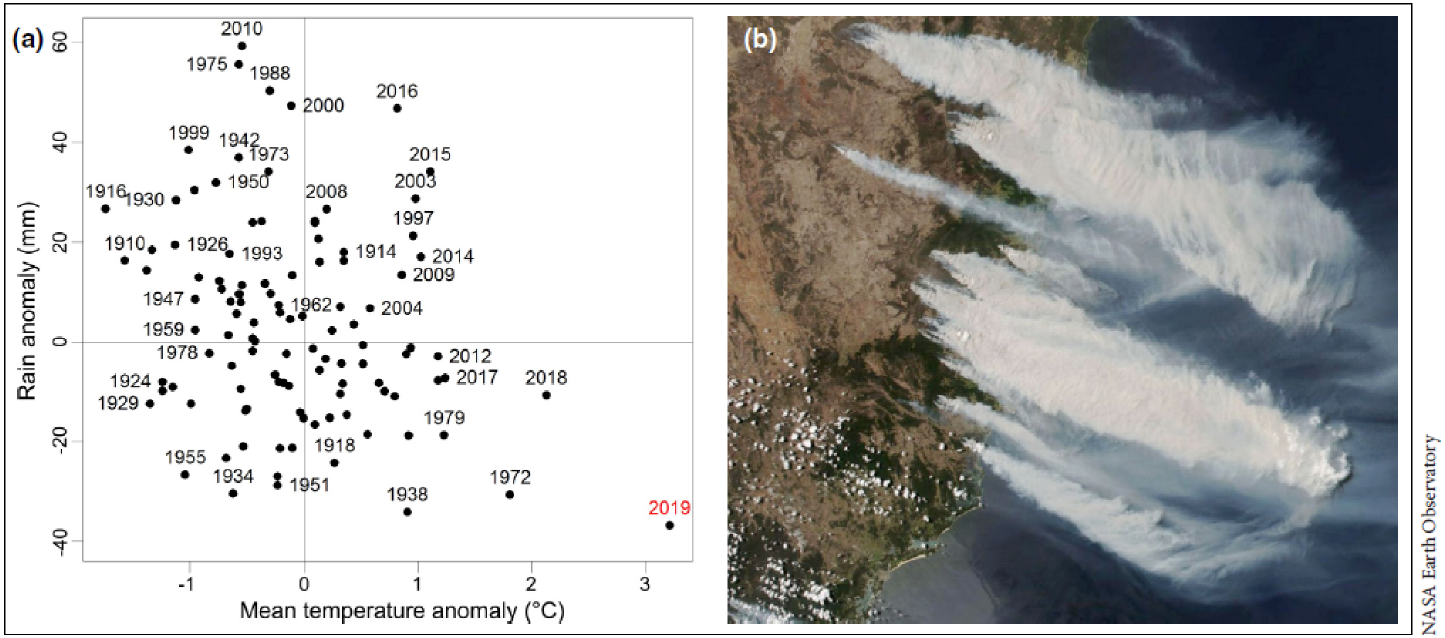


Figure 3. The 2019–2020 bushfires in southeastern Australia were driven by the combination of an extended drought and severe fire weather conditions. (a) Mean temperature anomaly and rainfall anomaly in Australia for the month of December for all years with available climatic records (1910–2019). (b) Smoke plumes showing the importance of wind in driving multiple fires (8 Nov 2019). Graph in (a) elaborated from data by the Australian Bureau of Meteorology.

Fire weather

- Definition:
  - the weather conditions directly affecting fire behavior, i.e., size and duration.

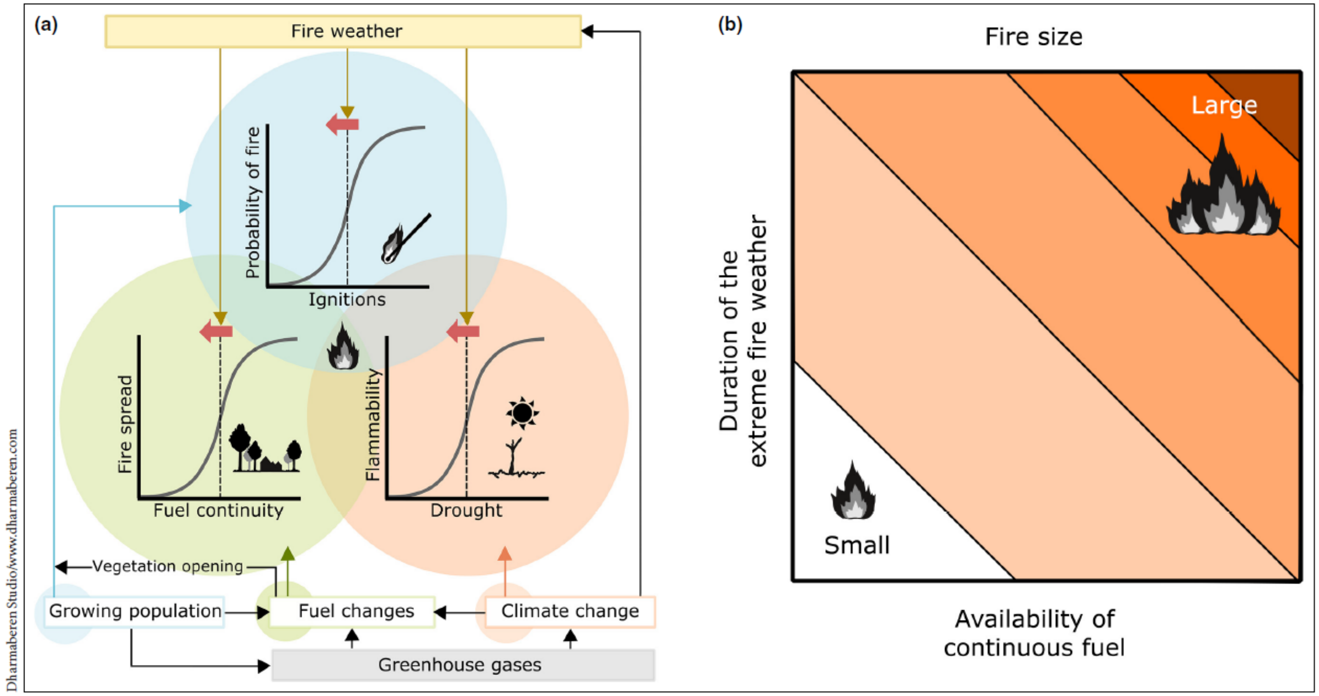


Figure 1. Conceptual model of relationships between fire parameters and their drivers. (a) Probability of fire occurrence versus ignitions, fire spread versus landscape fuel continuity, and fuel flammability versus drought. In these graphs, dashed vertical lines indicate thresholds. In all cases, fire weather (strong wind, high temperature, or low humidity) shifts the curve and the threshold toward lower values (thick red arrows; ie saturation is reached at lower values along the x-axis), consequently increasing the probability of an ignition resulting in a fire, fire spread (for a given landscape configuration), and vegetation flammability (fuel dries faster). The flow chart shows the main factors affecting the fire drivers, including human population growth in or near wildlands, altered fuel loads (fragmentation, oldfields, fire exclusion, among others), and climate change. Arrows indicate positive interactions, with the exception of changes in fuel, which can increase or decrease fuel continuity depending on the system (eg fragmentation versus fire exclusion or increasing oldfields). (b) Once all thresholds have been crossed, the size of the fire is determined by the duration of the extreme fire weather and the availability of continuous fuels in the landscape.

The Threshold Approach

- Wildfires occur when thresholds are crossed for:
  - Ignition
  - Fuel continuity
  - Drought
- Fire weather reduces thresholds, increasing wildfire likelihood.
- Thresholds vary by ecosystem and landscape structure.

Fire Weather Factors

- Key components (AT.1c):
  - Wind:
  - High Temperature and low humidity:

- Winds:
  - Thomas Fire in California (https://www.youtube.com/watch?v=xd4lMRCZQMA)
    - When:
    - Acres burned:
    - Structure destroyed:
  - Fires in Portugal and Spain (2017)
    - Hurricane Ophelia toward western Europe.
    - Transported the smoke to the UK.

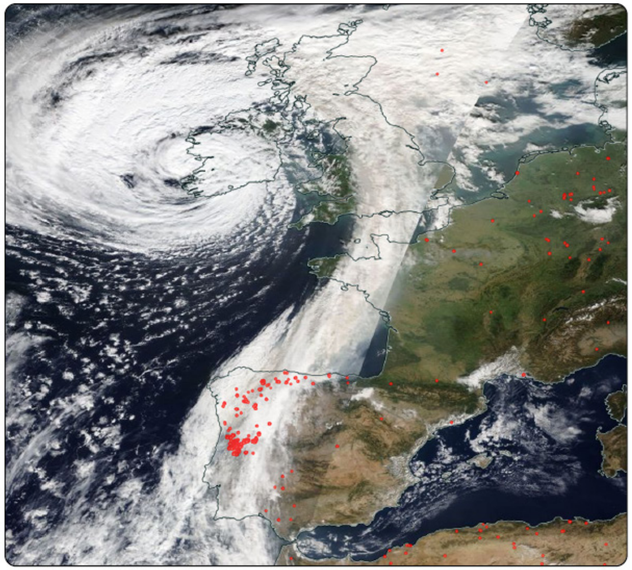
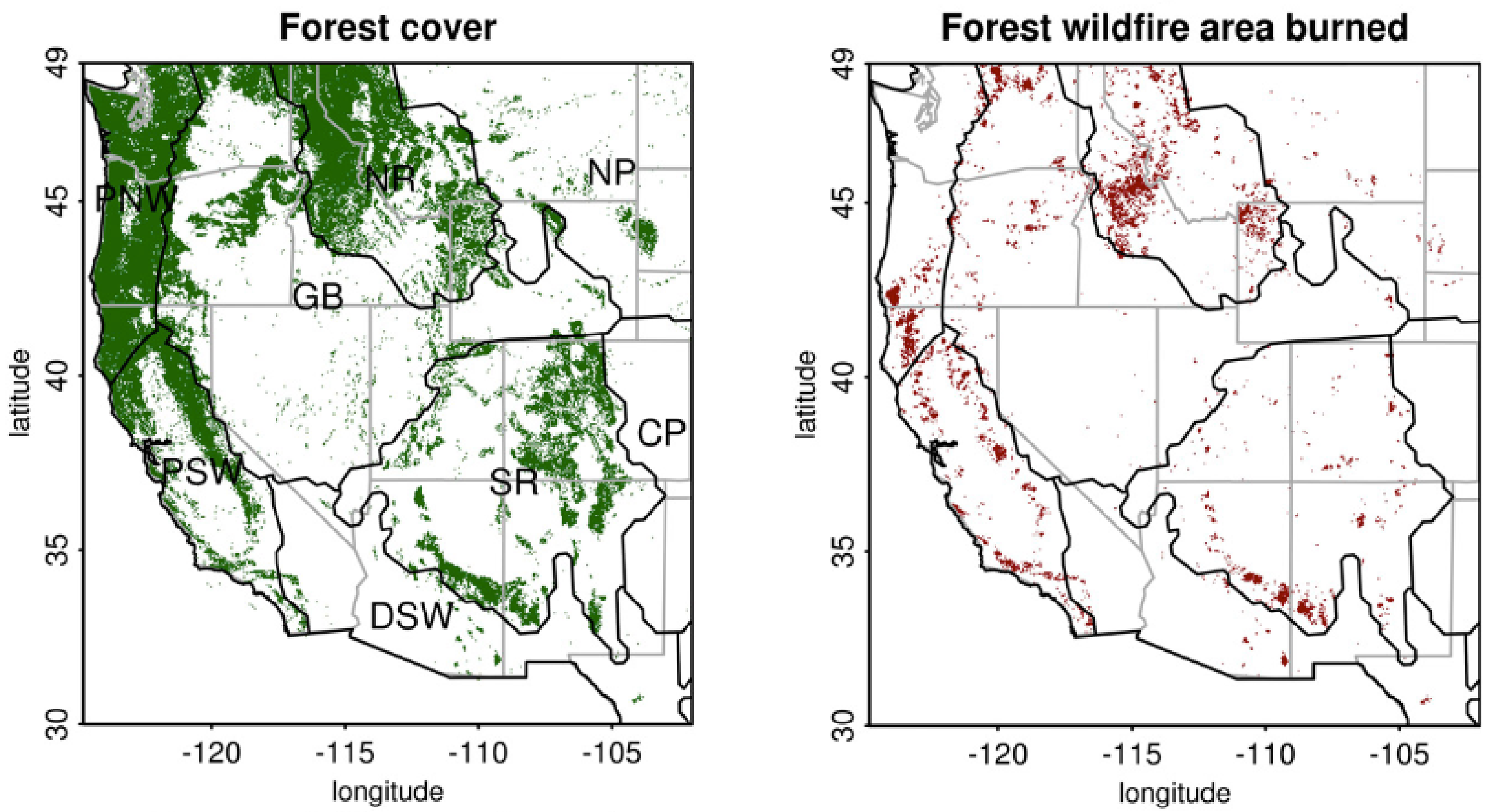


Figure 4. Hurricane Ophelia originated in the Caribbean and eventually reached Europe, where it fueled fires in Portugal and Spain, and covered the UK with smoke from those fires (16 Oct 2017). It is considered the easternmost Atlantic hurricane on record. Red circles are fires as detected by the Visible Infrared Imaging Radiometer Suite (VIIRS).

Decreasing Fire Season Precipitation and Wildfires

- Authors: Zachary A. Holden et al.
- Source: PNAS, 2018

Big picture



CP, Central Plains; DSW, Desert Southwest; GB, Great Basin; NP, Northern Plains; NR, Northern Rockies; PNW, Pacific Northwest; PSW, Pacific Southwest; SR, Southern Rockies.

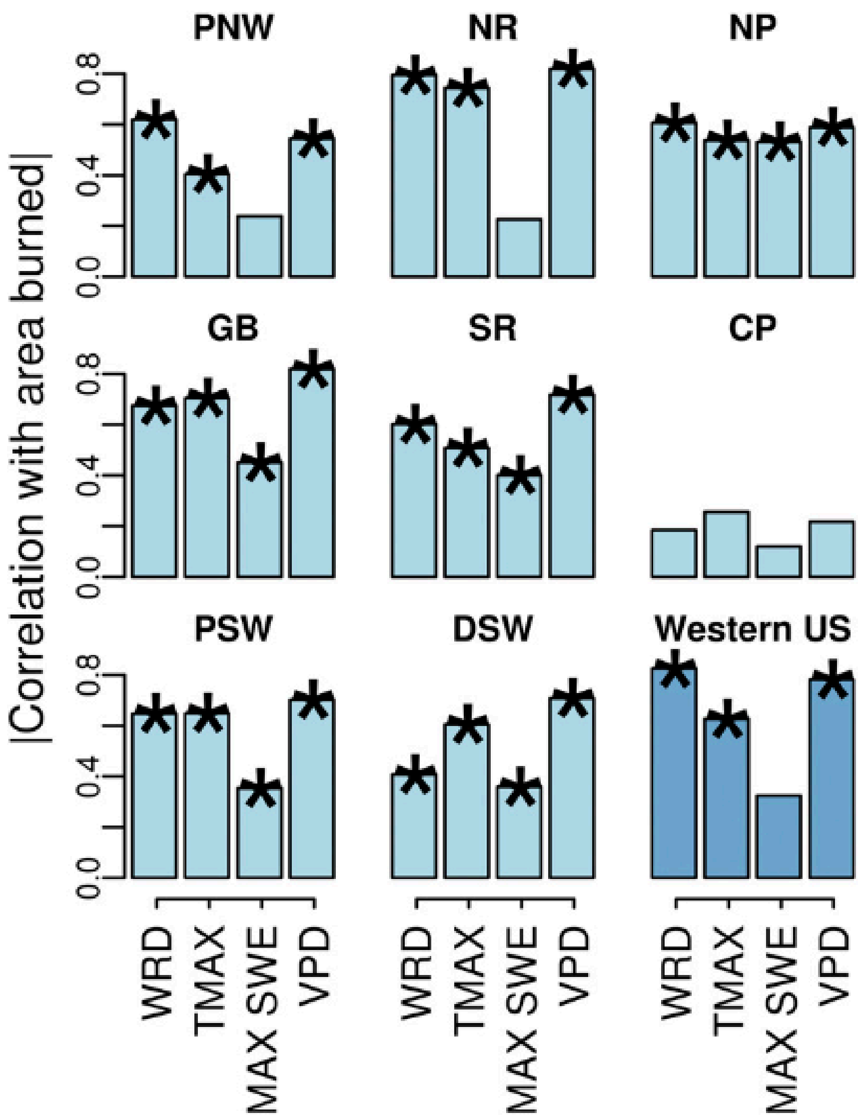
- Contrast effects of three hypothesis climatic drivers on the Western US wildfire activities.
- Precipitation trends in historical fire season (May-September).

What leads to the fire activities increase?

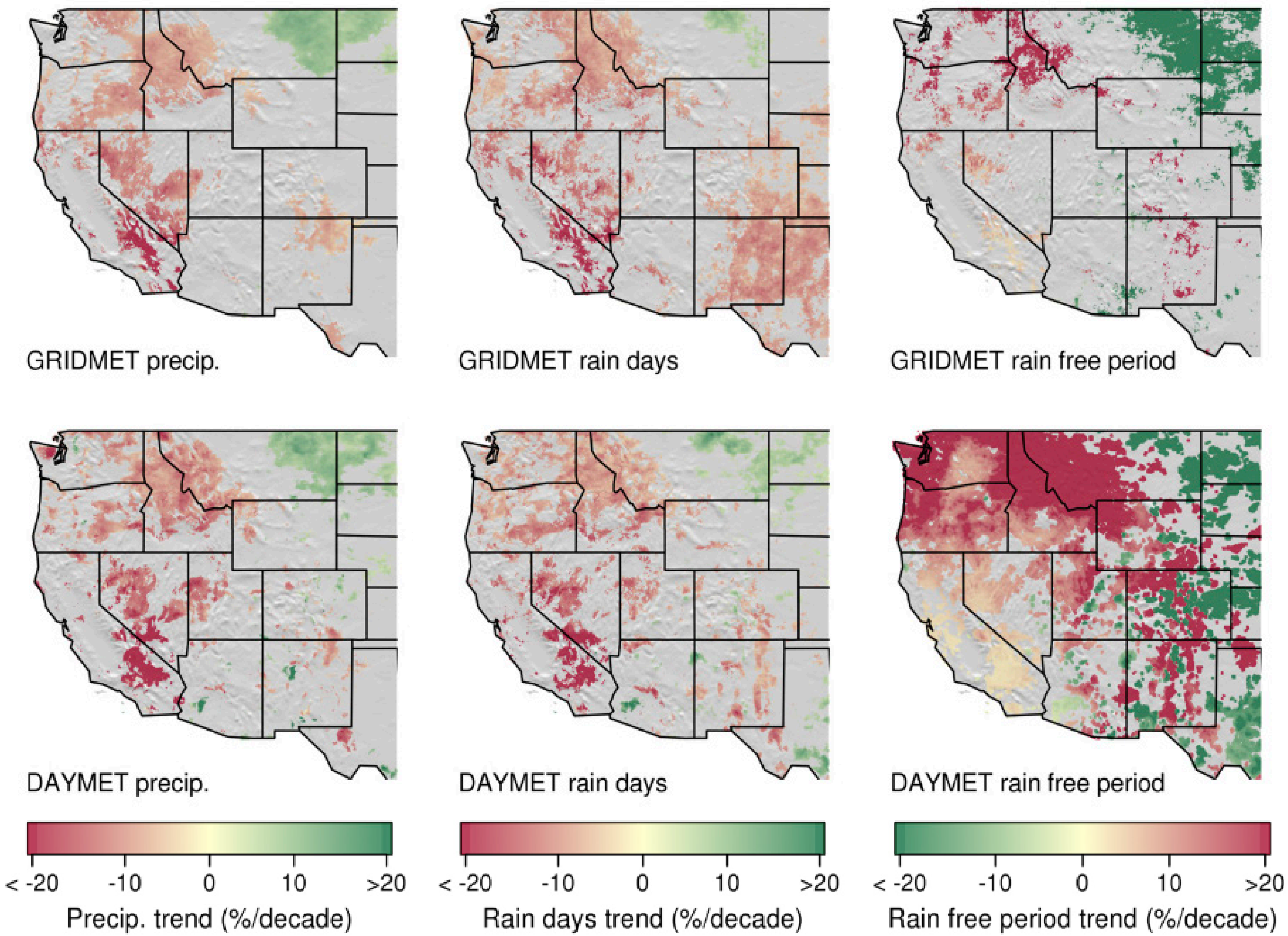
- Three hypothesis (two historical)(AT.2a):

Correlation with area burned

Temperature vs. snowpack vs. precipitation



Precipitation and Wetting Rainy Day (WRD)



- Trends in total May–September in the Western US:
  - _________ trends in precipitation across 82–94% of forested area.
  - _________ trends in WRD across 83–98% of forested area.

Precipitation and Wetting Rainy Day (WRD)

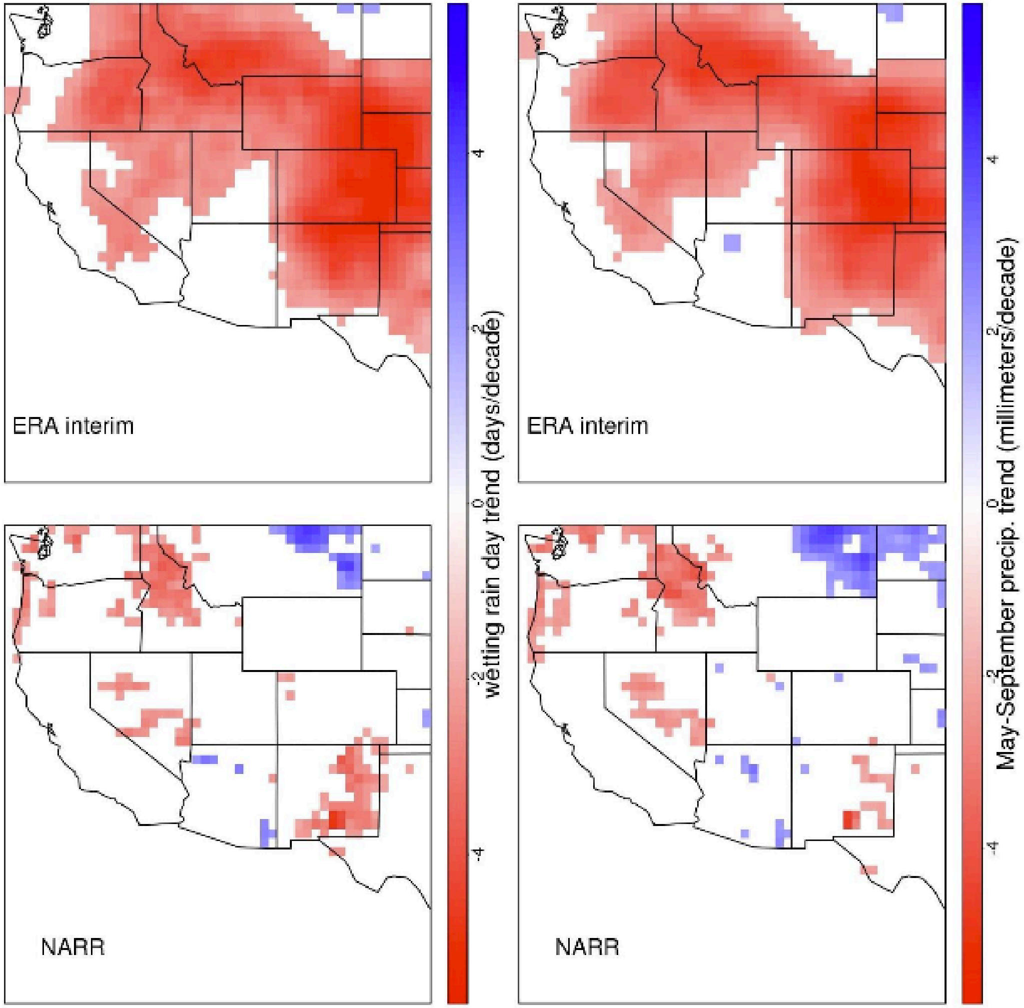
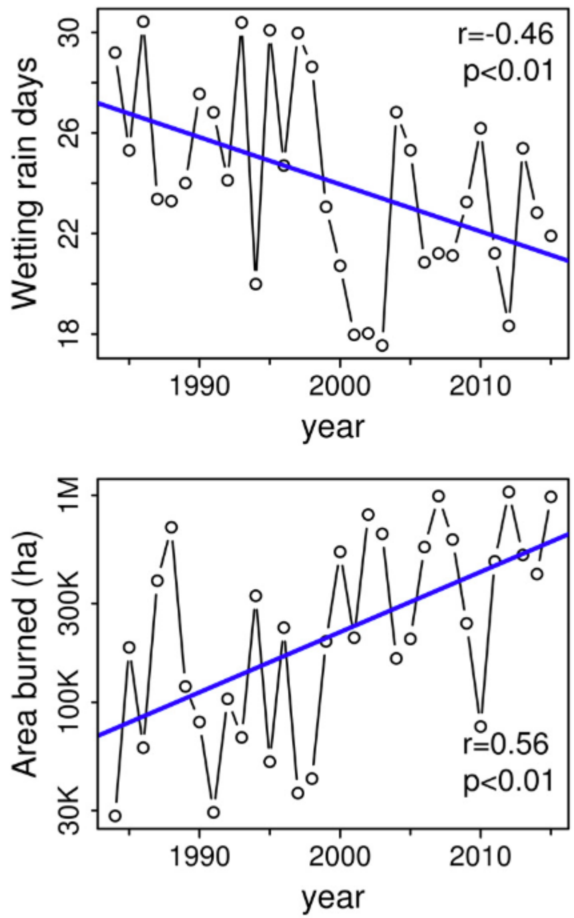


Fig. S8. Trends in May-September total precipitation and wetting rain days from 1979-2016 in the ERA-interim reanalysis and North American Regional Reanalysis (NARR) datasets. Trends are calculated using the Mann-Kendall trend test. Only pixels with significant trends at $p < 0.10$ are shown.

Precipitation and Wetting Rainy Day (WRD)



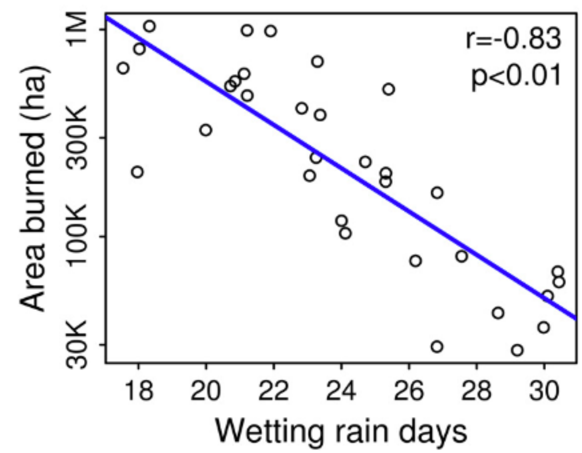


Fig. 4. Linear trends in WRD (*Top*), log-transformed wildfire area burned (*Middle*), and their correlation (*Bottom*) from 1984 to 2015 in forested areas of the western United States.

- Aggregation across the Western US for the 1984-2015 period:
  - Significant _________ of WRD in fire seasons (r = -0.46)
  - Significant _________ of area burned (r = 0.56)
  - Larger _________ correlation between area burned and wetting rain days

Summer precipitation

Near-surface air temperature

VPD

How they relate to each other? By what?

Statistic analysis between TMAX, VPD, and WRD

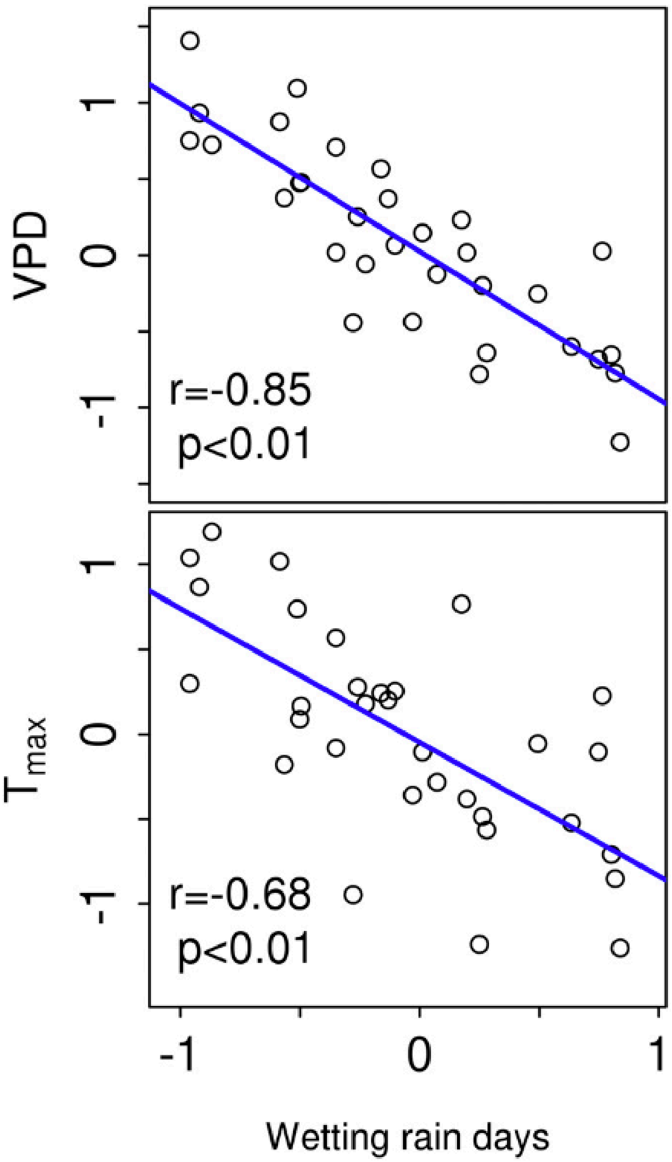


Fig. 5. May–September WRD anomalies correlated with maximum VPD and maximum temperature anomalies for western US forested areas from 1984–2015.

- Strong correlations between WRD and TMAX and VPD.
- They tightly couple with each other!

Path Analysis

Why we need path analysis?

- Evaluate the relative influence of _snowpack_, _temperature_, and _precipitation_ on wildfire area burned.
- Determine which of the three hypotheses _best_ accounts for interannual variations in western US burned area.

Decouple individual influences!

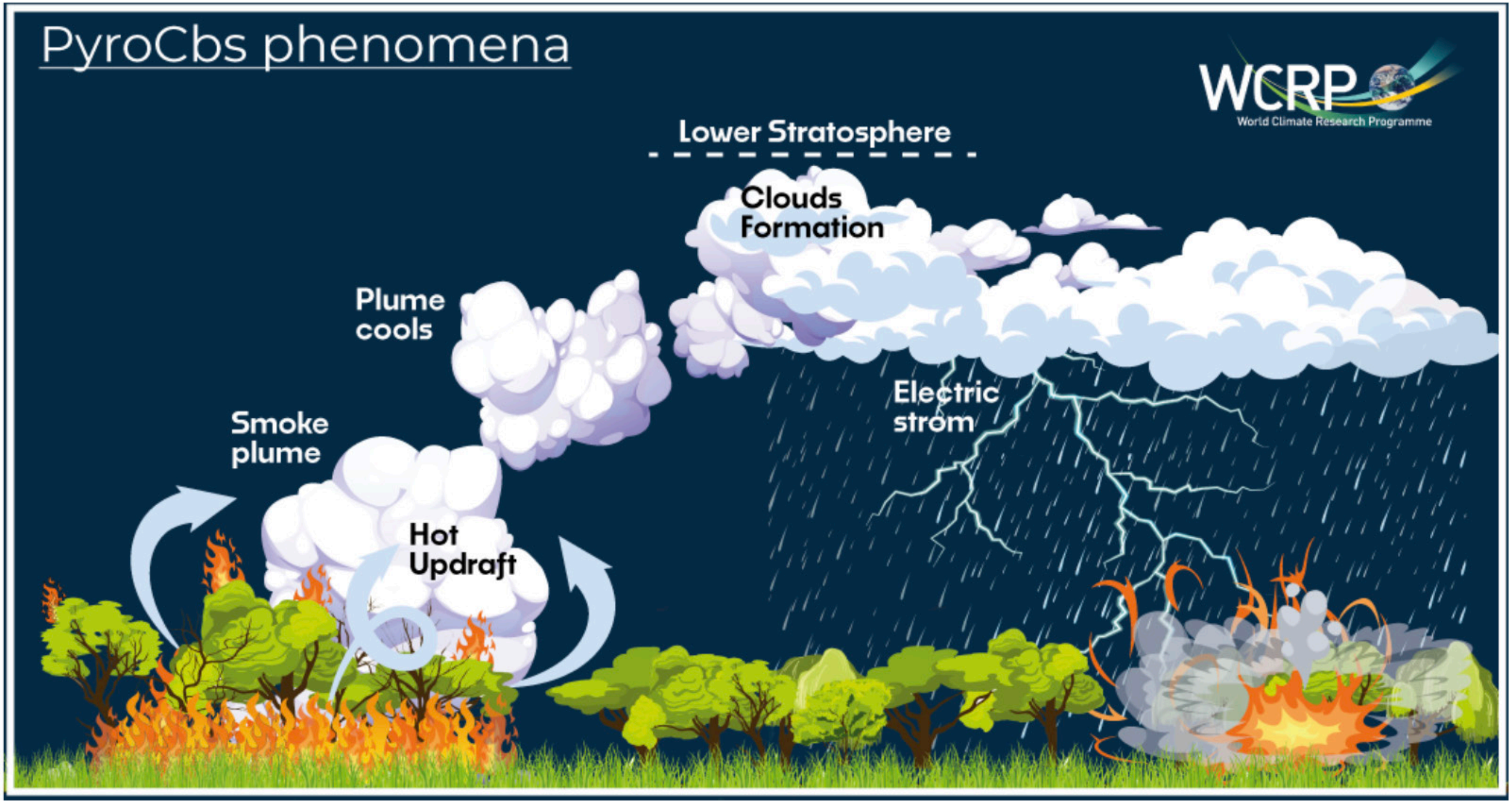
Take away messages

- Traditional focus on snowpack and temperature may miss critical factors.
- Declines in summer precipitation and WRD are major contributors to wildfire increases.
- Shallow snowpack and shorter snow-covered seasons show a relatively small influence on increased wildfire activities.

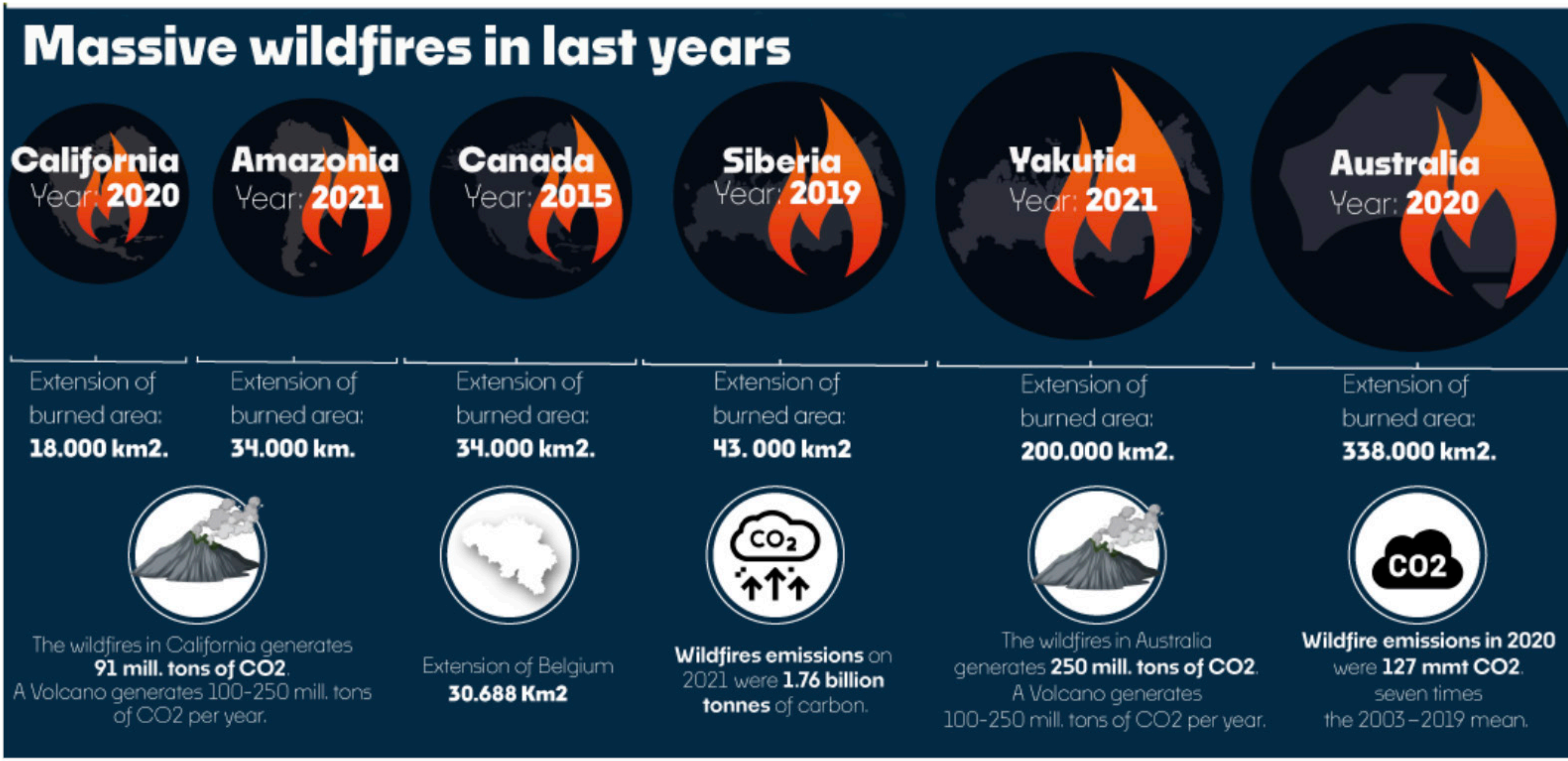
Climate Change Increases the Potential for Extreme Wildfires

- Authors: Giovanni Di Virgilio et al.
- Source: Geophysical Research Letters, 2019

Pyrocumulonimbus (AT.3a)



PyroCbs wildfires



Big picture

- Pyrocumulonimbus (pyroCb) Wildfires:
  - Extreme wildfires coupled with atmospheric conditions.
- Driven by:
  - Atmospheric dryness and instability, C-Haines.
  - Surface fire weather conditions, FFDI
- Method:
  - A regional climate model (RCM) ensemble
- Location:
  - Southeastern Australia.
- Period (three 20-years period):
  - Historical: 1990-2009.
  - Near-future: 2020-2039
  - Far-future: 2060-2079

Changes!

Method - C-Haines

- Haines Index (HI):
  - three variants of the HI (low/medium/higher elevations) were proposed in _____ by Haines.

Table 4: Components of the mid-level Haines Index, following McCaw et al. (2007).

Stability Term: 850-700 hPa Temperature Difference HA	Stability Score	Moisture term: 850 hPa Dewpoint Depression HB	Moisture Score
< 6C	1	< 6C	1
6-10C	2	6-12C	2
>10C	3	>12C	3

- HI = HA + HB :
  - Range of HI is _____.
  - Higher HI indicates _______ fire danger!

Mills, G. A., & McCaw, L. (2010). *Atmospheric stability environments and fire weather in Australia—Extending the Haines Index*. Australia: Australian Government, Bureau of Meteorology.

Method - C-Haines (AT.3b)

- C-Haines (CH):
  - ”Continuous Haines Index”.
  - CA: a __________ term
  - CB: a __________ term
  - C-Haines ranges from ~7 to ~10 depending upon location in southeastern Australia.

$$CA = 0.5\,(T850 - T700) - 2.$$

$$CB = 0.3333\,(T850 - DP850) - 1.$$

$$CH = CA + CB$$

Mills, G. A., & McCaw, L. (2010). *Atmospheric stability environments and fire weather in Australia—Extending the Haines Index*. Australia: Australian Government, Bureau of Meteorology.

Method - FFDI

- Forest Fire Danger Index (FFDI):
  - Was first calculated in 1980.
  - Indicates surface fire weather conditions.

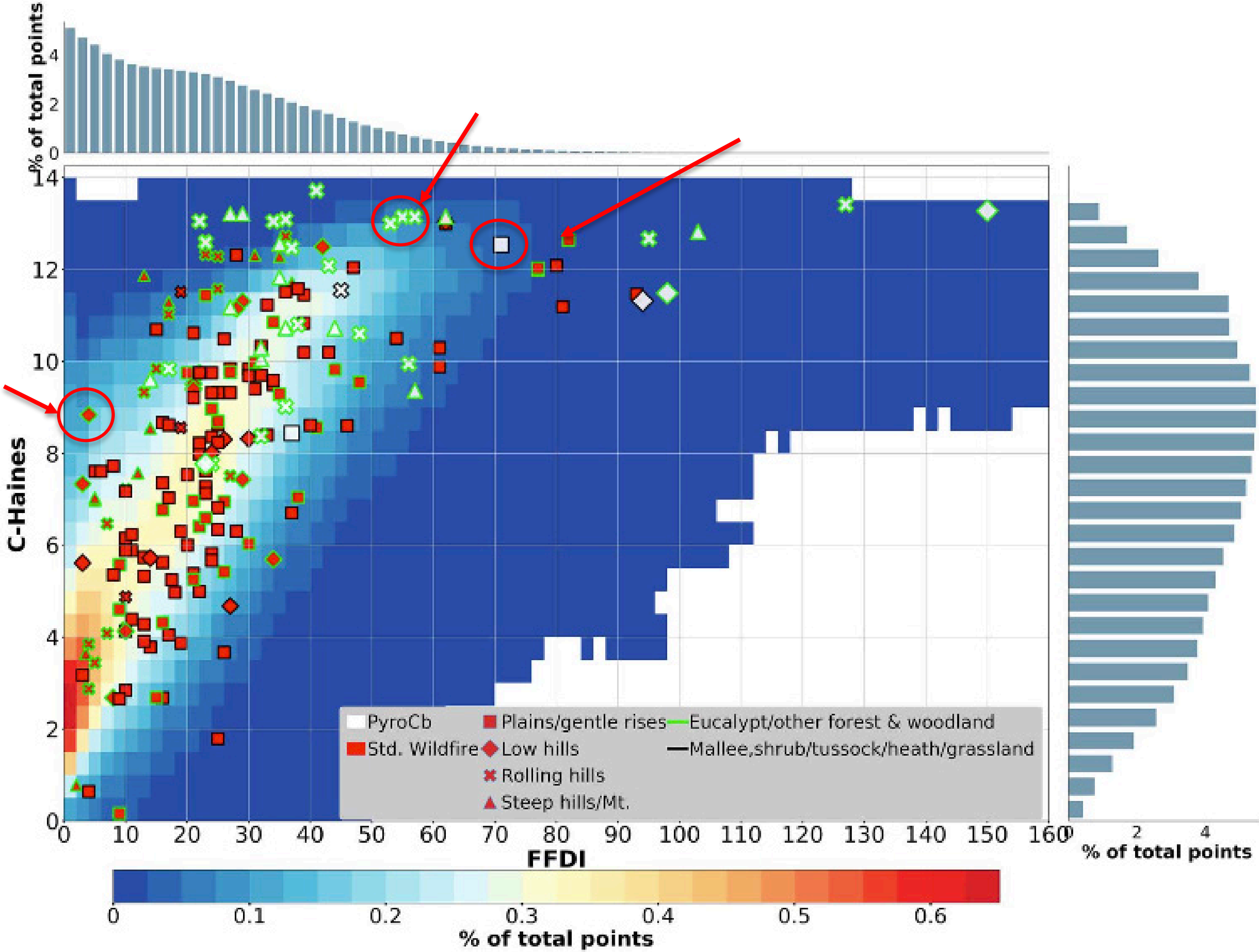
TABLE 1. Explanation of symbols used in the text

Symbol	Variable	Units
C	Degree of curing	percent
D	Drought factor	–
F	Fire danger index	–
H	Relative humidity	percent
I	Keetch-Byram drought index	(mm equivalents)
M	Fuel moisture content	percent
N	Time since rain	days
P	Amount of precipitation	mm
R	Rate of forward spread of fire on level to undulating ground	km hr^{-1}
R_θ	Rate of forward spread on ground of slope θ	km hr^{-1}
S	Distance of spotting from flame front	km
T	Air temperature	°C
V	Average wind velocity in the open at a height of 10 m	km hr^{-1}
W	Fuel weight	tonnes ha^{-1}
Z	Flame height	m
θ	Slope of ground surface	degrees

$$F = 2.0 * \exp(-0.450 + 0.987 * \ln(D) - 0.0345 * H + 0.0338 * T + 0.0234 * V)$$

Noble, I. R., Bary, G. A. V., & Gill, A. M. (1980). McArthur fire-danger meters expressed as equations. *Australian Journal of Ecology*, **5**(2), 201–203. https://doi.org/10.1111/j.1442-9993.1980.tb01243.x

Obs



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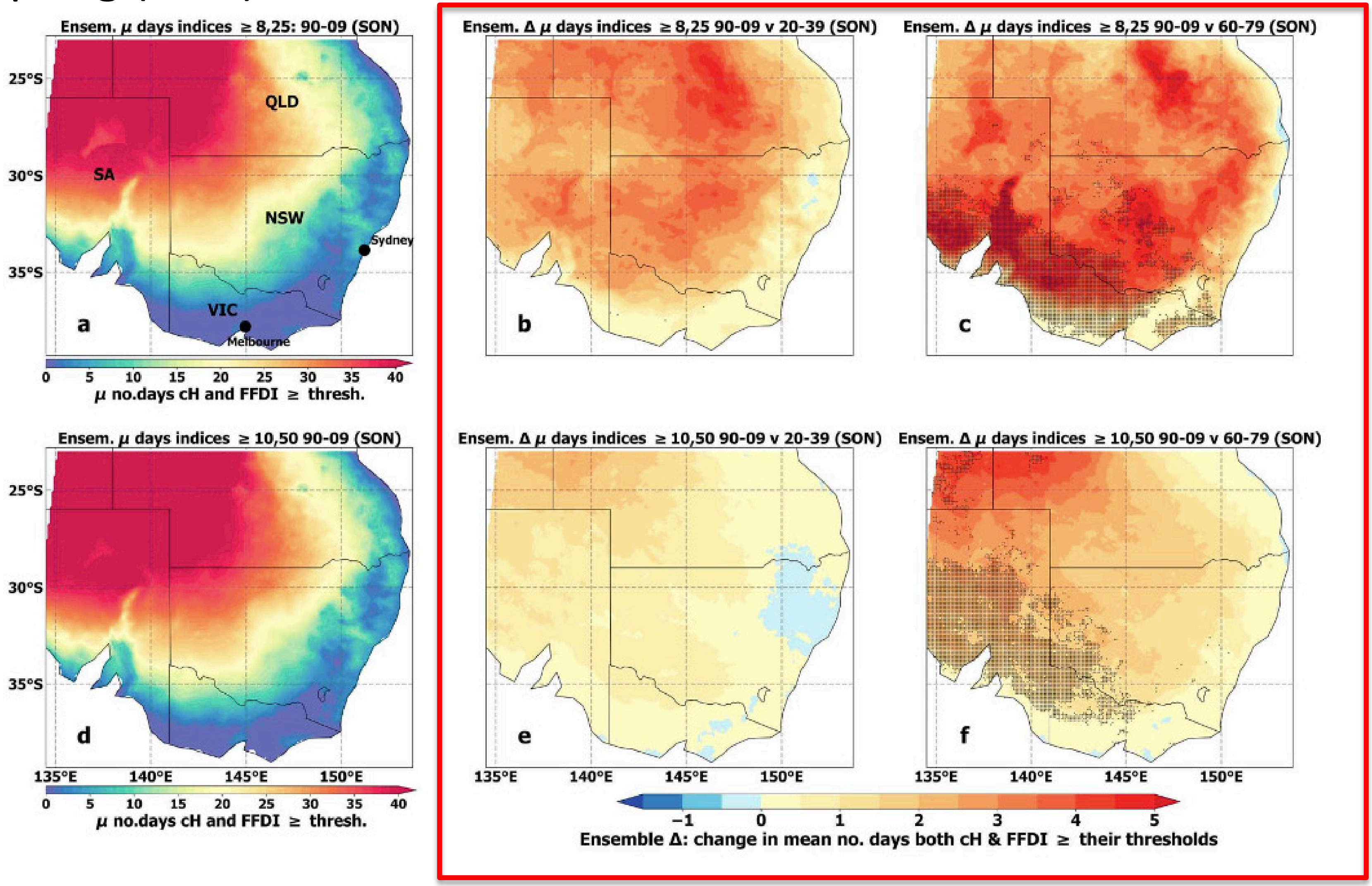
– C-Haines: ________ range, _____ values, between 10 and 13.7.

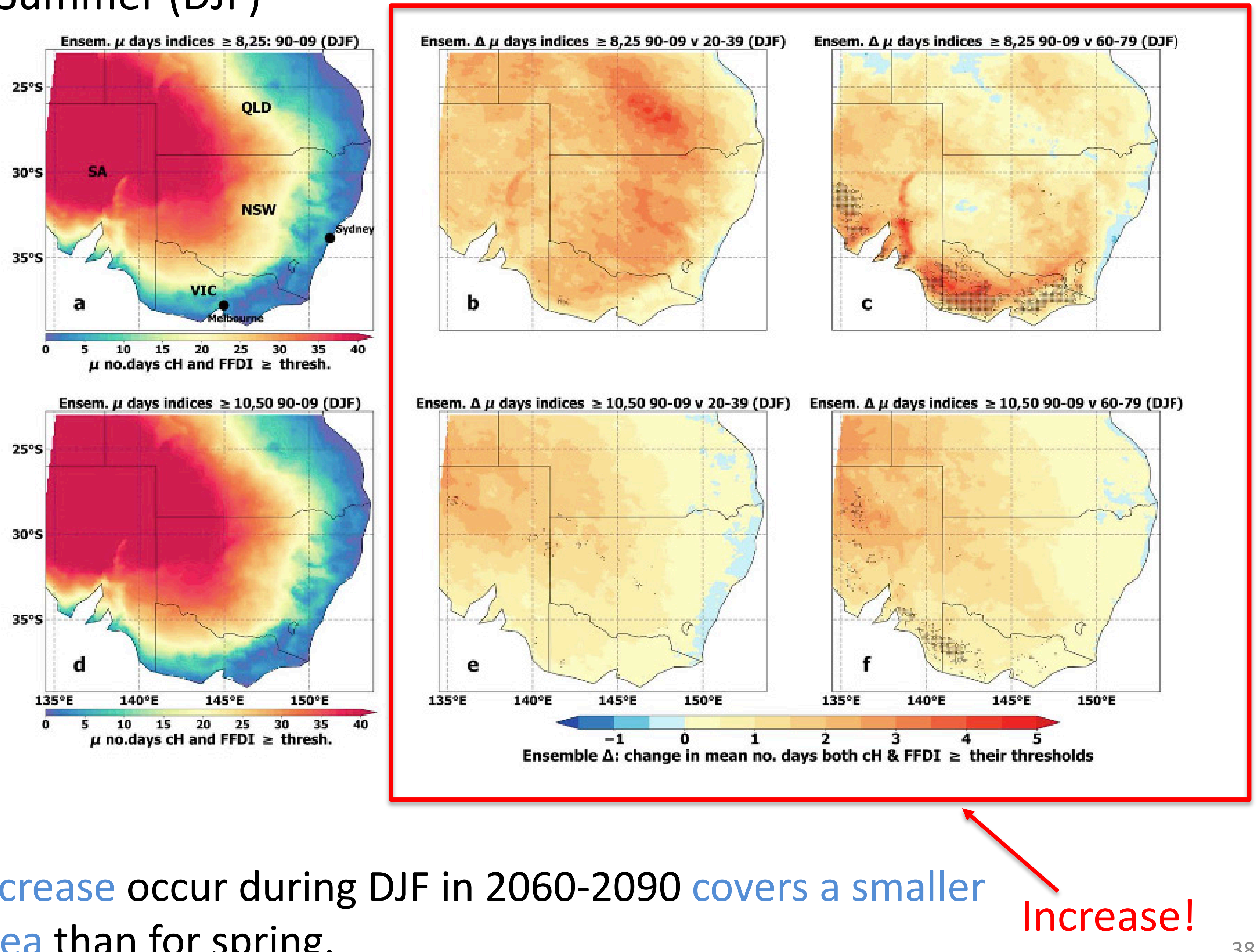
– FFDI: ______ range, between 25 and 150

Spring (SON)



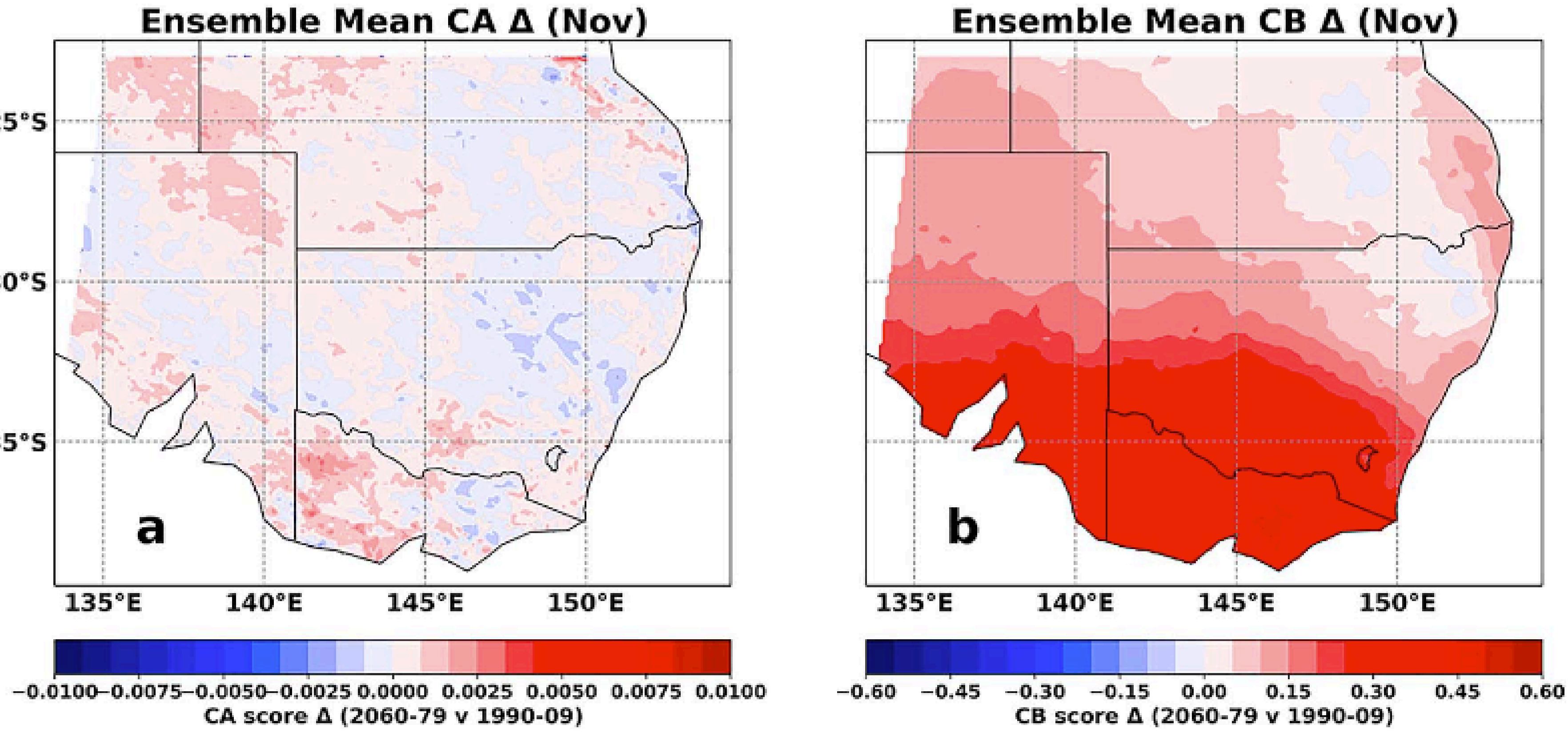
Significant increase in 2060-2090 during SON occur over areas that include agricultural regions and near urban areas up to 4-5 days.

Summer (DJF)



Increase occur during DJF in 2060-2090 covers a smaller area than for spring.

C-Haines Changes



- CB (moisture term) change is larger than CA (stability term)
  - Largest over the southern region

$$CA = 0.5 (T850 - T700) - 2.$$

$$CB = 0.3333 (T850 - DP850) - 1.$$

$$CH = CA + CB$$

Take away messages

- Climate change amplifies pyroCbs risk through:
  - Increased atmospheric instability and dryness.
  - Shifted seasonality to earlier (Spring) in the year.
- Urgent need for:
  - Updated fire management strategies.
  - Integration of climate adaptation policies.