Forest fires

Global Warming Science EPS101

Eli Tziperman

https://courses.seas.harvard.edu/climate/eli/Courses/EPS101/

CBS Sunday Journal: Apocalyptic Western wildfires, Sep 13, 2020

https://www.youtube.com/watch?v=mC_TP2Syk7s

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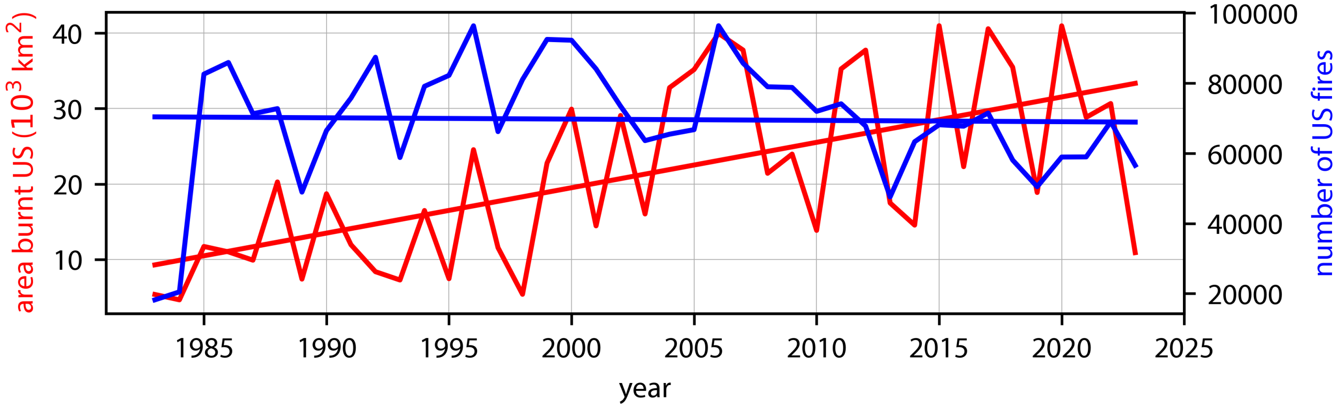
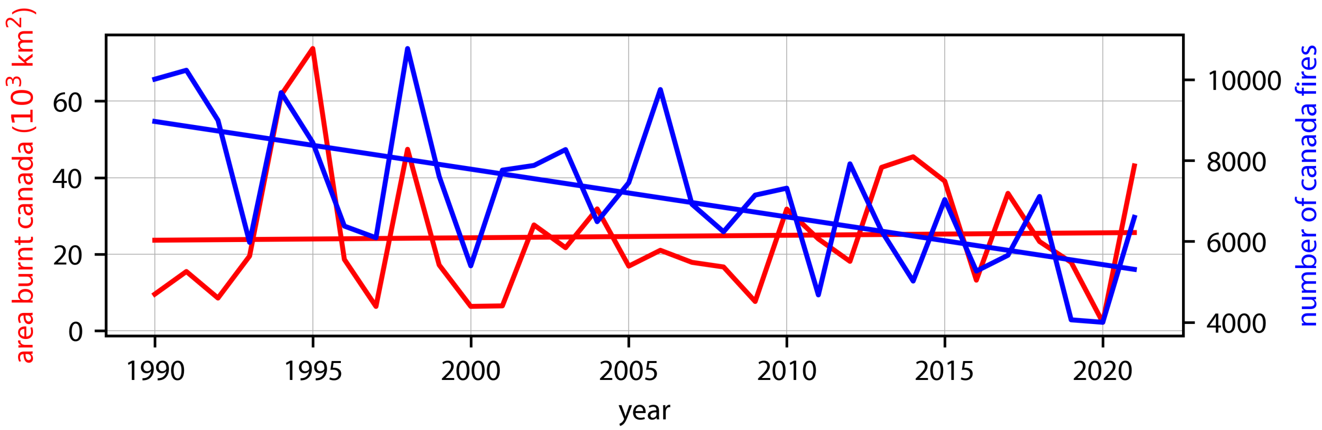
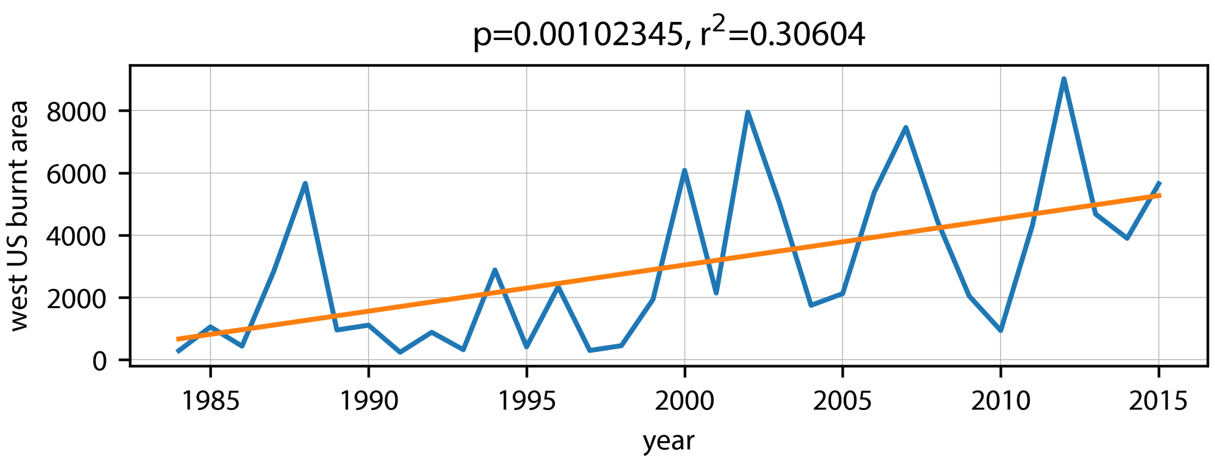
Workshop #1:

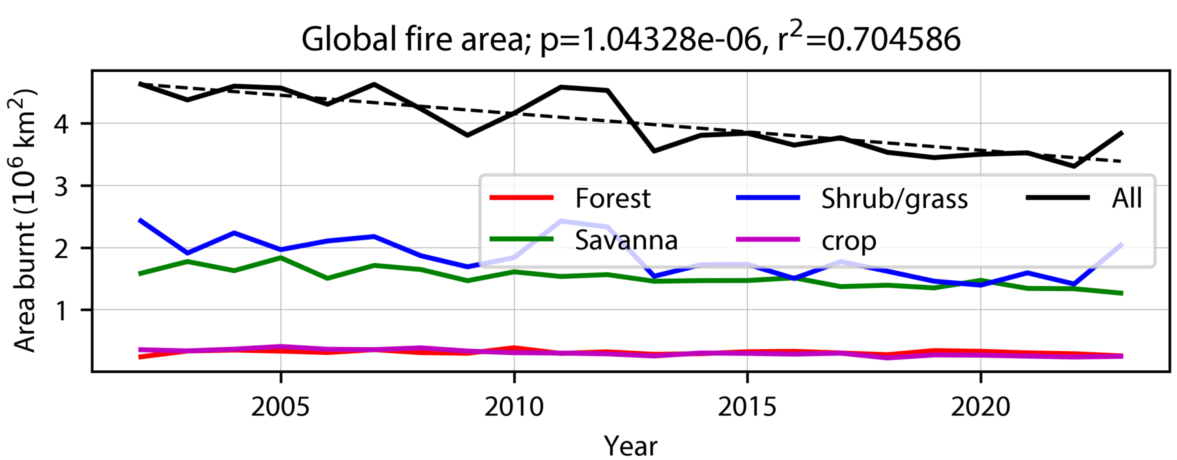
Observed fire trends

Observed Forest Fire trends



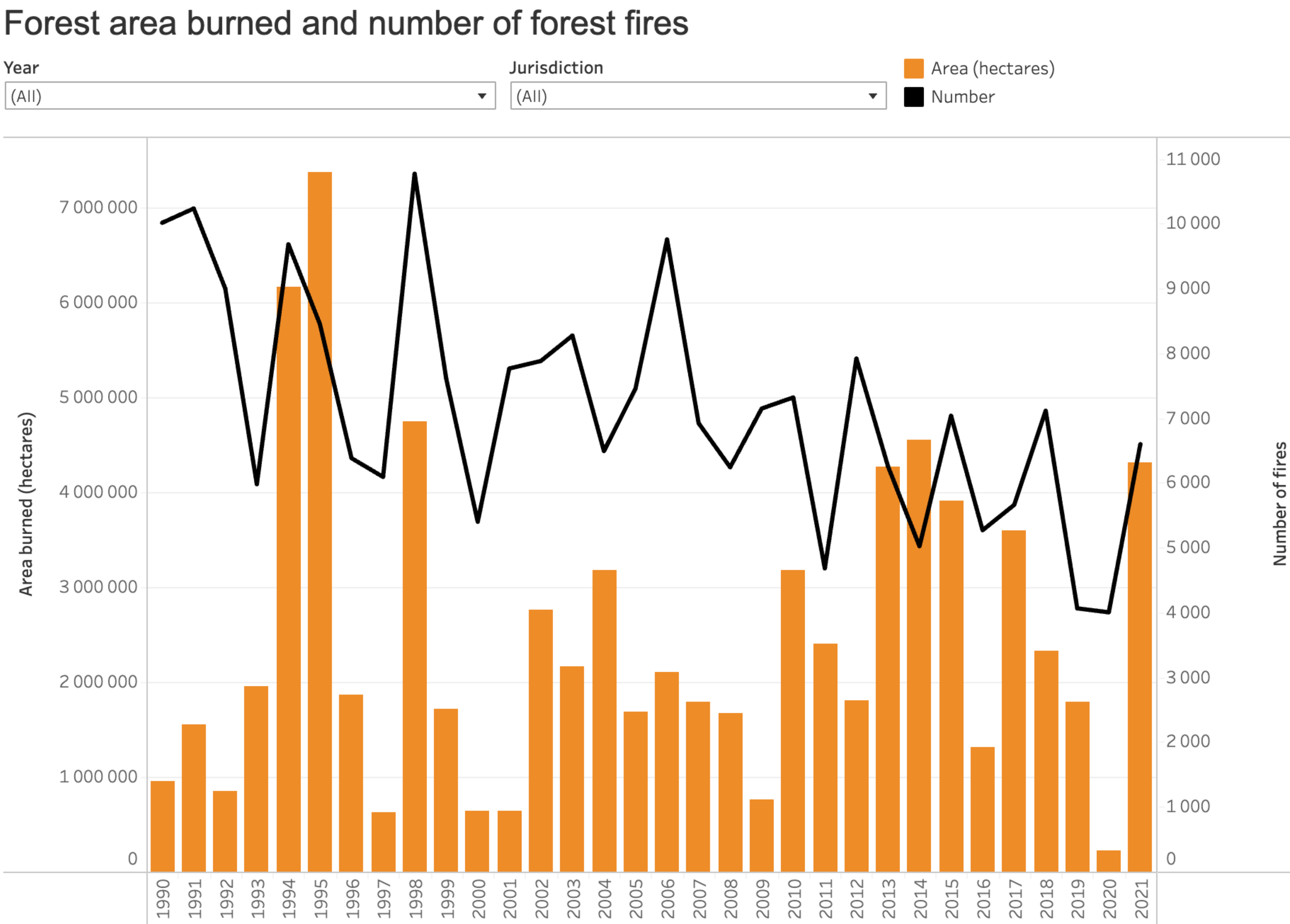






It’s complicated…

Canadian Forest Fire area and number



Over 8000 fires occur each year, & burn an average of over 2.1 million hectares. Lightning causes ~50% of all fires but accounts for ~85% of annual area burned.

https://cwfis.cfs.nrcan.gc.ca/ha/nfdb?type=poly&year=9999

The Science Behind Forest Fires | NYTimes, May 15, 2014

https://www.youtube.com/watch?v=mj75koAJBvY

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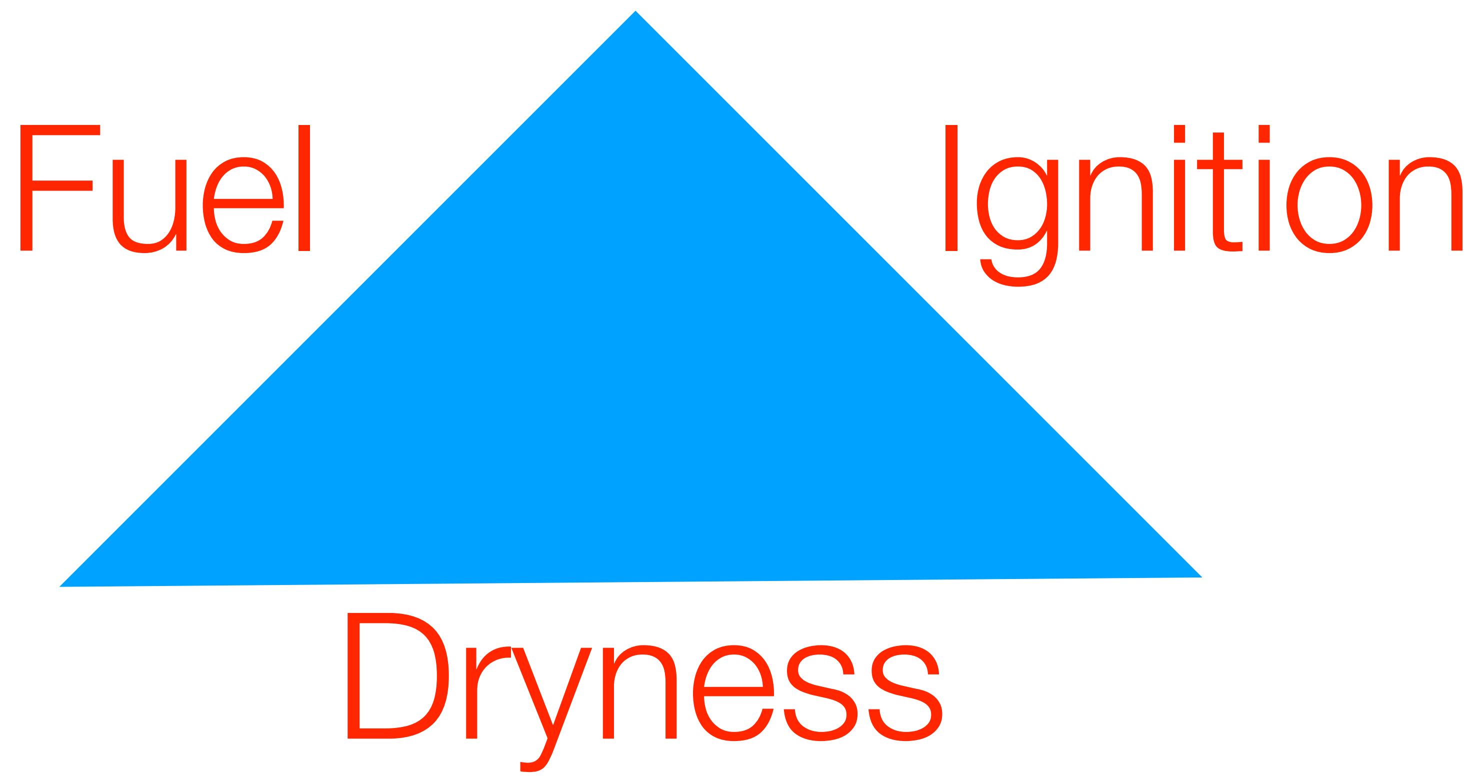
The basics



The three factors determining fire’s ability to start and spread

It's complicated…

Climate factors affecting fire frequency and size:

It’s complicated…

Climate factors affecting fire frequency and size:

prior rainy season precipitation, earlier spring snowmelt ➨ **More vegetation growth and more fuel availability**. Warming, droughts, dry weather ➨ **drier fuels.** Strong&dry winds (Santa Ana, S. CA) ➨ **accelerate drying & fire spread.**

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Non-climate related human effects:

It’s complicated…

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Non-climate related human effects:

95% of fire ignitions in some areas are human-caused, logging, conversion of land to and from agriculture-use, fire suppression policies & buildup of fuels, population increases (more ignitions; building in fire-prone areas ➨ more fire damage).

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For sea ice, Hurricanes, etc., detection requires the signal to be separated from natural climate variability. For forest fires, human effects include non-climate change factors ➨ detecting a trend not due to natural fire variability is insufficient.

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Additional factors:

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Additional factors:

changes of unknown origin to composition of forests (tree type, size, density), effect of past fires on connectivity of forests & ability of fires to spread, on fuel availability in following years.

Lightning-ignited forest fires are natural, part of ecosystem dynamics

Pre-anthropogenic past forest fires are recorded in ash layers in lake sediments, and as burn signs in tree ring records

https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/fire-history

Lightning-ignited forest fires are natural; a part of ecosystem dynamics

Lab experiments: resinous bonds between cone scales begin to break between 45–60 ˚C; serotinous cones touched by fire expand and allow seeds to be released.

https://fitznaturalist.com/2016/11/29/sometimes-indivuals-lose-while-species-win/

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Notes section 14.1:

Tools:

- Vapor pressure deficit (VPD),
- Climatic water deficit (CWD),
- Fire indices

(Use next slides)

Vapor pressure deficit (VPD):

The saturation water vapor pressure minus actual vapor pressure ($VPD = e^*(T) - e$). Higher VPD ➨ more ability to evaporate water ➨ faster drying of fuels. Clausius-Clapeyron ➨ $e^*(T)$ & VPD increase exponentially with T even if specific humidity q is constant. VPD increases with T even for RH=constant, where q increases with T. The strong correlation of VPD with burnt area ➨ important role for warming in forest fires!

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Evaporation from soil + evaporation from stomata in leaves fed by transpiration, the movement of water within plants from roots to leaves.

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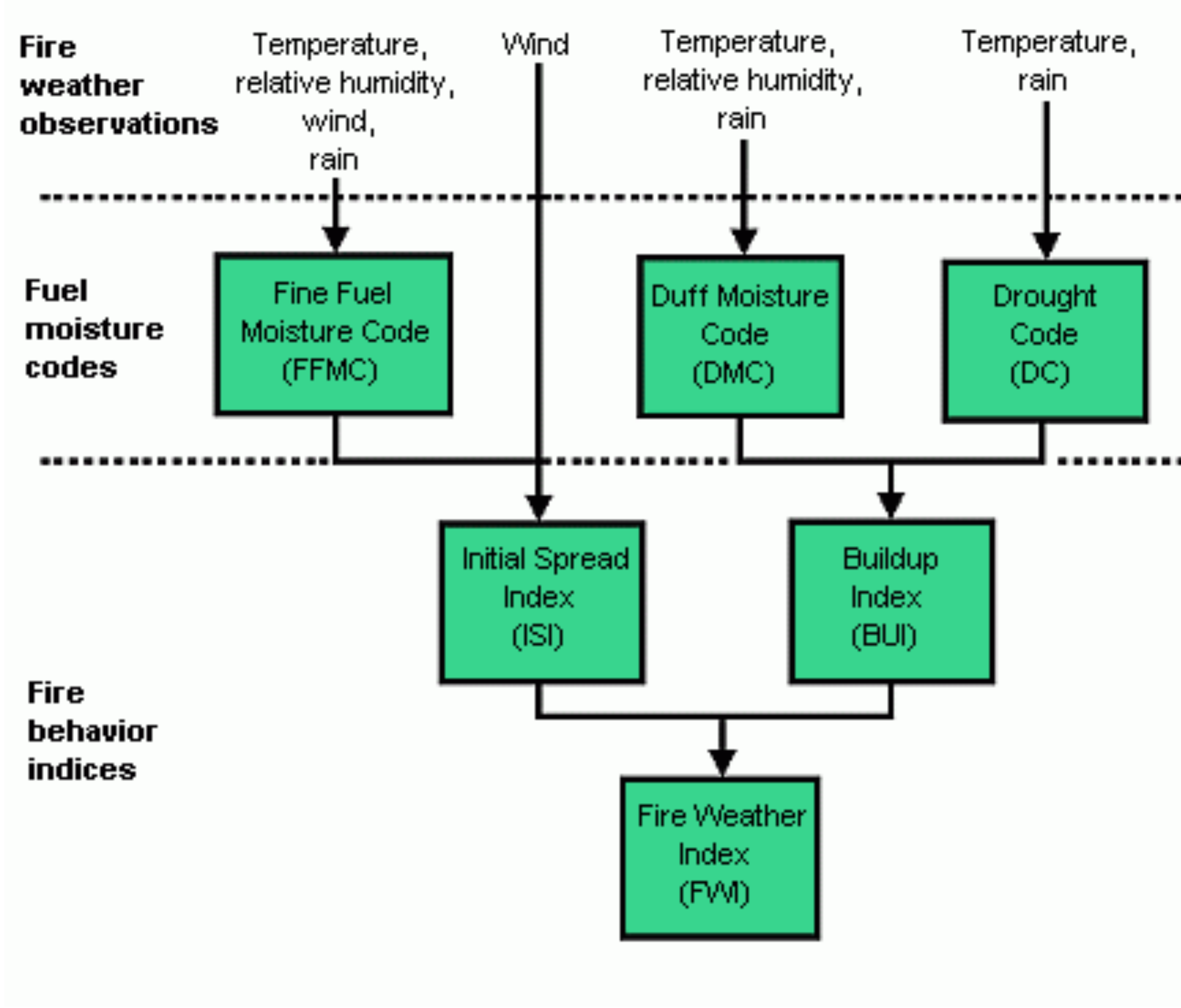
Climatic water deficit (CWD):

The seasonally integrated potential evapotranspiration (PET) minus the actual evapotranspiration.

Canadian Forest Fire Weather Index (FWI) System

Fine Fuel Moisture Code (FFMC): moisture content of litter & other cured fine fuels. Indicator of relative ease of ignition & flammability.



https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

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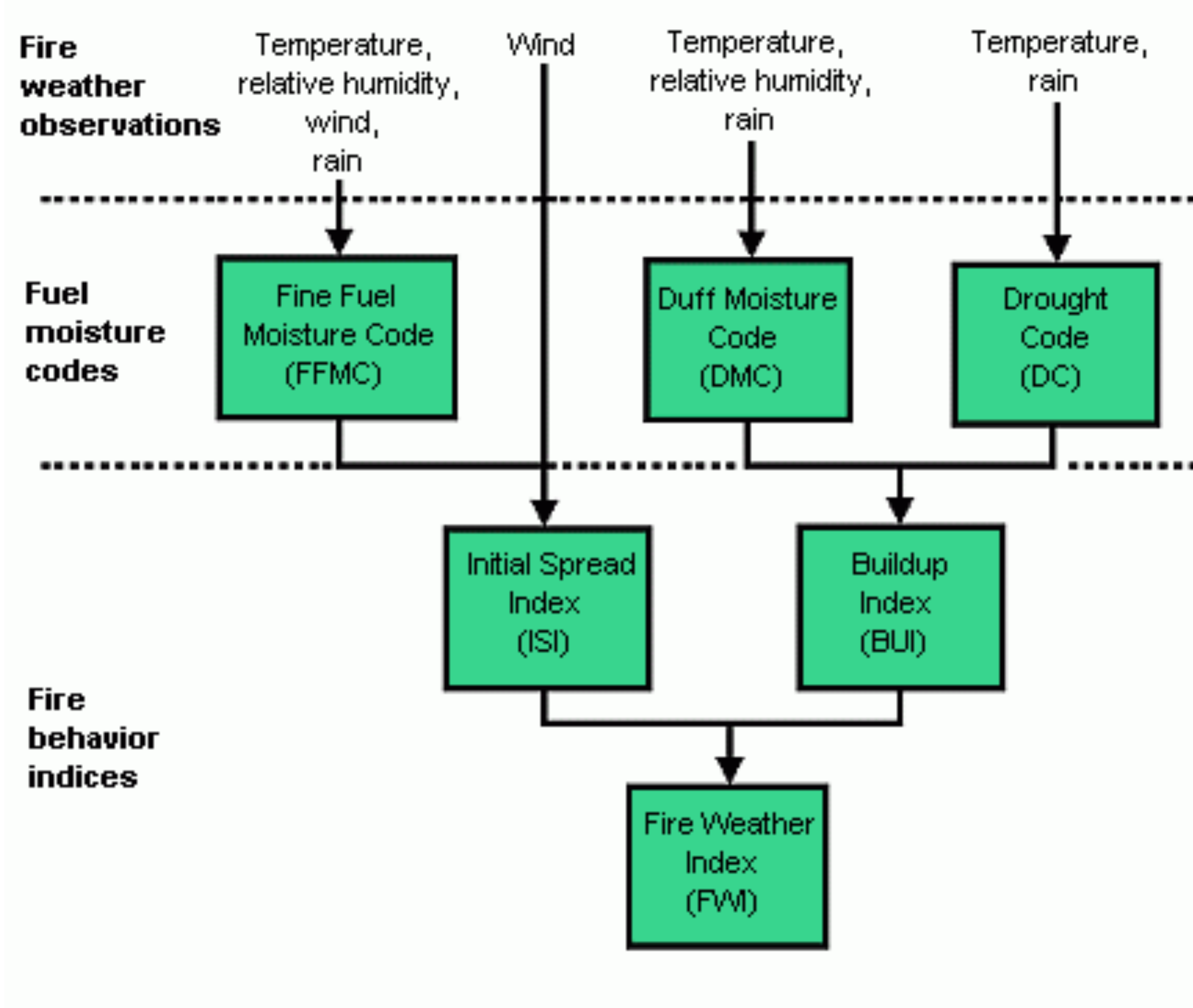

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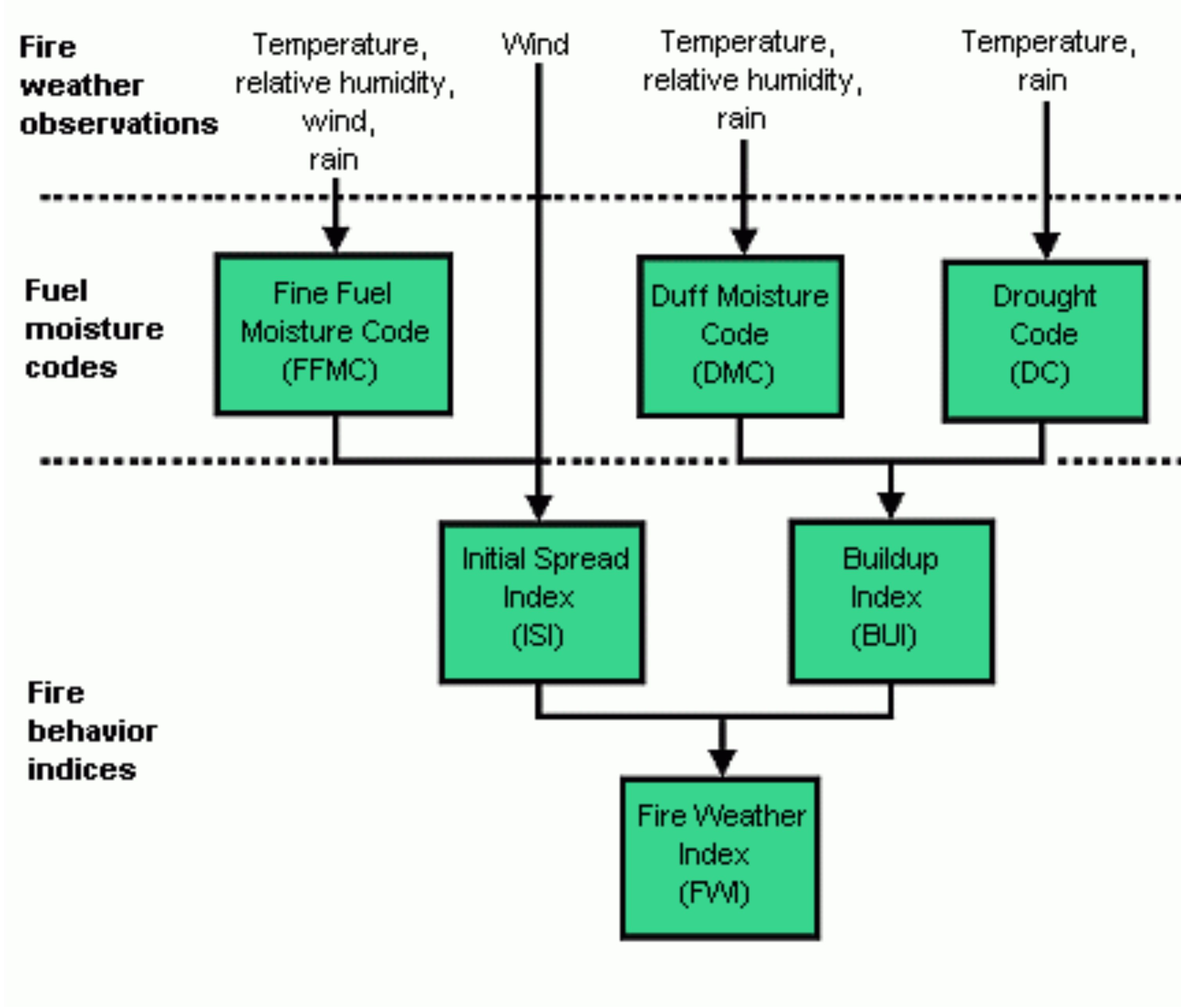

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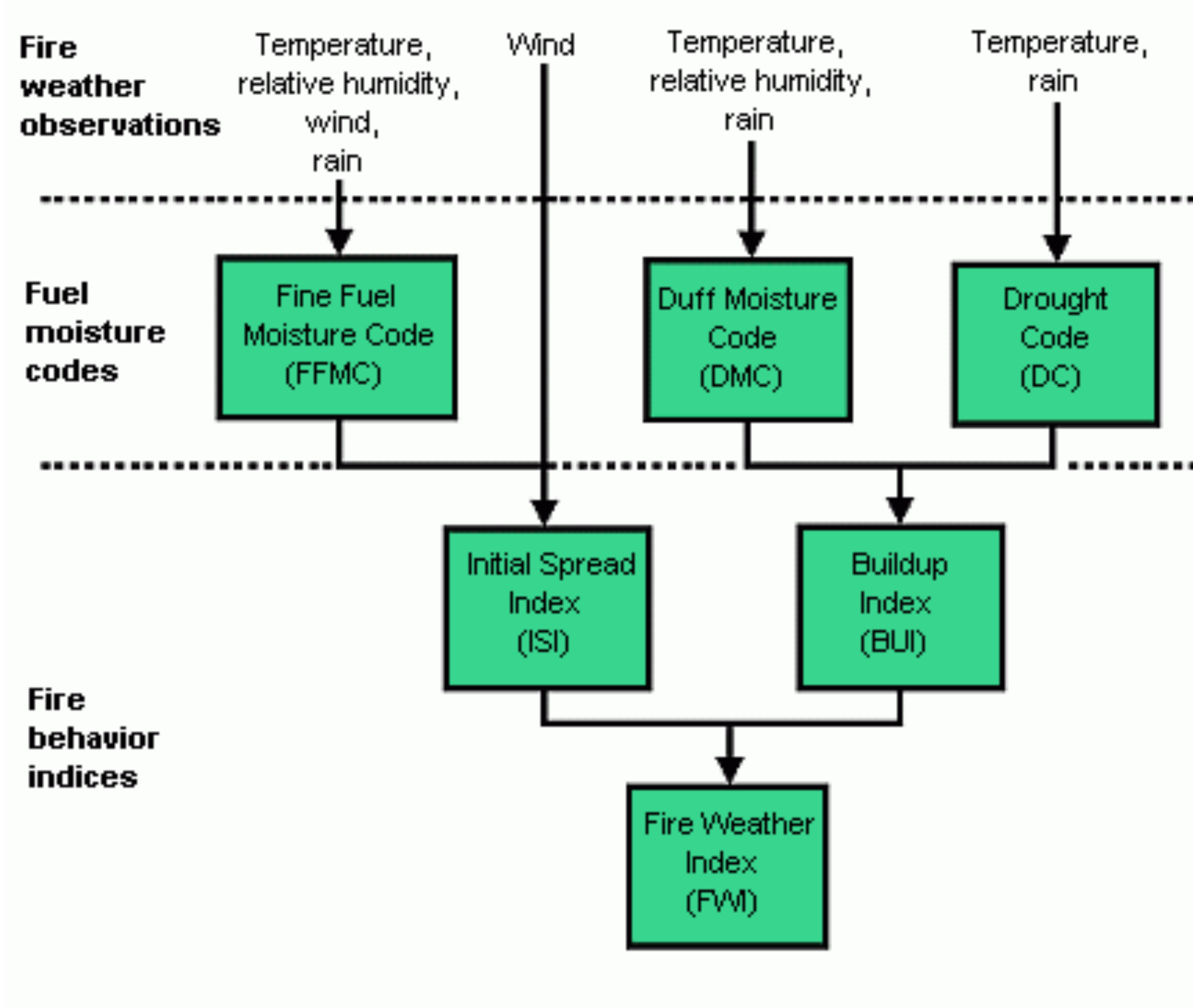

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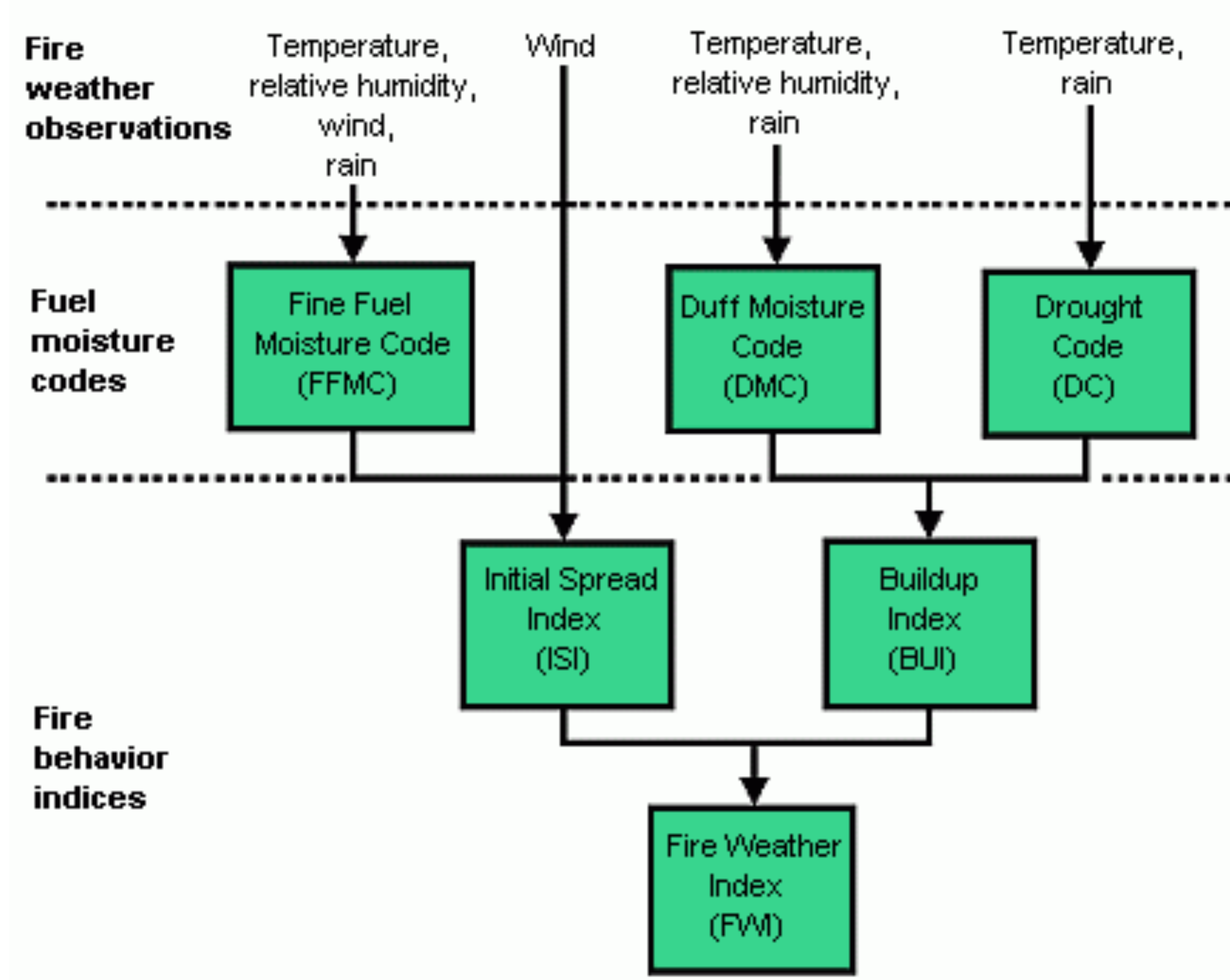

Buildup Index (BUI): total amount of fuel available for combustion. Based on DMC and DC.

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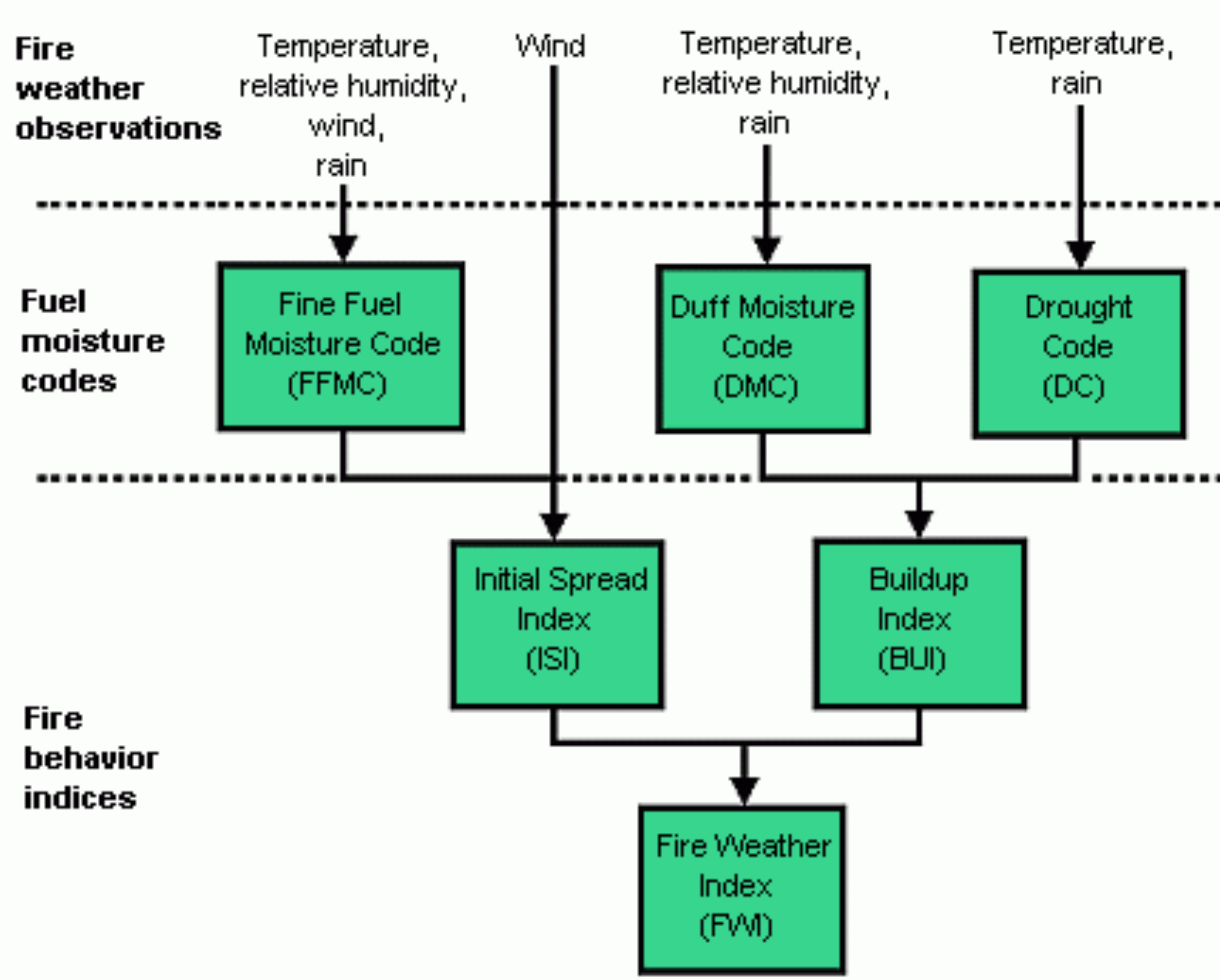

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Fire Weather Index: fire intensity. Based on ISI & BUI, used as a general index of fire danger.

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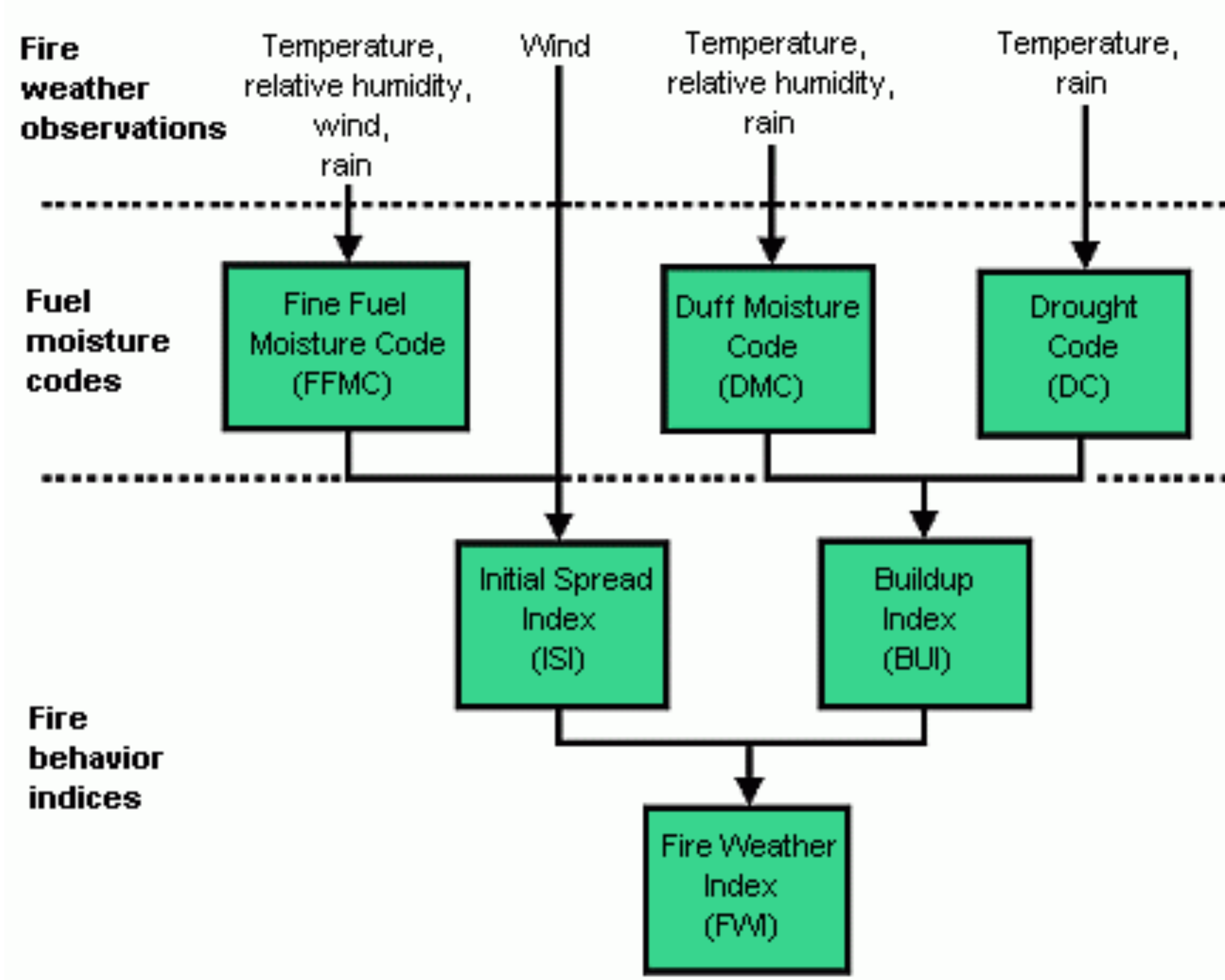

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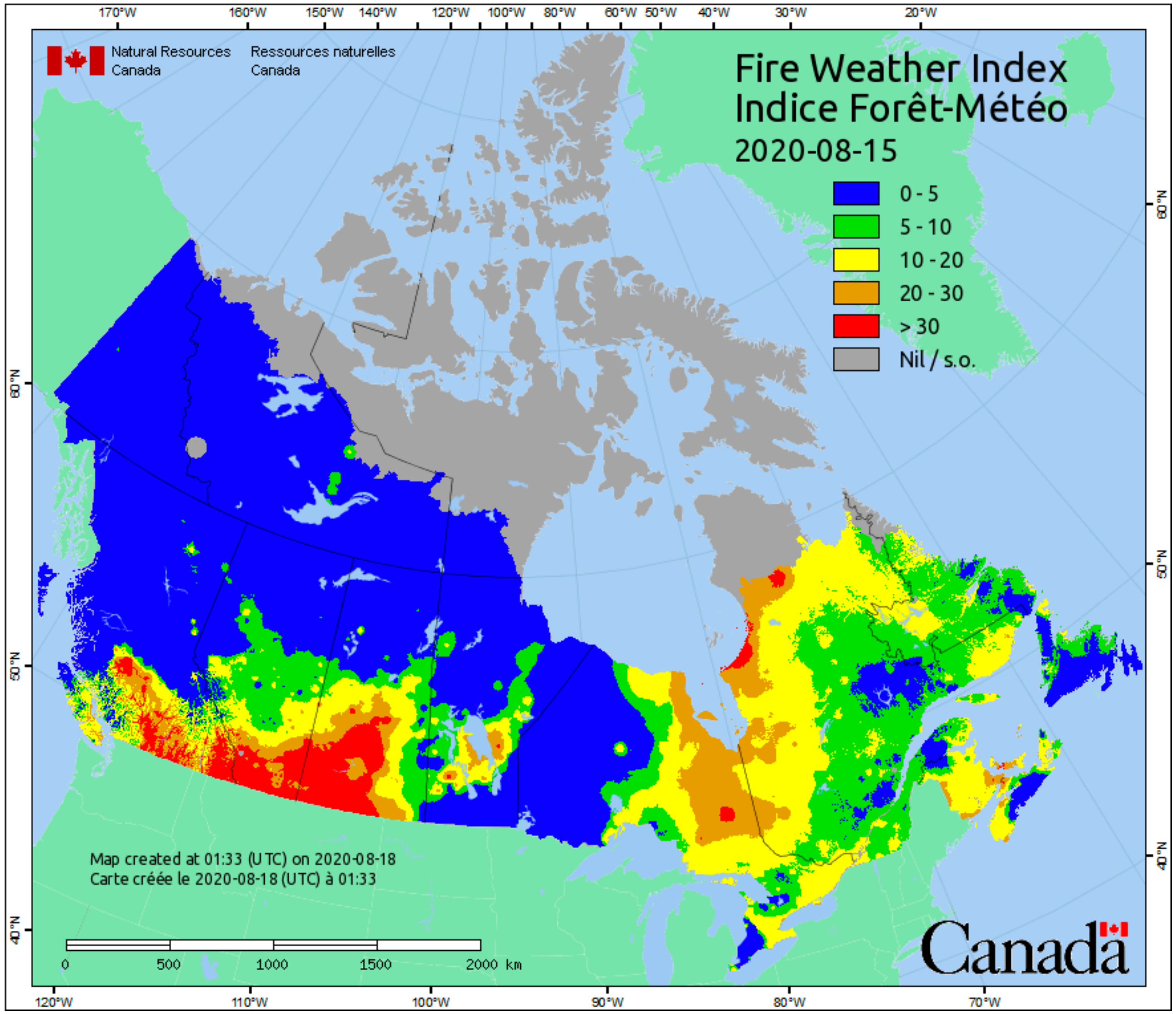
Fire Weather Index: fire intensity. Based on ISI & BUI, used as a general index of fire danger.

Daily Severity Rating: the difficulty of controlling fires. Based on the Fire Weather Index but it more accurately reflects the expected effort required for fire suppression.

https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

Fires and weather/climate: fire Weather Maps

https://cwfis.cfs.nrcan.gc.ca/maps/fw



Fire indices use a variety of factors to predict daily fire danger. commonly used ones: Canadian Fire Weather Index (FWI), Australian (McArthur's) Forest Fire Danger Index (FFDI) & US Burning Index. They depend on daily weather measurements, including temperature, relative humidity, wind speed, and precipitation over the past few days. They also take into account fuel dryness/aridity, fine fuel moisture, drought, buildup of fuel and the ability of fire to spread.

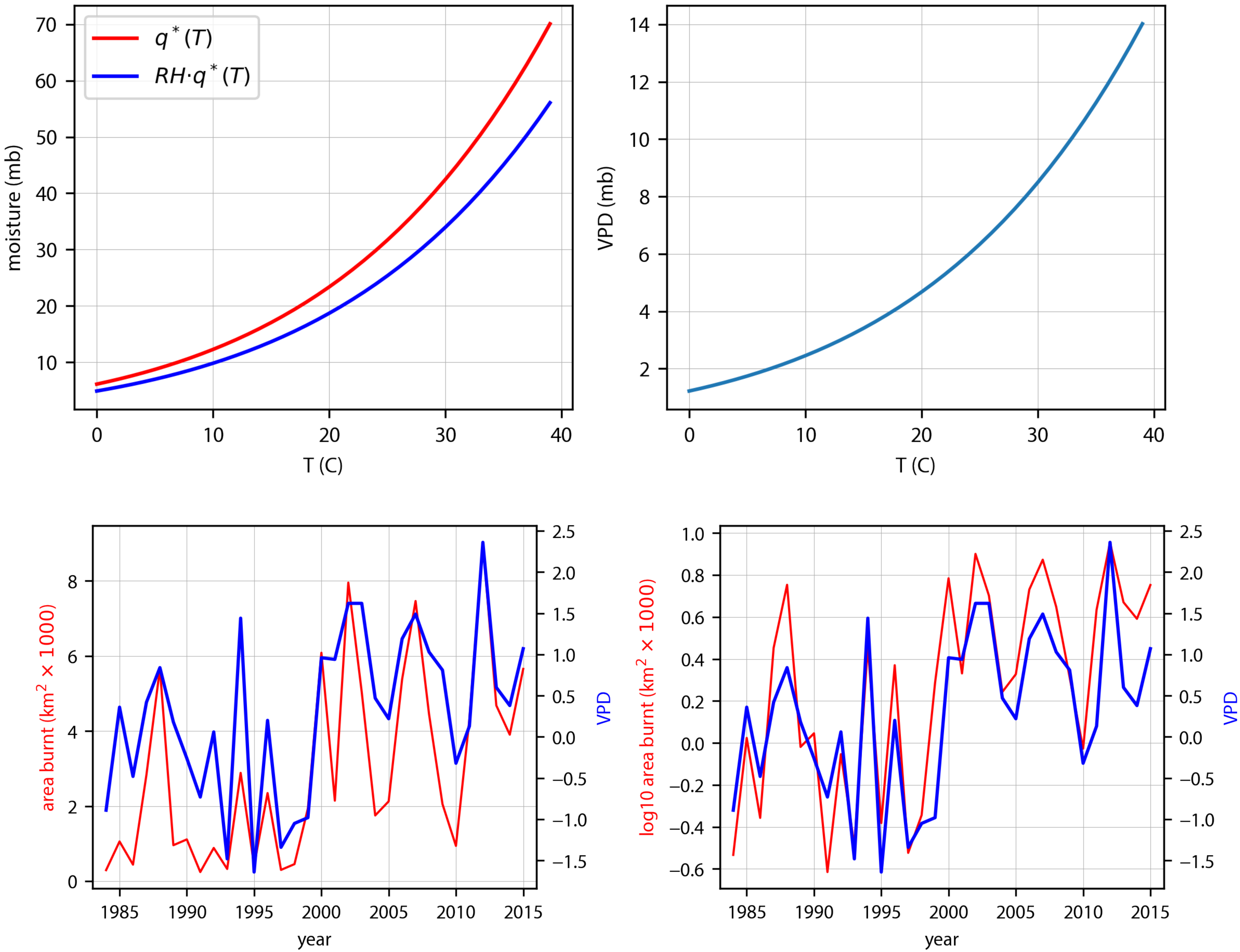
https://cwfis.cfs.nrcan.gc.ca/background/summary/fwi

Workshop #2:

VPD as a fire danger index:

a) Understanding VPD: Plot the saturation water vapor pressure and the water vapor partial pressure assuming an 80% relative humidity versus temperature. Plot the difference between the two curves (i.e., the VPD for a constant relative humidity) versus temperature.

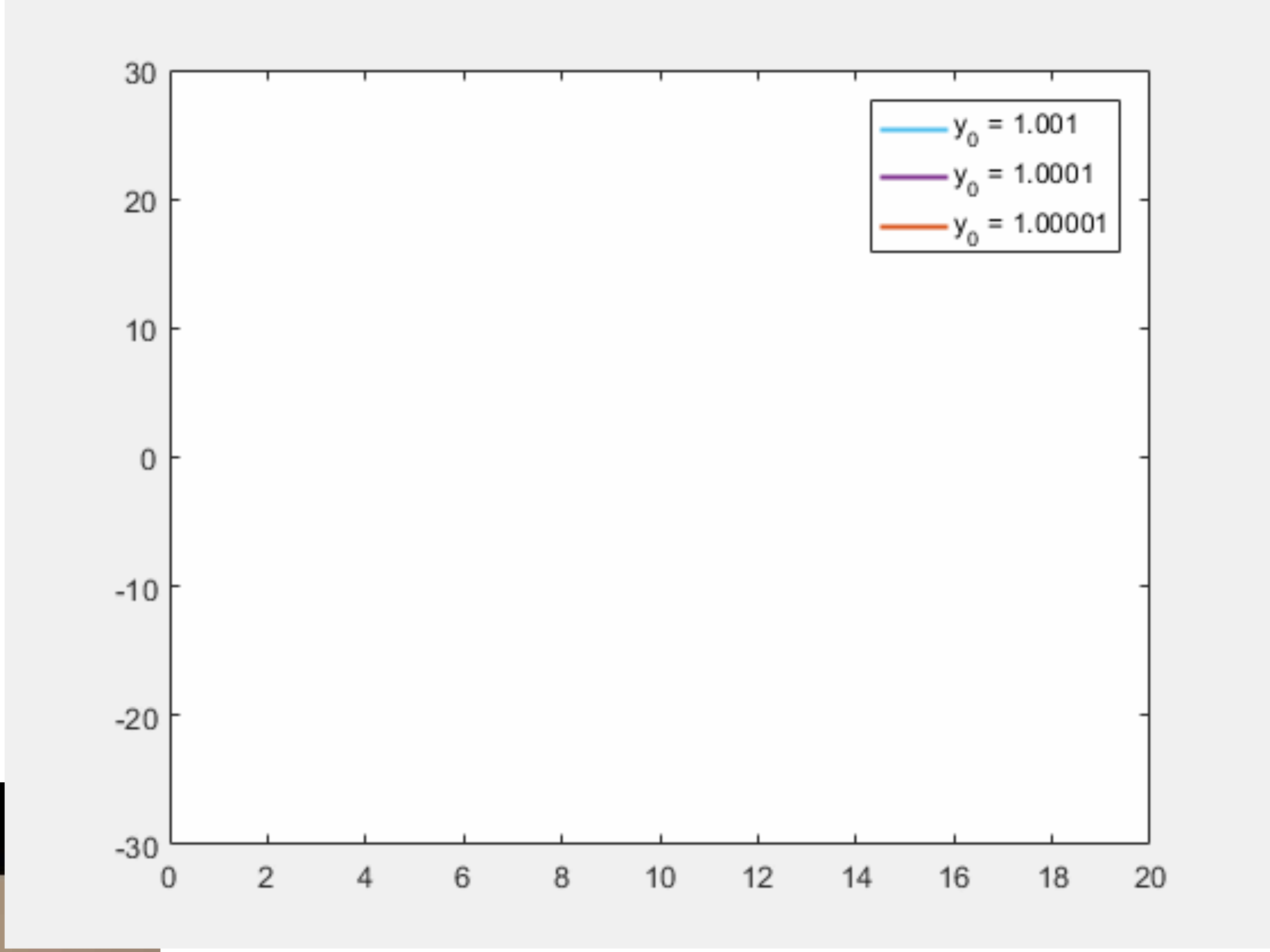
b) Plot the western US VPD and area burnt versus time on the same axes. Then repeat using VPD and the $\log_{10}$ of area burnt. Calculate the correlation coefficient between the two plotted time series for each of the two cases.


$q^*(T)$
$RH{\cdot}q^*(T)$
moisture (mb)
T (C)
VPD (mb)
T (C)
area burnt (km^2 × 1000)
VPD
year
log10 area burnt (km^2 × 1000)
VPD
year

Notes section 14.2 (first part)
Detection of burnt area due to ACC

Ensemble model runs, chaotic behavior and sensitivity to initial conditions, weather/climate variability vs forced ACC signal (use next two slides)

Weather chaos, sensitivity to initial conditions: The butterfly effect!



http://www.youtube.com/watch?v=EjNAyOFcwoc

https://upload.wikimedia.org/wikipedia/commons/8/8e/SensInitCond.gif

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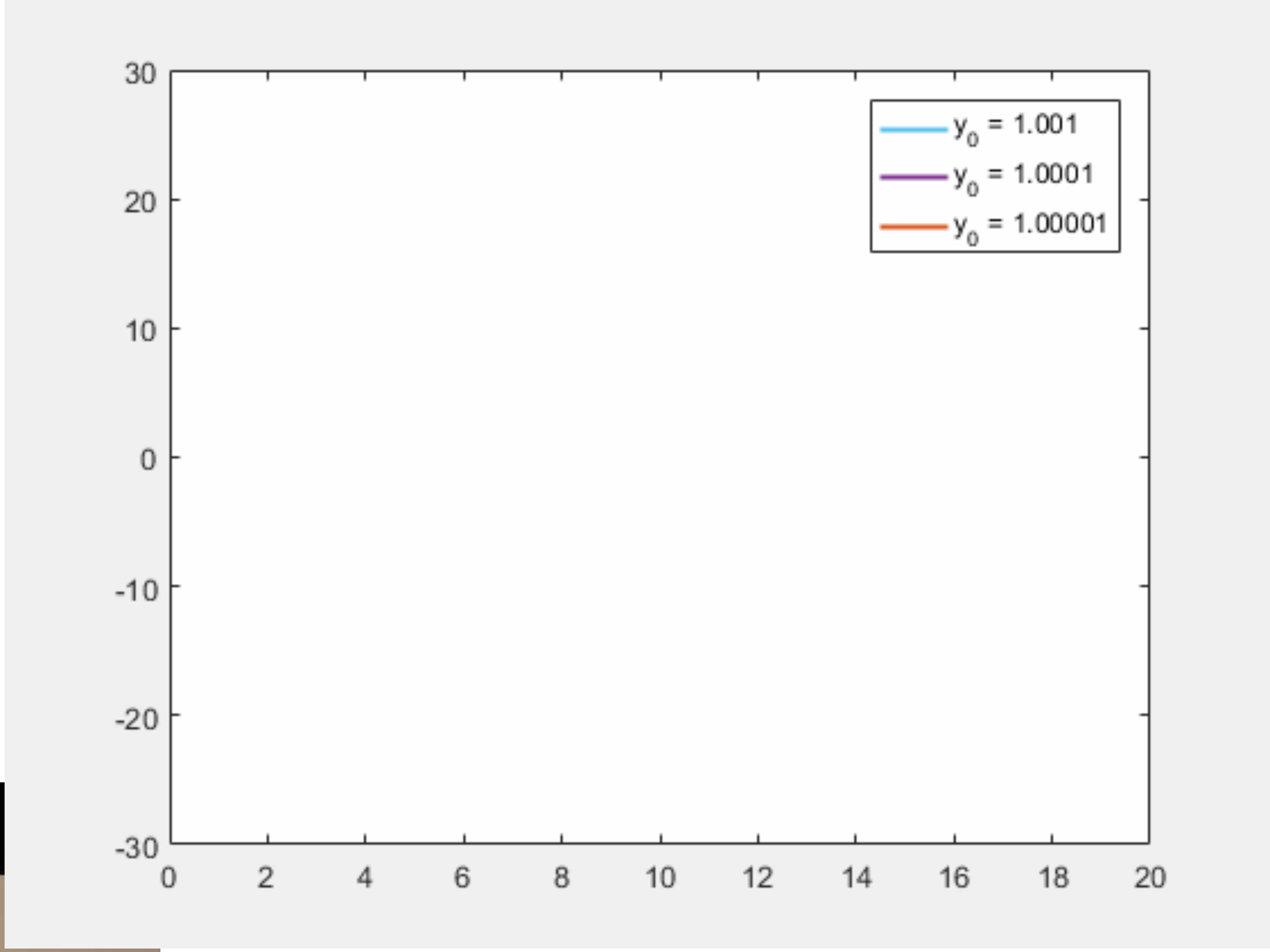

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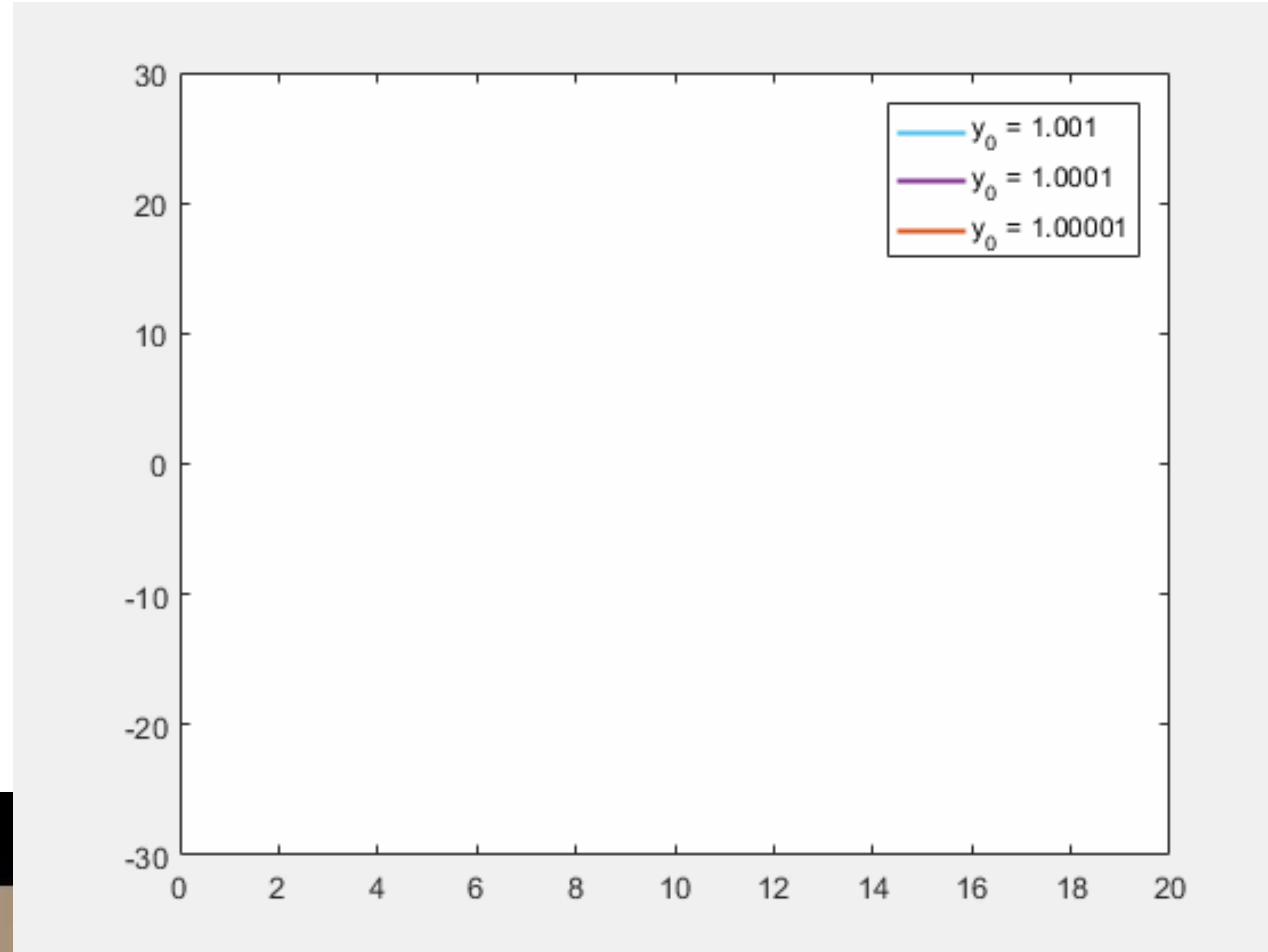


https://upload.wikimedia.org/wikipedia/commons/8/8e/SensInitCond.gif

Ensemble model runs, weather/climate variability vs forced ACC signal

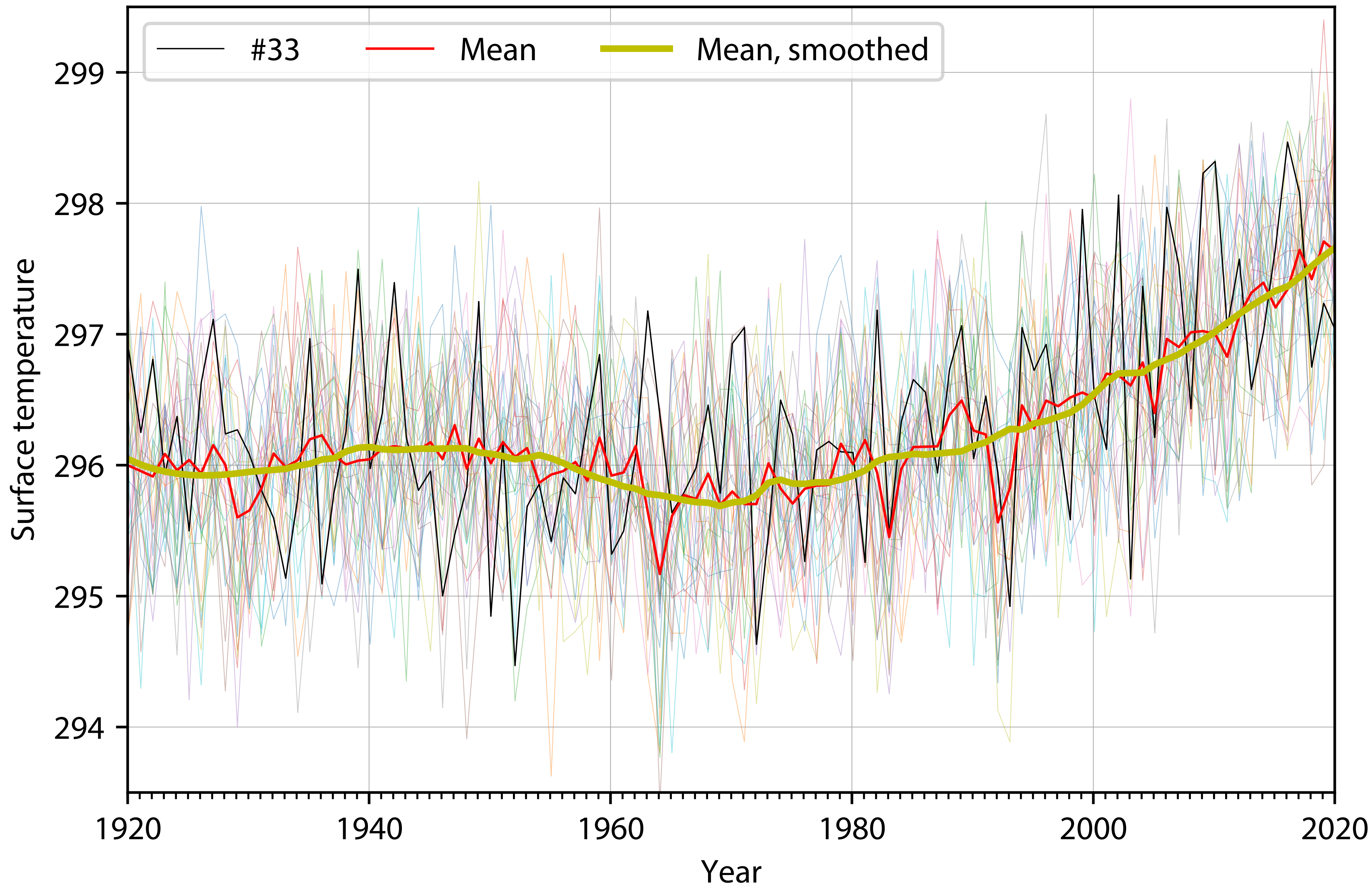


Figure 14.2: Example of extraction of ACC signal from multi-model mean. Showing August temperature (K) averaged over the western US from an ensemble of climate model runs, following the RCP8.5 scenario to year 2100. Thin color lines are individual ensemble members. The black line is of ensemble member number 33, the **red line** is the average over all ensemble members, and **the thick yellow line** is the *smoothed & averaged* time series *representing the ACC signal estimated using this model ensemble.*

Workshop #3:

Separating ACC from variability: Extract the ACC signal in temperature from an ensemble of model runs for 1920–2020. Plot all ensemble time series and superimpose the estimated ACC signal.

Leave for HW, use notes' Fig 14.2 for now if needed for workshop #4

Notes section 14.2: (continued, 2nd part)
Detection of burnt area due to ACC
[ACC=anthropogenic climate change]

Outline:

1. Find regression coefficients from the full time series of area and VPD, by plotting a scatter plot of VPD vs $\log_{10}$(area burnt) and fitting a line:

$$\log_{10}(\text{area burnt}) = a \times VPD + b.$$

2. Calculate climate contribution to VPD trend as an ensemble model average

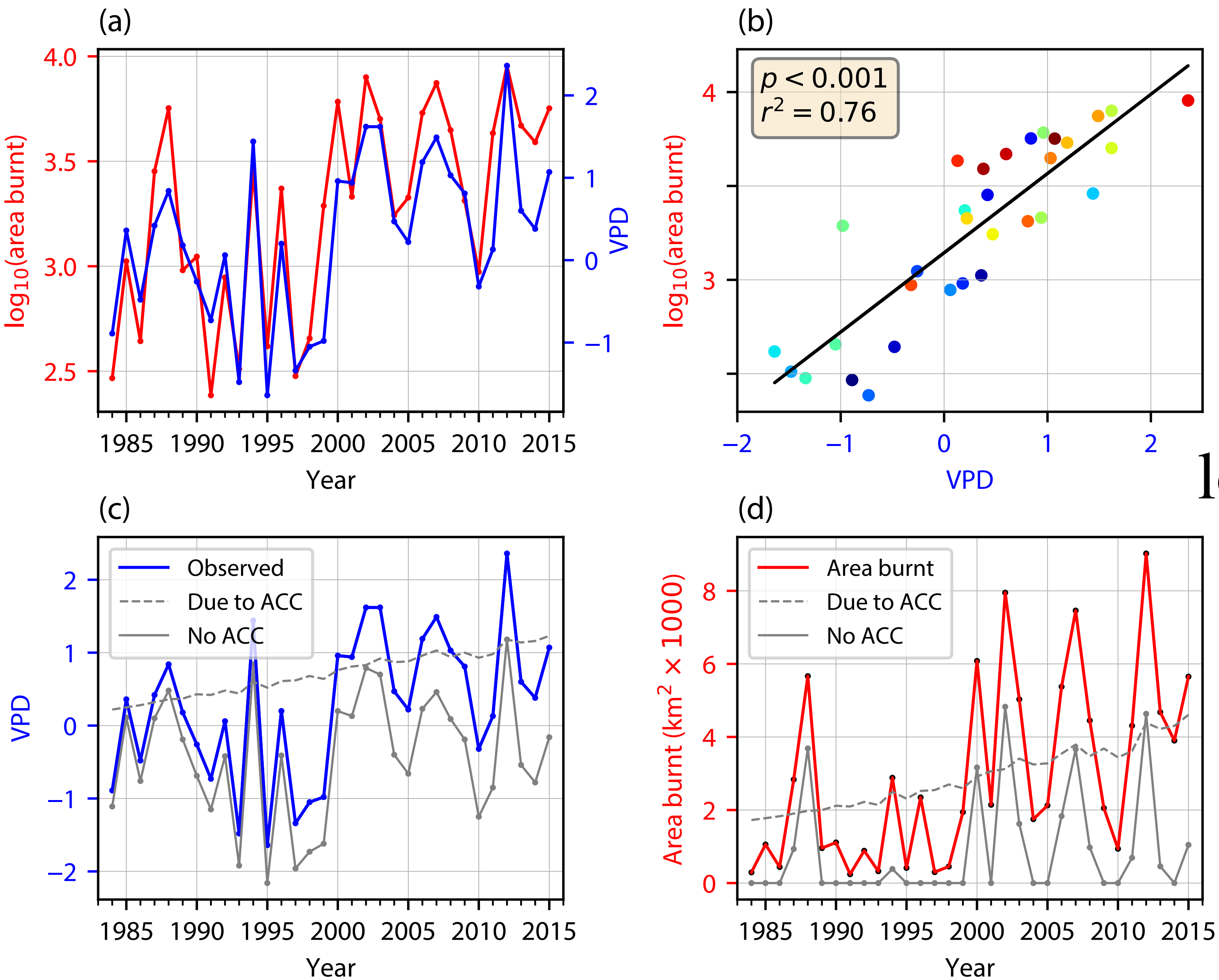
3. Apply a & b to ACC trend in VPD to find area burnt due to climate change

4. Subtract from full area burnt record to find natural variability in the area burnt

(use the following slide)

(Following Abatzoglou & Williams 2016)

Detection of west-US burnt area due to ACC



(Data, methodology and results based on Abatzoglou & Williams 2016)

$$\log_{10}(\text{area burnt}) = a \times VPD + b.$$

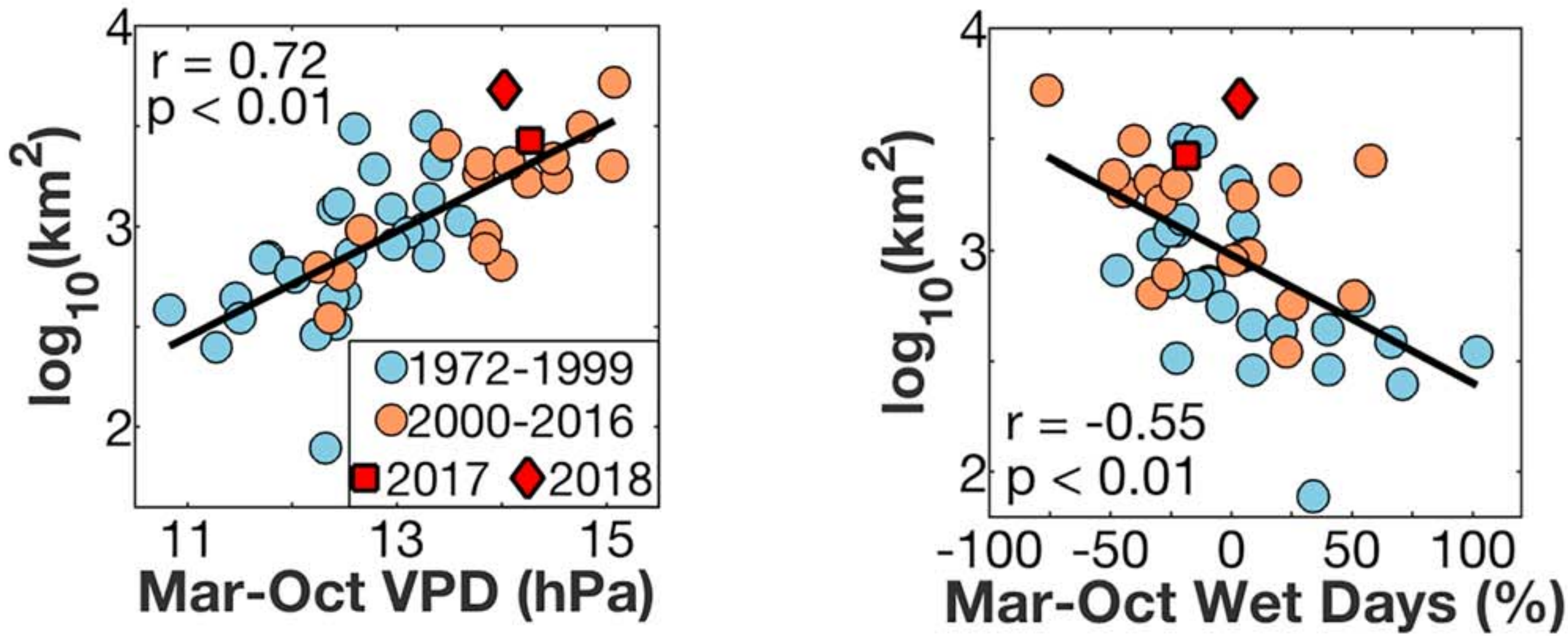
Figure 14.1: Estimating the contribution of ACC to the western US forest fire area. (a) Red line: $\log_{10}$(area burnt, 10^3 km^2). Blue: standardized VPD. (b) Regression between $\log_{10}$(burnt area) & VPD. Points color-coded by year, blue to red. (c) Blue: VPD over western US. Dash: contribution of ACC from a multi-model average. Solid gray: VPD time series w/ ACC signal removed. (d) Dash gray: estimated contribution to the burnt area due to ACC, calculated from VPD due to ACC using the regression relation. Solid gray: estimated burnt area without the contribution of ACC.

Workshop #4:

Estimate the contribution of ACC to western US forest fire area (following Abatzoglou and Williams 2016):

Uncertainty in projection of future west-US burnt area due to ACC

VPD vs frequency of wet days



Both measures are good predictors of observed burnt area, but their future trajectories under warmer climate are very different ➡ difficult to know which one to use for projections of forest fires.

Observed Impacts of Anthropogenic Climate Change on Wildfire in California, A. Park Williams et al (2019)

Los Angeles fires, January 2025

[Gavin Madakumbura, Chad Thackeray, Alex Hall, Park Williams, Jesse Norris, and Ray Sukhdeo]

Three extreme climate events combined to drive the extreme January 2025 wildfire activity in coastal southern California

1. High fuel loads due to rapid plant growth after very wet conditions from winter 2023 through spring 2024

https://sustainablela.ucla.edu/2025lawildfires https://www.aparkwilliams.com/

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A. Climate change may be linked to roughly a quarter of the extreme fuel moisture deficit when the fires began.

B. The fires would still have been extreme without climate change, but probably somewhat smaller and less intense.

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Australian fires of 2019/20: Natural climate variability modes vs Anthropogenic climate change

Australian fires of 2019/20

Clockwise from top left: Sydney's George Street blanketed by smoke in December 2019; Orroral Valley fire seen from Tuggeranong; Damaged road sign along Bells Line of Road; Gospers Mountain bushfire; Smoke plume viewed from the ISS; Uncontained bushfire in South West Sydney.

(Wikipedia: https://en.wikipedia.org/wiki/2019%E2%80%9320_Australian_bushfire_season)

The 2019–20 Australian bushfire season, known as Black Summer, was a period of unusually intense bushfires in many parts of Australia.

Australian fires of 2019/20 and SST variability modes

https://www.youtube.com/watch?v=wRBlvXov91E

Australian fires of 2019/20 and SST variability modes

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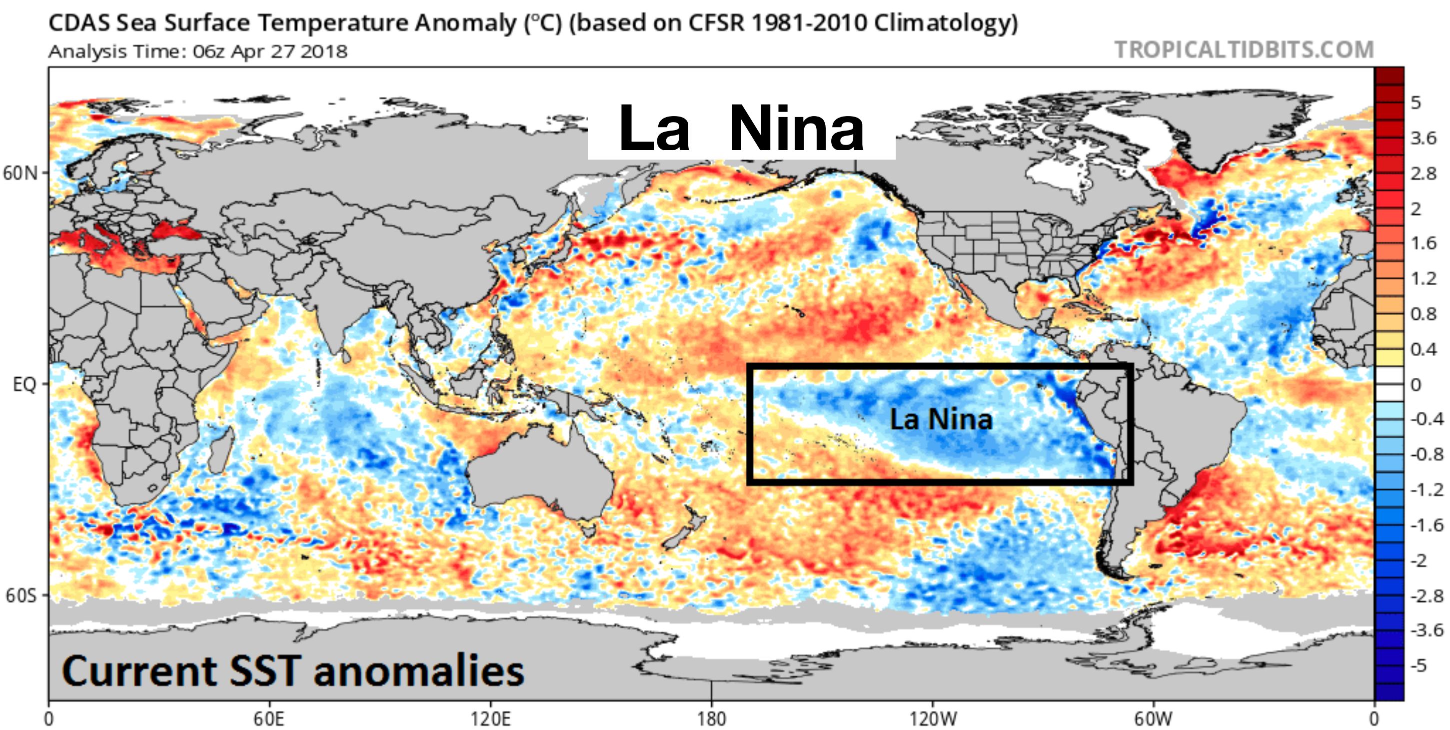
"The angry summer playing out in Australia right now was predictable. The scientific evidence is well known for how anthropogenic greenhouse gas emissions are causing long-term climate change and altering climate variability in ways that increase our fire risk. The role of climate change in the unprecedented fires gripping Australia is also well understood by our emergency services."

Australia fires 2020 and La Niña/SAM/IOD



King et al 2020: “The major Australian droughts of the past 100 years have coincided with several of the longer-lasting periods when La Niña and negative IOD events did not occur. The Second World War Drought from 1935 to 1945 includes two unusually long periods when neither a La Niña nor a negative IOD event occurred, from 1934 to 1938 and 1939 to 1942.”

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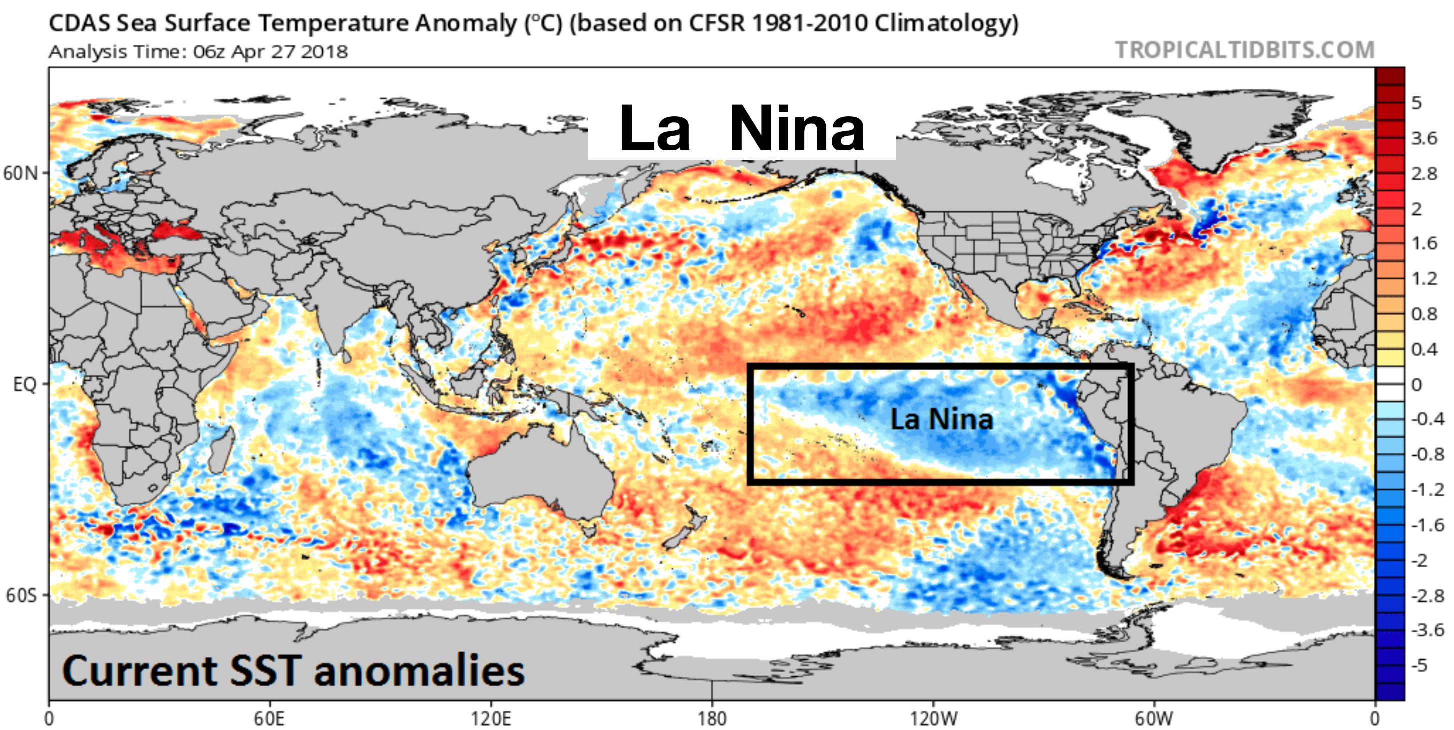

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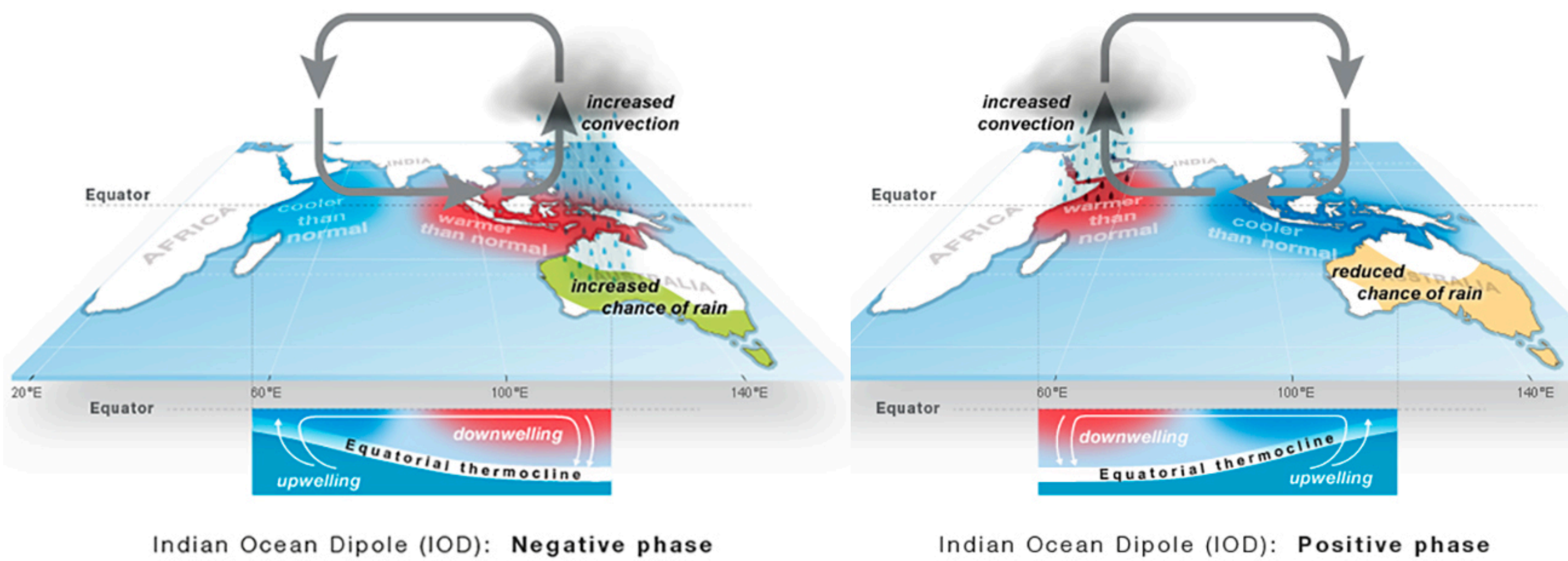
Indian Ocean dipole



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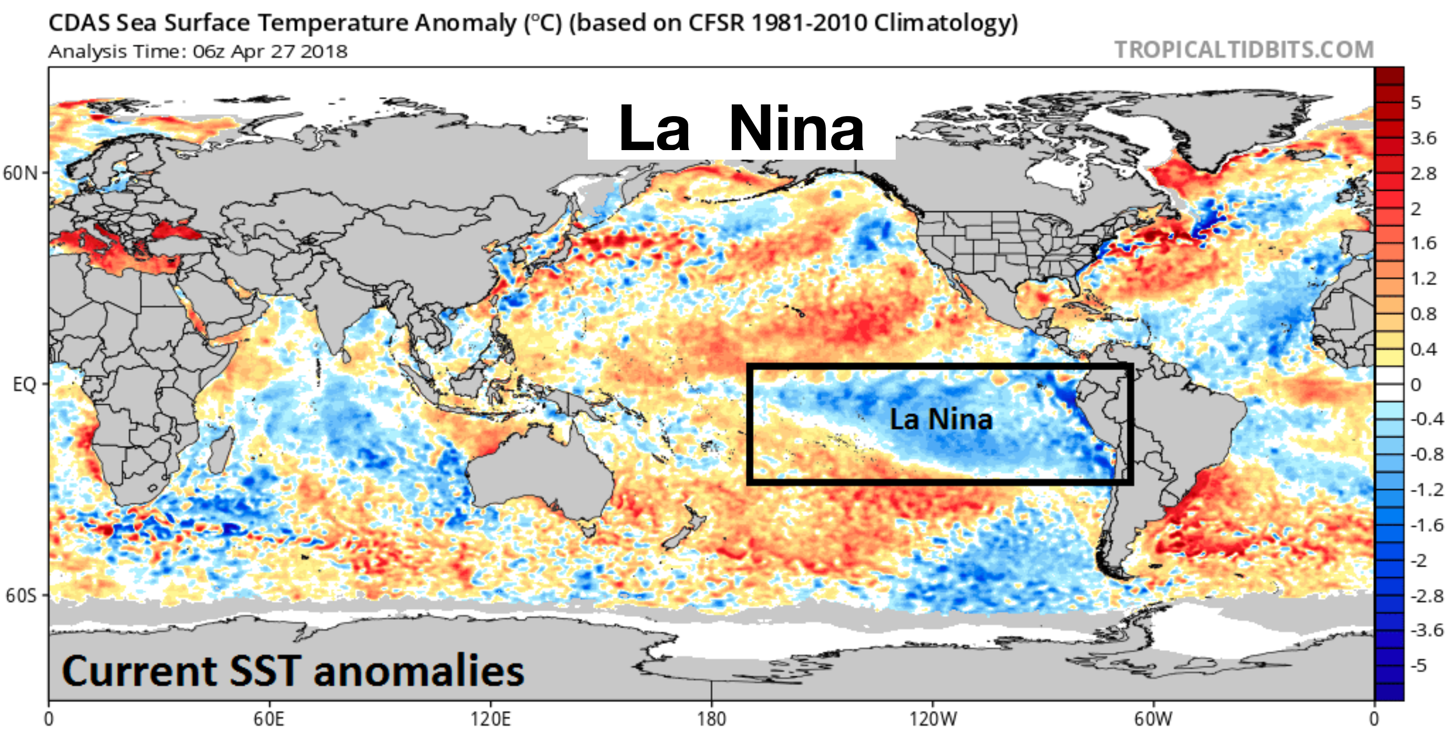

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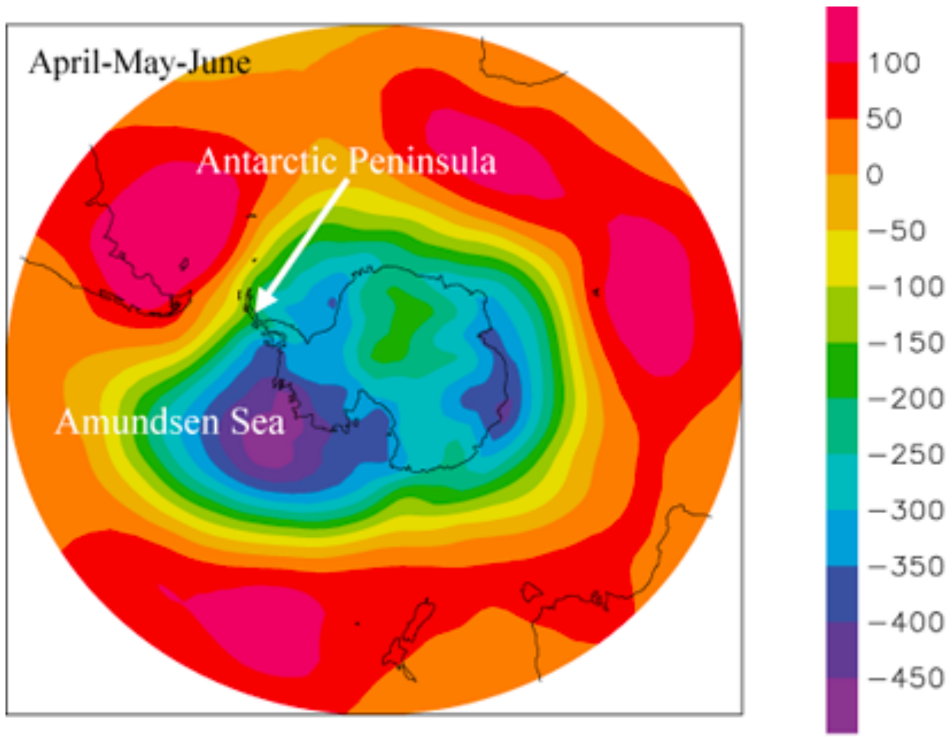
Southern Annular mode



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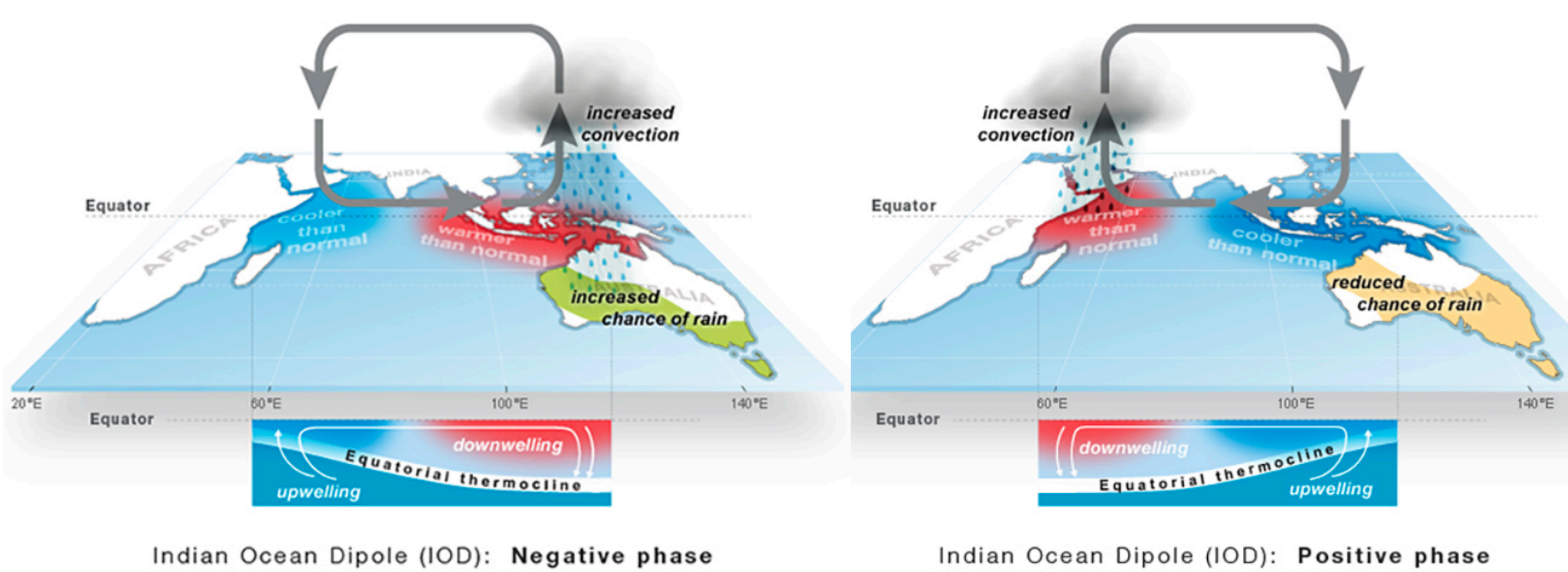

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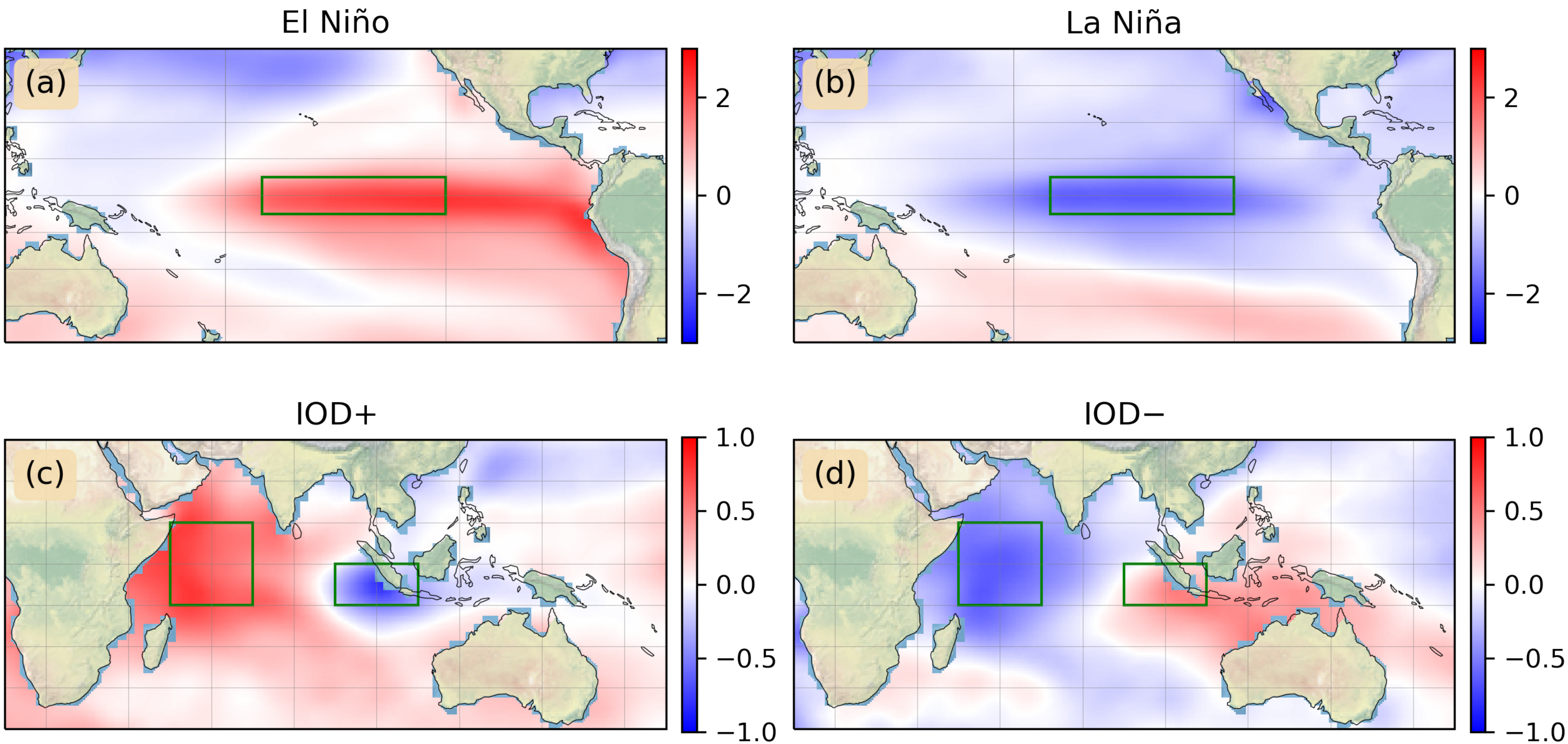

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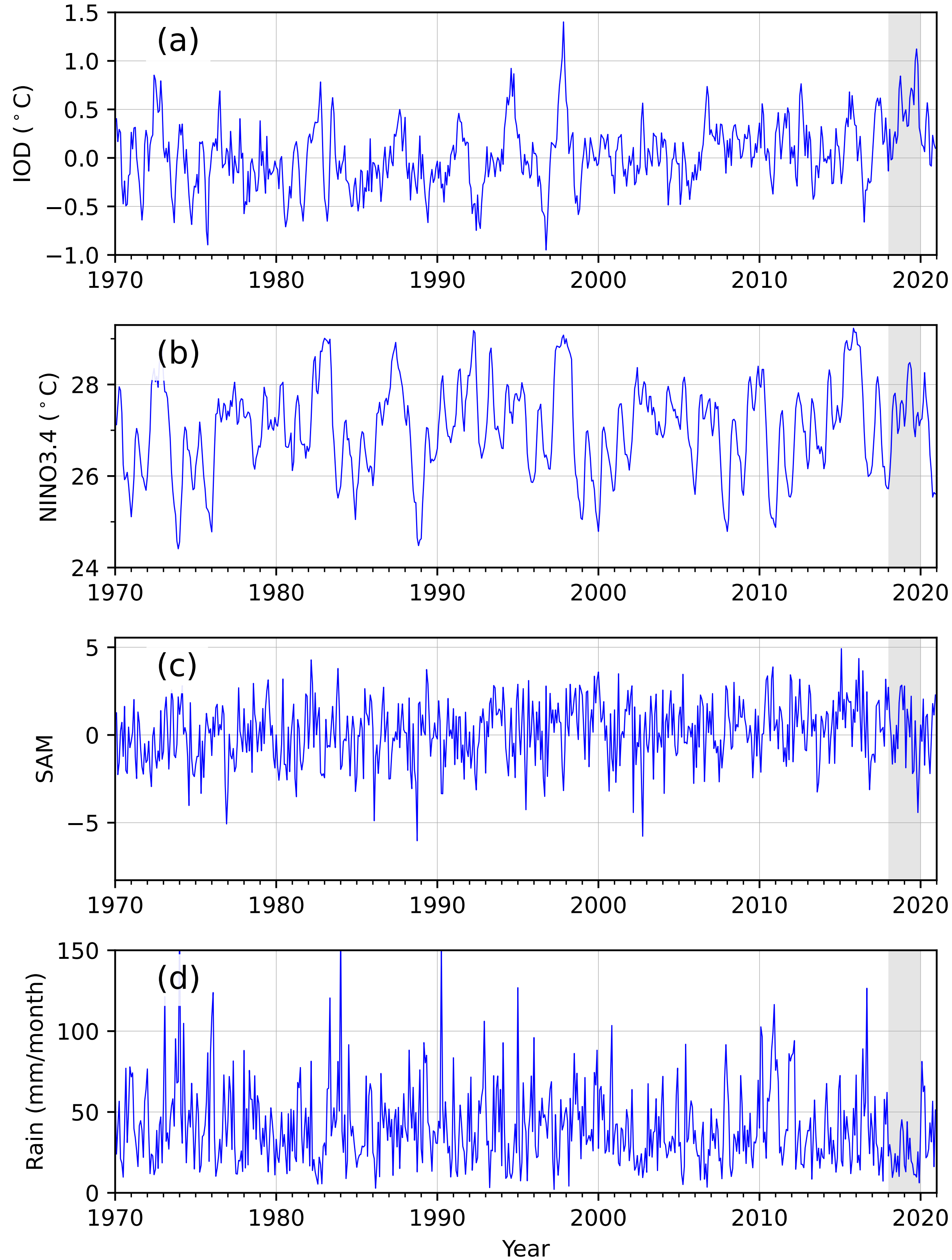
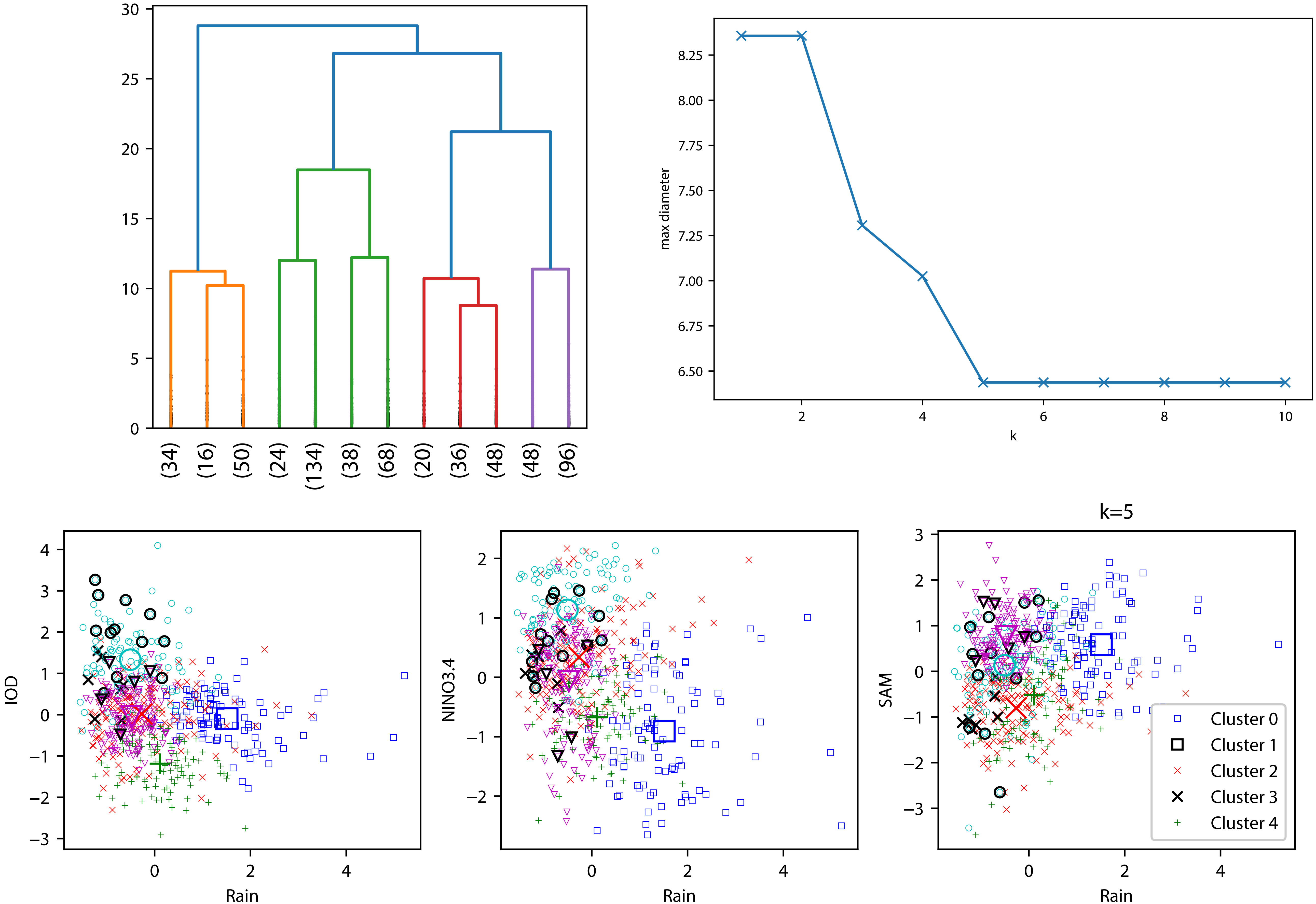


Figure 14.3: Factors contributing to Australian droughts. (a) IOD. (b) NINO3.4. (c) SAM. (d) Rain over the Murray-Darling Basin in south-east Australia.

Australian fires of 2019/20 and SST variability modes



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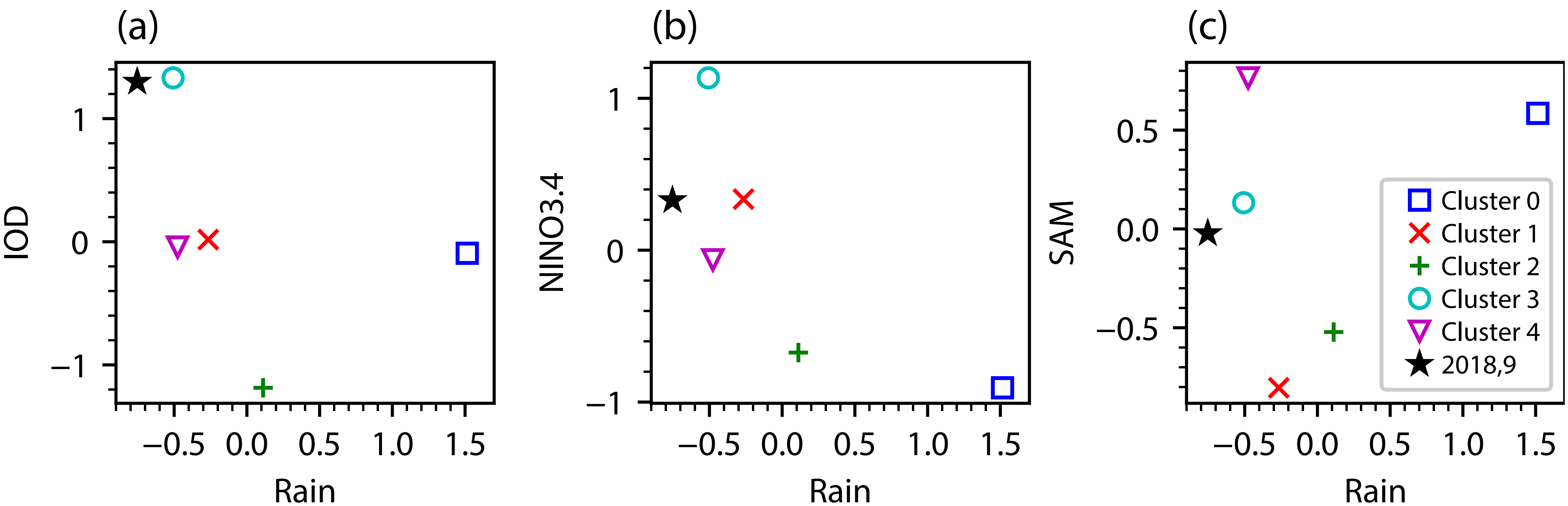


Figure 14.4: Cluster analysis results for Australian forest fires, showing the means for the five dominant clusters. (a) IOD vs. rain in the Murray-Darling Basin in southeast Australia. (b) NINO3.4 vs. rain. (c) SAM vs. rain.

The black star ★ shows the mean conditions during 2018–2020.

The blue square □ shows what leads to especially rainy conditions

Australian fires of 2019/20 & natural climate variability modes

Bottom line: Indian Ocean dipole, La Niña, and Southern Annular Mode all contributed.

(Anthropogenic Climate Change may have too, large uncertainty)

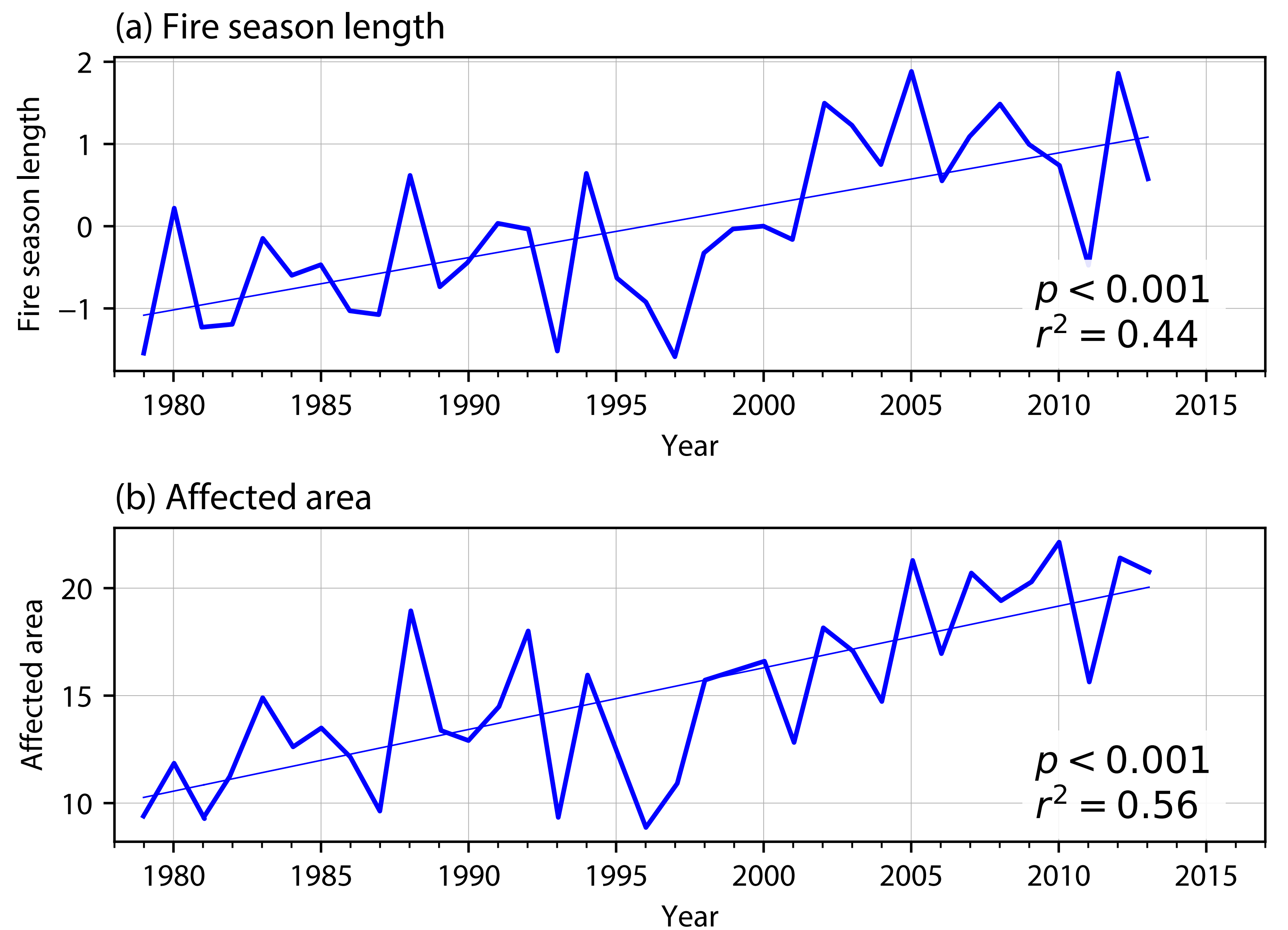
In the long term: anthropogenic warming may contribute to such fires.

Workshop #5: Role of variability modes

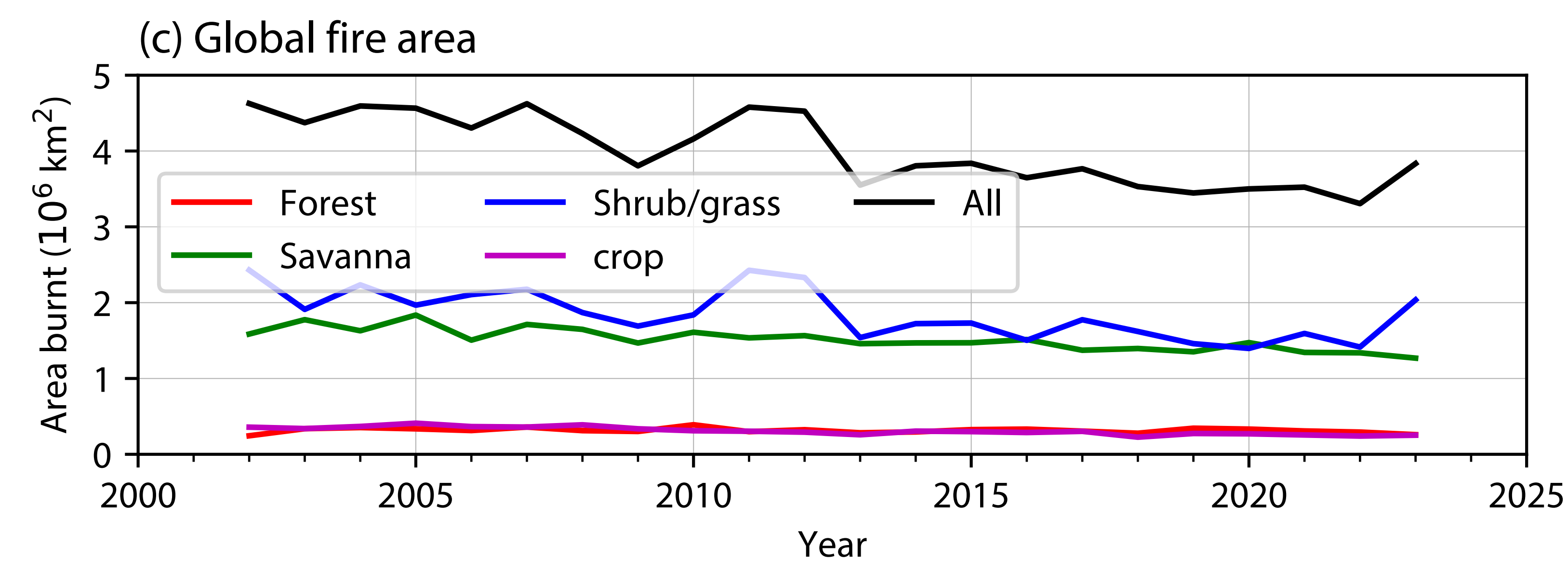
Calculate the averaged SAM/NINO3.4/IOD indices for rainy vs dry years (defined to be above and below one standard deviation, respectively) in south-east Australia following King et al. (2020), compare to 2018–9.

Global fire trends

Jolly et al. (2015)



MODIS satellite, see Giglio et al. (2013), Andela et al. (2017)



Area burnt reduction dominated by African land use changes

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➡ **It is therefore important to realize that temperature change is not necessarily the only or even the dominant factor determining fire activity in a future warmer climate.**

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3. Future projections in west US: may be different if using VPD vs frequency of wet days
4. **Bottom line:** w/enough warming, fires will change; they are part of the ecosystem dynamics ➡ any change is undesired

The End