Implications of threshold relationships for projecting fire-regime responses to climate change

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Outline

I. Motivation and research questions
II. Methods
III. Key results and future implications
What controlled past variability in fire activity?

What do these controls imply about responses to future climate change?
*Climate is a major driver of fire activity*
Fire and climate

Temperature

RCP8.5: 2046-2065

RCP8.5: 2081-2100

Precipitation

2046-2065 - JJA

2081-2100 - JJA

IPCC AR5 (2013)
How can we anticipate future fire activity?

Three general approaches

Krawchuk and Moritz (2014) Environmetrics

1. Fire weather index models

2. Statistical-correlative models

3. Fire-process models

Change in CSR
- Large Increase (more than 3x)
- Increase (1.1 to 3x)
- No Change (0.9 to 1.1x)
- Decrease (0.33 to 0.9x)
- Large Decrease (less than 0.33x)

Increases
- 2.5x
- 2x
- 1.5x

Flannigan et al. (2013) For Ecol Mgmt

Moritz et al. (2012) Ecospheres

Pfeiffer et al. (2013) Geosci Model Dev
How can we anticipate future fire activity?

Young et al. (2017) Ecography

Fire-climate linkages

*Future climate will differ compared to the observational record.

Projected changes in fire activity

Obs. (1950-2009) 2010-2039 2040-2069 2070-2099

Young et al. (2017) Ecography
*Validate models with independent data source outside the observational record*

- Paleoecological reconstructions
  - Offer independent records of ecological dynamics over past millennia
Limitations to future projections

Why might projections be wrong?

1. Data biases or errors
   • Used to construct or inform statistical models
   • e.g., GCM projections

2. Changing vegetation and ecosystem dynamics
   → Changing fire-climate relationships
Nature of fire-climate relationships

*Fire-climate relationships are nonlinear and contain thresholds

*Small errors or changes may significantly change predictions

Young et al. (2017) Ecography
Key research questions

(1) How do threshold relationships impact statistical predictions outside the observational range?

(2) How sensitive are predictions to modified fire-climate relationships?

(3) What are the implications of using threshold relationships to project 21st-century changes?
I. Motivation and research questions

II. Methods
   1. Statistical modeling
   2. Model-paleodata comparisons

III. Key results and future implications
Modeled $P(\text{fire})$ at 30-yr timescales

Spatial variation in fire activity

Presence/absence approach
Statistical models

Boosted Regression Trees (BRTs)

- Machine learning algorithm
- Able to fit complex, nonlinear relationships between response and explanatory variables

Explanatory Variables (1950-2009)

- Temp. Warm. Month
- Ann. Moisture Avail. (P-PET)
- Topography
- Veg. Type

Fire Data: Alaska Large Fire Database (fire.ak.blm.gov)
Veg. Data: Circumpolar Arctic Veg. Map (www.geobotany.uaf.edu/cavm)
Climate Data: Scenarios Network for Alaska and Arctic Planning (www.snap.uaf.edu)
*Statistical models explain spatial variability in fire presence/absence*
Historical fire-climate relationships

*Non-linear fire-climate relationships reveal thresholds

*Small climatic changes may result in large fire regime changes
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Predicting fire activity for 850-1850 CE

Use Global Climate Model (GCMs) experiments

Step 1: Select “best” GCMs
I. GISS-E2-R
II. MPI-ESM-P
III. MRI-CGCM3

Step 2: Downscale GCM data for 850-1850 CE

Native GCM Resolution

Step 3: Create 30-yr climatologies in AK (per pixel)
Alaskan paleofire records

Photo Credits: P. Higuera (2002)
Alaskan paleofire records

29 fire-history reconstructions in AK

CHAR = Charcoal Accumulation Rate

Model-paleodata comparisons

- Evaluating total number of fires for 850-1850 CE
- **NOT** evaluating predictions over time

**Example**

- Pred. = 7.21 Fires/1000 yr
- Obs. = 7 Fires/1000 yr
Limitations to future projections

Why might projections be wrong?

1. Data biases or errors
   - Used to construct or inform statistical models
   - e.g., GCM projections

2. Changing vegetation and ecosystem dynamics
   - Changing fire-climate relationships
Limitations to future projections

Why might projections be wrong?

1. Data biases or errors
   - Modify value of temperature threshold

2. Changing fire-climate relationships
   - Modify shape of relationship
Modifying fire-climate relationships

*Evaluate sensitivity of model predictions to slight changes in original relationships

Modify threshold values

Three Modifications

+0.50 °C
+1.00 °C
+1.50 °C

Mean temp. of the warmest month (°C)
Modifying fire-climate relationships

*Evaluate sensitivity of model predictions to slight changes in original relationships

Modify shape of relationships

![Graphs showing the probability of fire vs. summer temperature for S1, S2, and S3, with original and modified lines comparison.](image-url)
Outline

I. Motivation and research questions

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   2. Model-paleodata comparisons

III. Key results and future implications
Q1: How do thresholds impact statistical predictions outside the observational range?

1950-2009 Mean temperature of the warmest month (°C)

*Prediction error varies as a function of threshold proximity*
Why might projections be wrong?

1. Data biases or errors
   • Modify value of temperature threshold

2. Changing fire-climate relationships
   • Modify shape of relationship
Q2: How sensitive are predictions to modified fire-climate relationships?

Modified threshold values

$T_1$: +0.50 °C

$T_2$: +1.00 °C

$T_3$: +1.50 °C

Prediction error (1950-2009)
Q2: How sensitive are predictions to modified fire-climate relationships?

Modified relationship shapes

*Uncertainty can arise from even small changes in fire-climate relationships*
Implications for future predictions
Q3: How do nonlinear, threshold relationships impact our ability to predict future conditions?

Projected changes in fire activity

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Implications for future predictions

Q3: How do nonlinear, threshold relationships impact our ability to predict future conditions?

Near threshold (Region of uncertainty) ± 2°C

Below threshold

Above threshold

30-yr Probability of fire occurrence

Mean temp. of the warmest month (°C)
Implications for future predictions

MPI-ESM-LR

1971-2000

2010-2039

%
Implications for future predictions

GISS-E2-R

1971-2000 vs 2010-2039

% | Below Thresh. | Near Thresh. | Above Thresh.
* Threshold-driven uncertainty will vary across AK regions in the 21st century.

What are the spatial patterns?
Implications for future predictions

* Tundra and forest tundra dominate areas of highest uncertainty
Implications for future predictions

* Tundra and forest tundra dominate areas of highest uncertainty

* Regions also most vulnerable to fire-regime shifts

Young et al. (2017) Ecography
Implications for future predictions

2010-2039

* Projections accompanied by higher uncertainty

2070-2099

* Projections have less uncertainty as climate moves beyond thresholds
Caveats and considerations

- Only consider one explanatory variable (temperature)
- Do not consider interactions among different driving variables (e.g., temperature and precipitation)
- Only looked at one modeling tool (i.e., boosted regression trees)
Conclusions

- Uncertainty varies in relation to threshold proximity, and predictions are sensitive to minor modifications.

- Threshold-driven uncertainty will vary across AK regions in the 21st century.

- Anticipating fire-regime shifts may be accompanied by less threshold-caused uncertainty at the end of century.
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Questions?


Moritz, M. A. et al. 2012. Climate change and disruptions to global fire activity. — Ecosphere 3:


Westerling, A. L. 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. — Philosophical Transactions of the Royal Society B-Biological Sciences 371:

**Data Sources**

**Fire Data**

**Observational Climate Data (1950-2009)**

**Vegetation Data and Ecoregions Map**

**Topographic Data**

**Boosted Regression Tree Modeling**

**GCM data†**

†Data retrieved from Earth System Grid Federation: [https://esgf.llnl.gov/](https://esgf.llnl.gov/)

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