Development of a Machine Learning System for Detection of the Atmospheric Potential of Wildfire-Driven Thunderstorms

Evan Krell, Chuyen Nguyen, Jason Nachamkin, David Peterson, Edward Hyer, Scott A. King, Philippe Tissot, Beto Estrada, Kevin J. Tory, and James Campbell

Pyrocumulonimbus (pyroCb)

- Strong fire's rising thermal may produce a pyroCb
- Requires strong fires & particular atmospheric conditions
- May inject massive smoke/dust into lower stratosphere
- Navy: strategic implications of a large aerial smokescreen

Prior Work

Peterson et al., 2017:

26 N.A. pyroCb events → reanalyzed meteorological model outputs → conceptual model of pyroCb development

Tory et al., 2021:

PyroCb Firepower Threshold (PFT): software tool that calculates pyroCb potential based on atmospheric data. Developed based on fire weather domain expertise, not machine learning.

Machine Learning

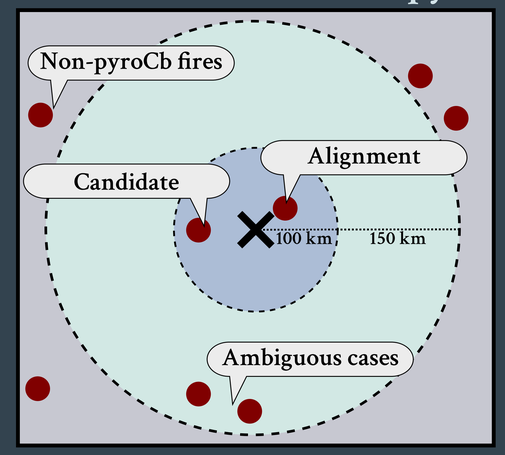
- Using brand-new NRL-produced pyroCb inventory
- Model task: given a fire → classify as pyroCb / non-pyroCb (detection!)
- But predictors are atmospheric variables (NAVGEM or GFS models)
- Goal: learn atmospheric conditions favorable to pyroCb development

Machine Learning Pipeline

Align pyroCbs to satellite fires
↓
Remove weaker fires
↓
Add engineered features
↓
For valid dataset, drop either fire features or unaligned pyroCbs
↓
K-Best Feature Selection
↓
Data balancing techniques
↓
Train & evaluate models

Alignment Criteria

Fires within ±12 hours of pyroCb



Modeling Experiments

Training Data Variants

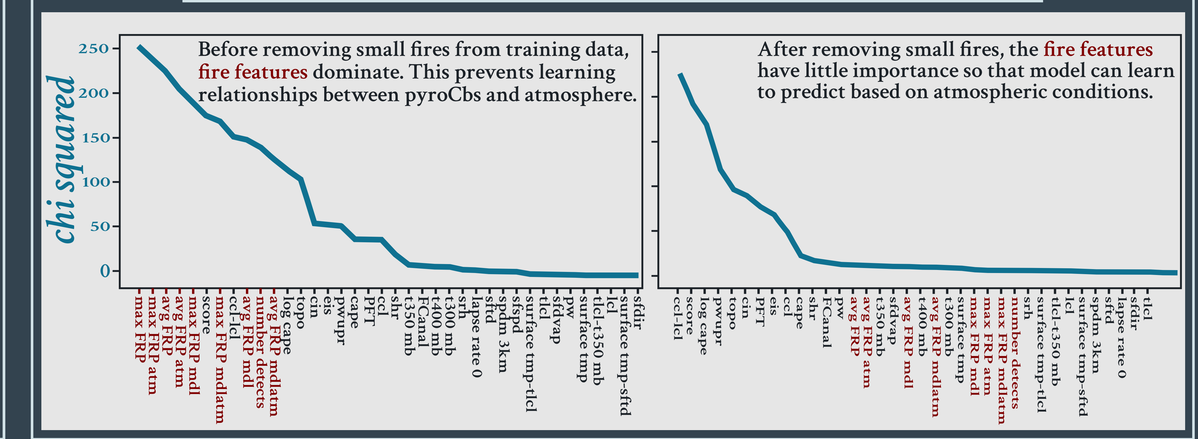
1. Fire features & aligned pyroCbs
2. No fire features & aligned pyroCbs
3. No fire features & all pyroCbs

Machine Learning Architectures

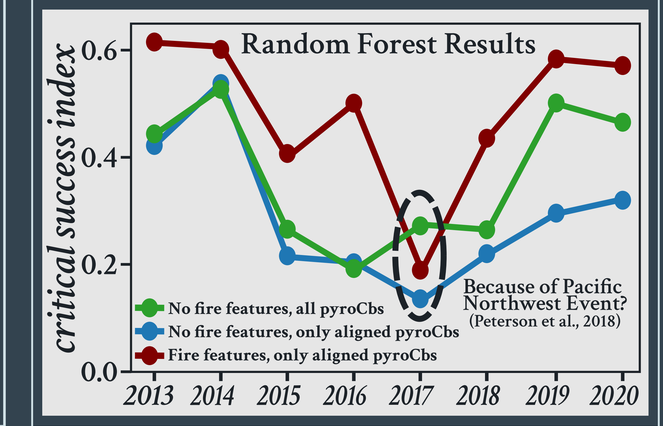
1. Random Forest
2. Weighted Random Forest
3. Support Vector Machine
4. Deep Neural Network

Observation #1: Alignment Failures

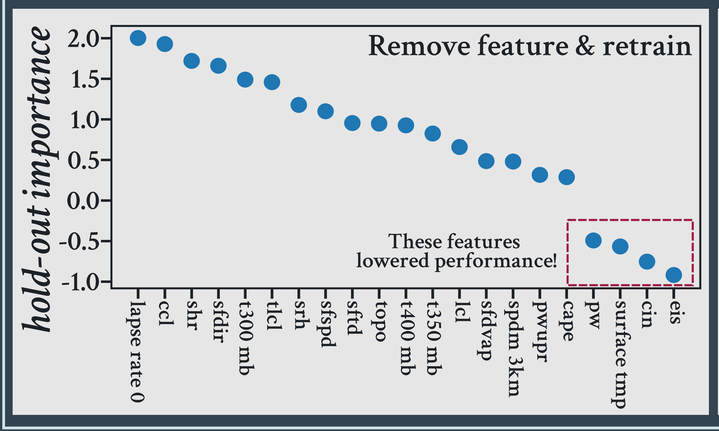
Observation #2: Controlling Fire Feature Influence

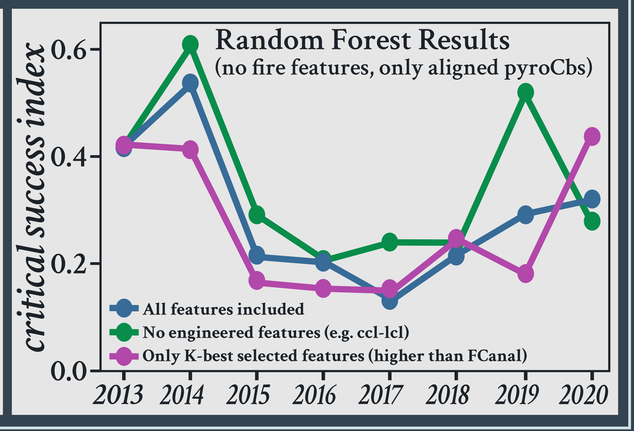


Observation #3: Model Performance

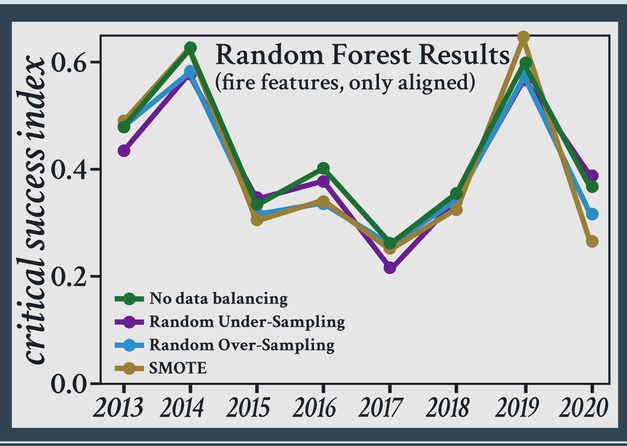


Observation #4: K-Best Feature Selection Hurts Performance





Observation #5: Data Balance Ineffective



Future Work

1. Compare to PFT
2. Investigate 2017 pyroCbs
3. More atmospheric features
4. Model tuning
5. Probe learned relationships with eXplainable AI (XAI)

References

Peterson, David A., et al. "A conceptual model for development of intense pyrocumulonimbus in western North America." Monthly Weather Review 145.6 (2017): 2235-2255.
Tory, Kevin J., and Jeffrey D. Kepert. "Pyrocumulonimbus Firepower Threshold: Assessing the atmospheric potential for pyroCb." Weather and Forecasting 36.2 (2021): 439-456.
Peterson, David A., et al. "Wildfire-driven thunderstorms cause a volcano-like stratospheric injection of smoke." NPJ climate and atmospheric science 1.1 (2018): 30.

This material is based upon work supported by the National Science Foundation under award 2019758. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation