Fire In The Mojave Ecoregion: Past, Present, And A Little Bit Into The Future

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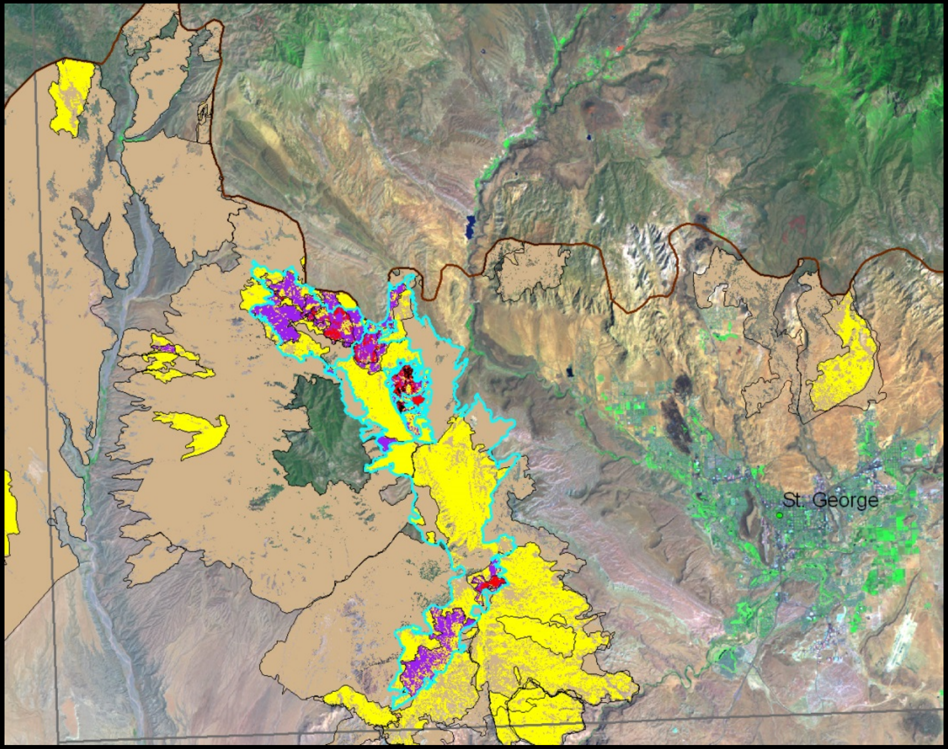
Approach

- Present overview of two large-scale integrated projects
- Explain the derivation of the foundational data for the project
  - Fire severity
- Spatial analysis
  - Brief (Jerry Tagestad's more detailed analysis)
- Temporal pattern
  - Correlations with precipitation and lightning
  - Rarity of 2005 & 2006
- Short-term forecasts
- Transition to Jerry's talk



Overview of Project

Analysis Component

- Overarching goal was to understand ecoregional-scale relationships between climate, fire, vegetation dynamics, and non-native annual species
- Mapping and characterizing fires > 405 ha (1000 acres) provided the foundational data of the analyses
    - Severity
    - Postfire vegetation dynamics

Overview of Project
Modeling Component

- Overarching goal was to use data and information from the analyses to model:
  - **Habitat suitability for four non-native annual species**
  - **Non-native annual species biomass**
  - **Postfire vegetation states and transitions**
  - **Likelihood of ignition across the ecoregion**
  - **Fire severity across the ecoregion**
- Develop tools for managers from these models

Integrated Multi-Scale Project

Remote Sensing Data

Fire

Climate

Lightning

NDVI

Vegetation Plots (Chronosequence)

Structure

(Cover, biomass, density)

Composition

(Identity, relative abundance)

SDM's

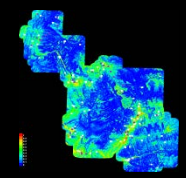
Presence/absence

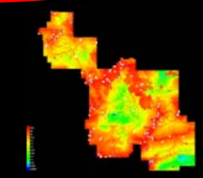
Abundance

(*B. rubens, B. tectorum, E. cicutarium, S. barbatus*)

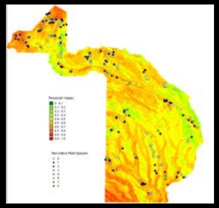
Spatio/Temporal Patterns

1972 - Present



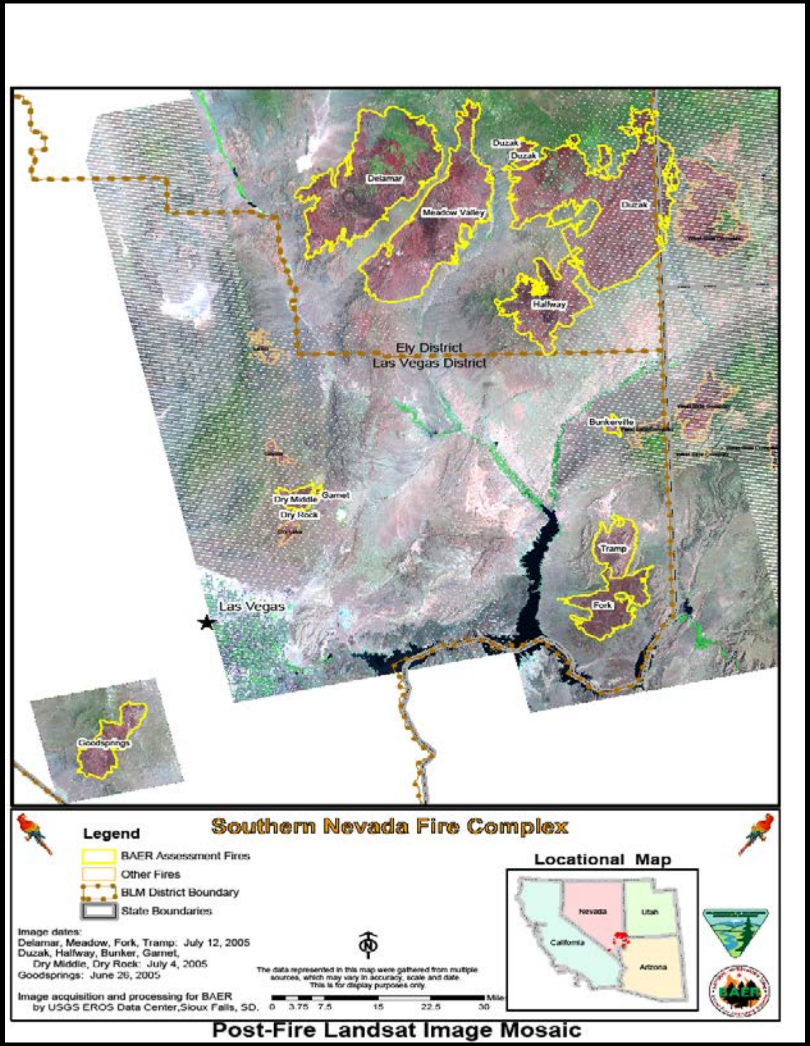


Vegetation State-Transition & Fire Hazard Models



Motivation For Project
2005 Mojave Fire Season

- ≈ 51 fires in June & July
- ≈ 385,000 ha in Mojave bioregion
  - 132% of total area burnt in previous 25 years
- ≈ 289,000 ha in Clark and Lincoln counties
- Two consecutive wet winters
- Very wet winter of 2004/2005
- Huge series of lightning storms
- Followed in July 2006 by ≈ 37 fires (≈ 276,000)

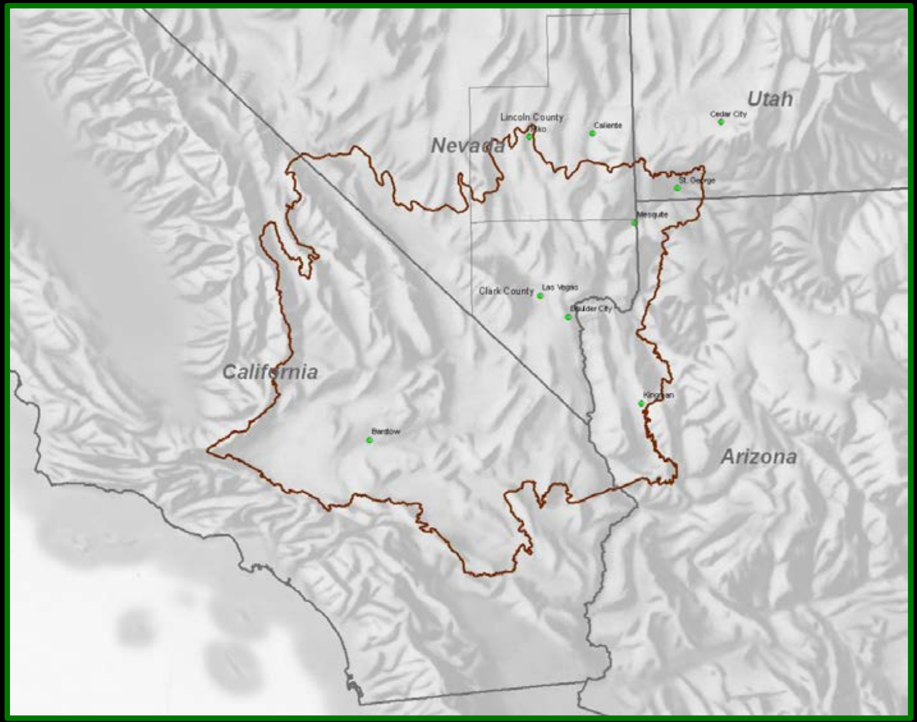


Raised Many Questions

- Was fire in the Mojave increasing?
  - Number of fires
  - Area burned
  - Severity
- Were vegetation communities being altered?
  - Non-native annual species

Fire Mapping As The Cornerstone of the Project

- **An evolving set of objectives**
  - Identify large fires (>1,000 acres) in Lincoln and Clark counties of Nevada for the period 1972 to 2007 using Landsat satellite imagery
  - Expand fire mapping to the full Mojave bioregion
  - Map all "identifiable" fires for the 1972 to 1983 period for the full Mojave including assessments of burn severity
  - Use USGS MTBS project data to characterize fires for the 1984 to 2010 time period
    - Burned area extent, frequency, and severity over time
  - Link remotely sensed fire severity and frequency data with vegetation structure and composition



Fire Mapping As The Cornerstone of the Project

- An evolving set of analyses and models
  - What constitutes a “good” remotely sensed measure of fire severity
  - Temporal and spatial variation in fire occurrence
  - Short-term forecasts of fire occurrence
  - Model likelihood of ignition
  - Model fire severity
  - Produce dynamic fire hazard prediction surfaces

What Do We Mean By Fire Severity?

- The effect of a fire on ecosystem properties, usually defined by ***biomass loss***, the ***mortality*** of vegetation, or degree of ***soil heating***
- Not just fire intensity (heat released per unit area)
- Fire Intensity + Residence Time + Vegetation Characteristics + Soil Structure

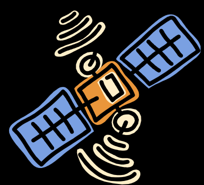
How Do We Measure Fire Severity?

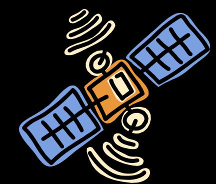
Ground-based Measures

- Vegetation characters
- Soil structure
- Composite Burn Index (CBI)
  - Vegetation loss and soil combined
- Some problems with these:
  - Subjective
  - Limited in spatial extent and scope

How Do We Measure Fire Severity?

Remote Sensing Measures





Pre-burn ← Compare Reflectance → Post-burn

Remote Sensing Measures Of Fire Severity

- Continuous measures
  - NDVI (Normalized Difference Vegetation Index)
  - dNDVI (Differenced Normalized Difference Vegetation Index)
  - NBR (Normalized Burn Ratio)
  - dNBR (Differenced Normalized Burn Ratio)
  - RdNBR (Relativized Differenced Normalized Burn Ratio)
- All work on idea of measuring photosynthetically active vegetation ("greenness") while adjusting for bare soil

Remote Sensing Measures Of Fire Severity

- Categories ("Severity Classes")
  - Derived from dNBR/RdNBR
  - Unburned, Low, Moderate, High, Very High

Vegetation Indices (NDVI and dNDVI)

- **The Normalized Difference Vegetation Index (NDVI)** is widely used to identify vegetated areas and to estimate their condition. NDVI is computed using Landsat ETM+/TM near infrared (NIR) and visible red (RED) spectral bands (4 and 3) respectively. Can be derived from other sensors (i.e Landsat MSS) with VNIR bands. NDVI is calculated as follows:

$$NDVI = (NIR - RED)/(NIR + RED)$$

- For burn severity mapping or change detection purposes, the **differenced NDVI (dNDVI)** is calculated using two images acquired at different time intervals (i.e. pre-fire and post-fire) as shown in this example for mapping burn severity:

$$dNDVI = NDVI_{prefire} - NDVI_{postfire}$$

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Burn Severity Indices (NBR, dNBR and RdNBR)

- The **Normalized Burn Ratio (NBR)** is computed using Landsat ETM+/TM near infrared (NIR) and short wave infrared (SWIR) spectral bands (4 and 7). The NBR proposed by Key and Benson (1999) is calculated as follows:

$$NBR = (NIR - SWIR)/(NIR + SWIR)$$

- For burn severity mapping purposes the NBR is generally calculated for both a pre-fire and post-fire image and then used to derive a differenced NBR (dNBR) as follows:

$$dNBR = NBR_{prefire} - NBR_{postfire}$$

- Miller and Thode (2007) proposed the relative differenced NBR (RdNBR) to remove the biasing of the pre-fire vegetation by dividing dNBR by the square-root of the pre-fire NBR as follows:

$$RdNBR = (NBR_{prefire} - NBR_{postfire}) / \sqrt{(\left|NBR_{prefire}\right| / 1000)}$$

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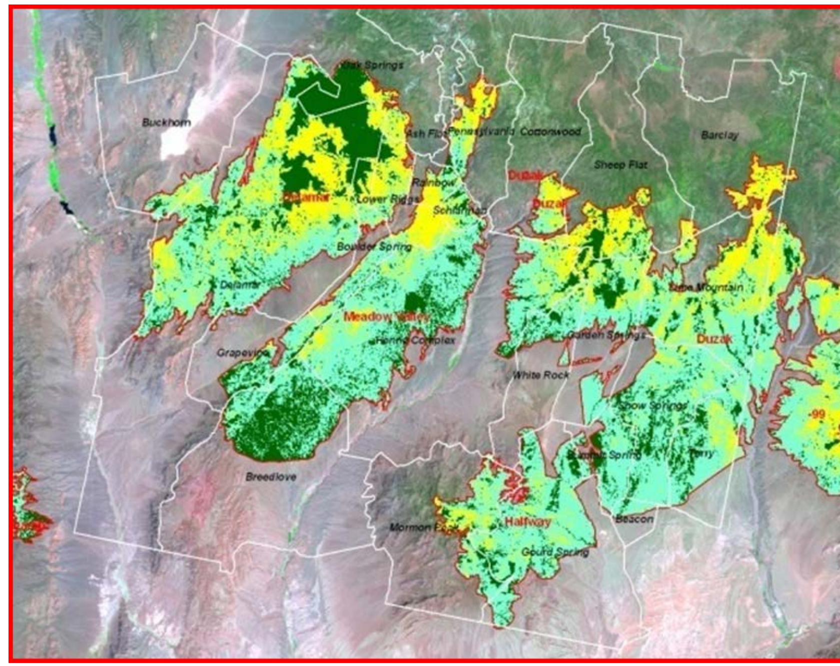
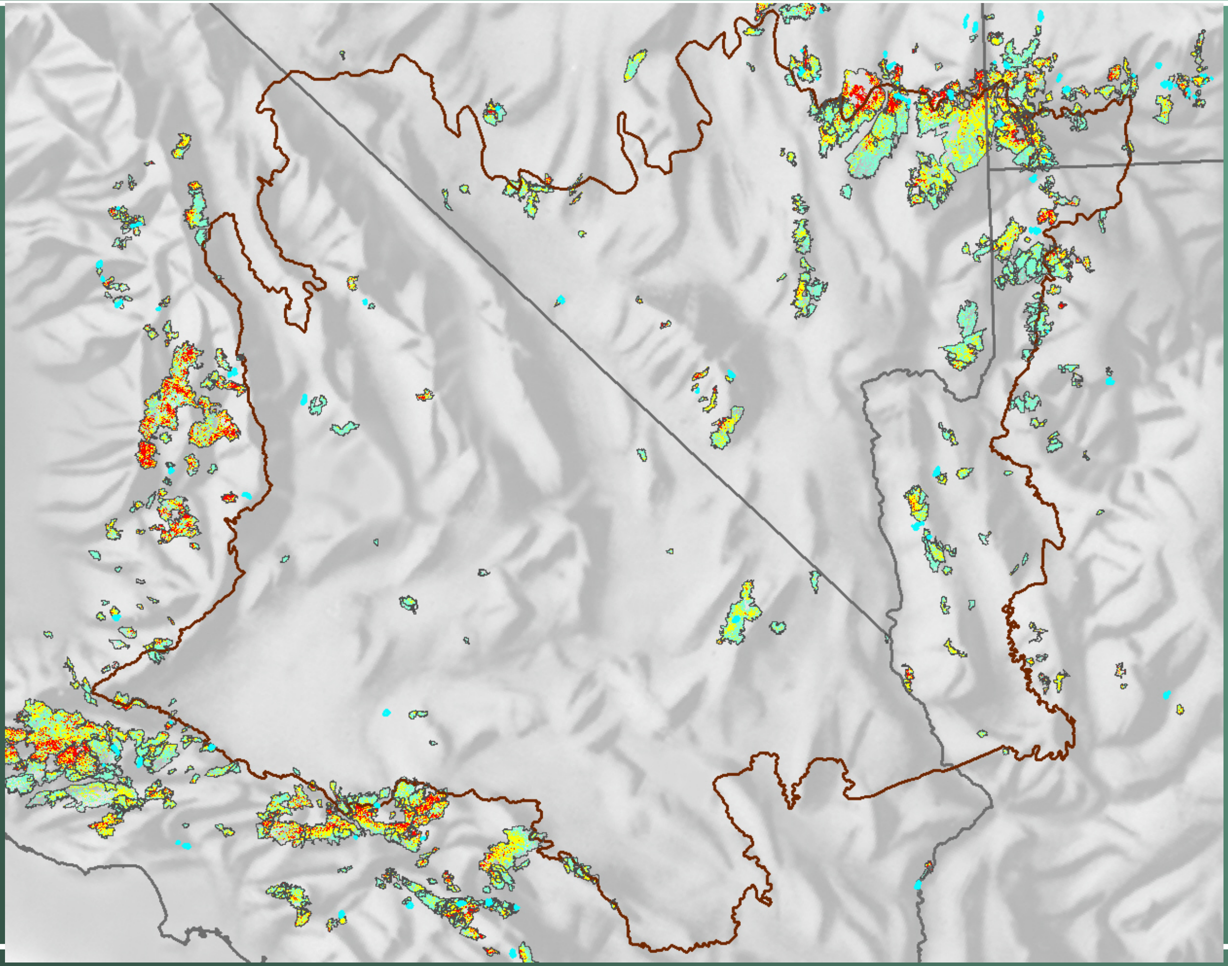
The Mapping Process

- Randy McKinley’s 8-year labor of:
  - Love
  - Hate
  - Infatuation
  - Despair
  - Triumph (finally)
- Mapped all fires > 405 ha (1,000 acres) in and adjacent to ecoregion 1984-2010)
- Mapped ***ALL*** fires in and adjacent to ecoregion 1972-1983)



Involved Identifying > 1,000 Fire Perimeters



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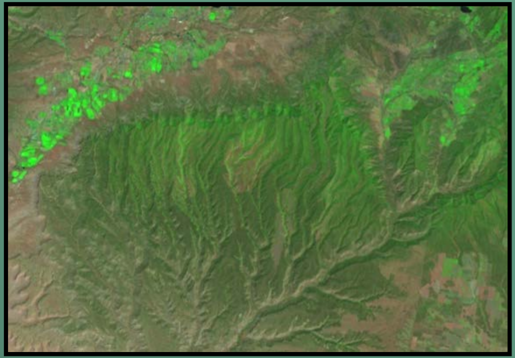
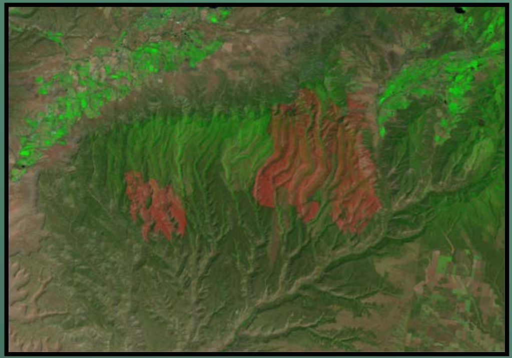
MTBS Process: Landsat Scene Selection

- Dates of pre- and postfire scenes are extremely important:
- dNBR: change detection specifically targeting burned area
- Ideally, results show only change caused by fire
- Pre and Post fire datasets should be chosen to match moisture content and phenology as closely as possible
- Images are terrain corrected and radiometrically processed to at-satellite reflectance

Bircher and Pony Fires of 2000
Mesa Verde National Park



Prefire Landsat: May 23, 2000



Postfire Landsat: June 11, 2001

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The Challenge - generating new spatial information for 1972-1983 fires for continuous severity measures

- Landsat satellite imagery spans 1972 to the present
- 1984 to Present – Thematic Mapper sensor at 30 meter resolution and Visible, Near Infrared and Short Wave Infrared (VINIR/SWIR) spectral bands, with SWIR providing increased sensitivity for burn mapping
- 1972 to 1983 - Multispectral Scanner (MSS) sensor at ~57 meter resolution and Visible/Near Infrared (VINIR) spectral bands (no SWIR band)

The Challenge - generating new spatial information for 1972-1983 fires (con't.)

- The Landsat MSS period compared to TM/ETM/ETM+
  - Increased scene registration issues
  - Additional calibration concerns
  - Reduced scene availability for some years
  - Reduced spatial resolution (80m versus 30m)
  - Fewer & less precise spectral bands, no SWIR
  - Increased incidence of bad lines, missing lines
  - Increased noise
  - Reduced radiometric resolution
- Result>> Used MSS and dNDVI to map 1972-2010 fires and SWIR to map 1984-2010

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Final Products

- **Burn frequency and reburn trends (1972 – 2010)**
- **Continuous burn severity and other variables for statistical analyses (1984 through 2010)**
  - But vegetation plots spanned 1972 – 2010 burns
- **Categorical burn severity layer**
  - Provide estimate of burn severity (low, mod, high)
  - Commonly used in maps of individual fires
  - ***Could*** provide a consistent measure of severity from 1972 - 2010

Three Issues Of Great Importance To Vegetation Analyses (stay tuned for this afternoon)…

- **How well did dNBR compare with on the ground measures of fire severity?**
- **How appropriate was it to use fire severity classes in analyses of:**
  - **Large-scale patterns and trends in severity?**
  - **Vegetation dynamics?**
- **Was there something we could do about the disconnect between dNDVI and dNBR in different time periods**

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…and an issue with dNBR

- Lets take a look at the equation again:

  $$dNBR = NBR_{prefire} - NBR_{postfire}$$

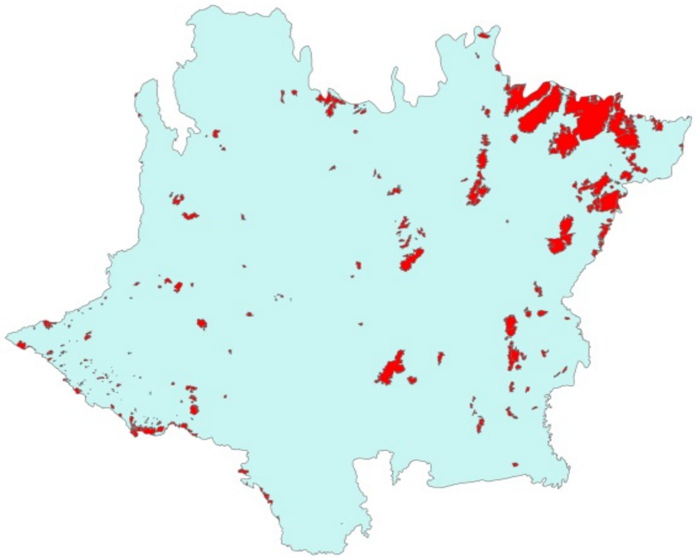
- The NBR values are problematic because they vary from fire to fire
- Likely confounds comparisons across burns
- RdNBR is a partial correction but relativizing dNBR introduces other problems
- Elegant solution
  - Develop an ***offset*** based on mean dNBR values just outside (≈ 100 m) of burn perimeter
  - Calibrates dNBR among fires to a more comparable scale

Now We Can Start Addressing Some Questions

- What are general patterns of area burned and fire frequency in the Mojave ecoregion since 1972?
- Where in the Mojave ecoregion have the fires occurred since 1972?
- Has there been an increase in the number of fires in the Mojave ecoregion since 1972?
- Has there been an increase in the area burned in the Mojave ecoregion since 1972?
- What environmental variables are correlated with variability in number of fires and area burned?
- Can we forecast how many fires or the area burned we are potentially looking at in a given year?

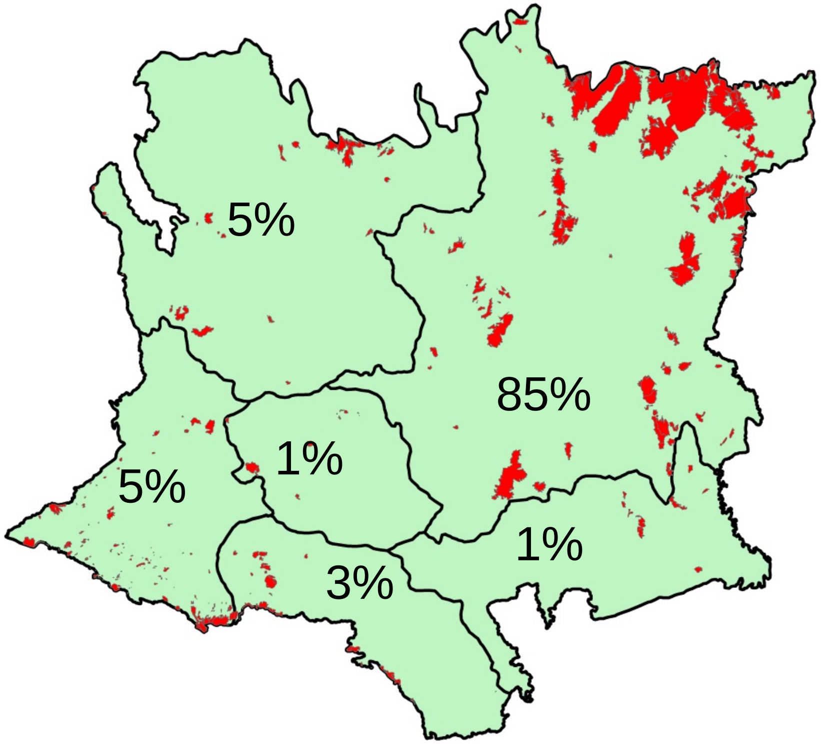
What Are General Patterns Of Area Burned?

- Basic statistics (fires > 405 ha)
  - Number of fires 1972-2010
    - 254
  - Area burned 1972-2010
    - 7,517 km^2
    - 5% of ecoregion
    - 76% of area burned has burned one time (3.6%)
    - 20% of area burned has burned two times (0.6% of ecoregion)
    - 4% of area burned has burned > 2 times (0.8% of ecoregion; maximum = 5)



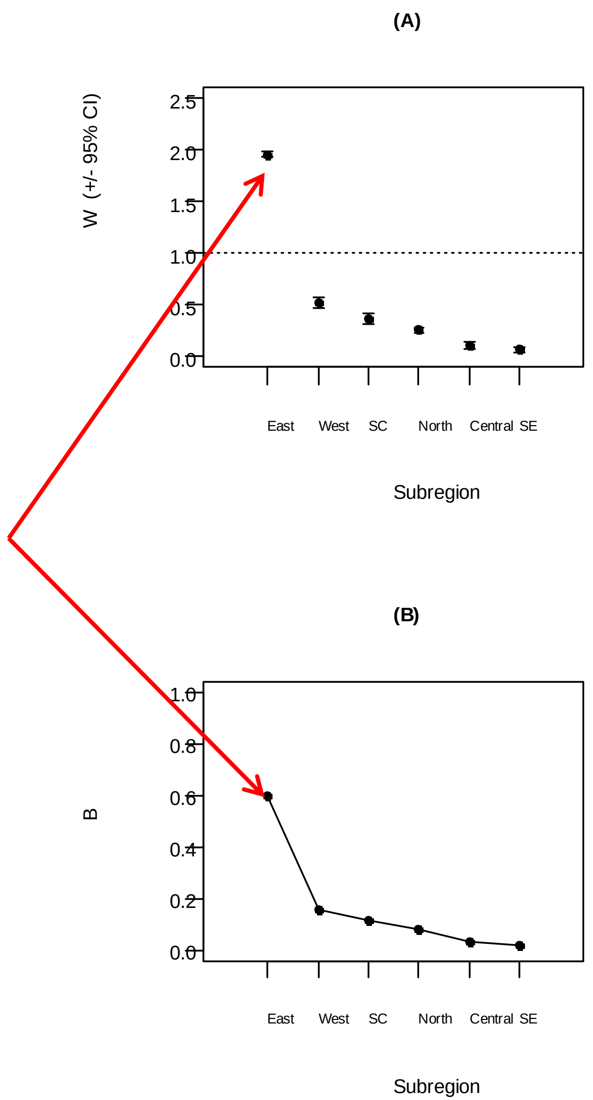
Where In The Ecoregion Is Fire Most Extensive?

- Proportion of total area burned across ecoregion
- Northern
- Western
- Southcentral
- Central
- Southeast
- Eastern
  - The east appears to be a “hot zone”



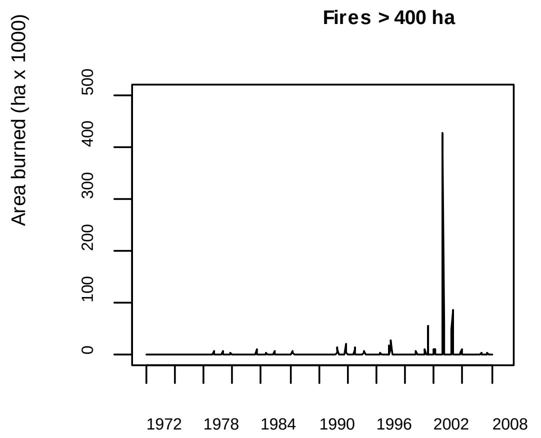
Where In The Ecoregion Is Fire Most Extensive?

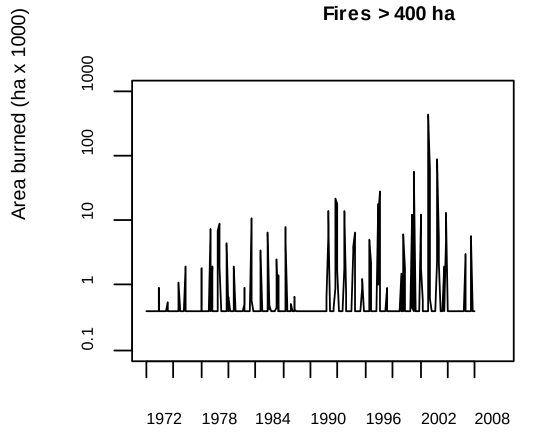
- Analysis of fire occurrence relative to area of the region
  - Absolute occurrence
  - Relative to other regions
- The area burned in the Eastern region is 2x greater than expected relative to its area
- The area burned in the Eastern region is 3x - 12x more than the other regions
  - Why? Stay tuned for Jerry Tagestad's presentation



Temporal Patterns

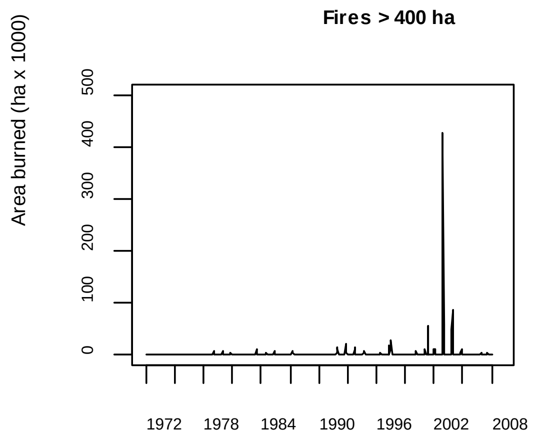
- Main Questions – Set 1
  - Is there evidence of a trend in:
    - Area burned
    - Number of fires
    - Variability in area burned and number of fires
  - 1972 through 2010
  - Ecoregional scale
- But patterns and trends are almost certainly related to other factors
  - Fuels
    - Precipitation!
  - Ignition
    - Lightning!

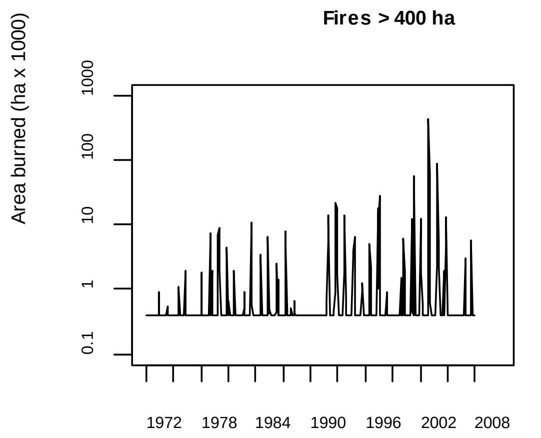




Temporal Patterns

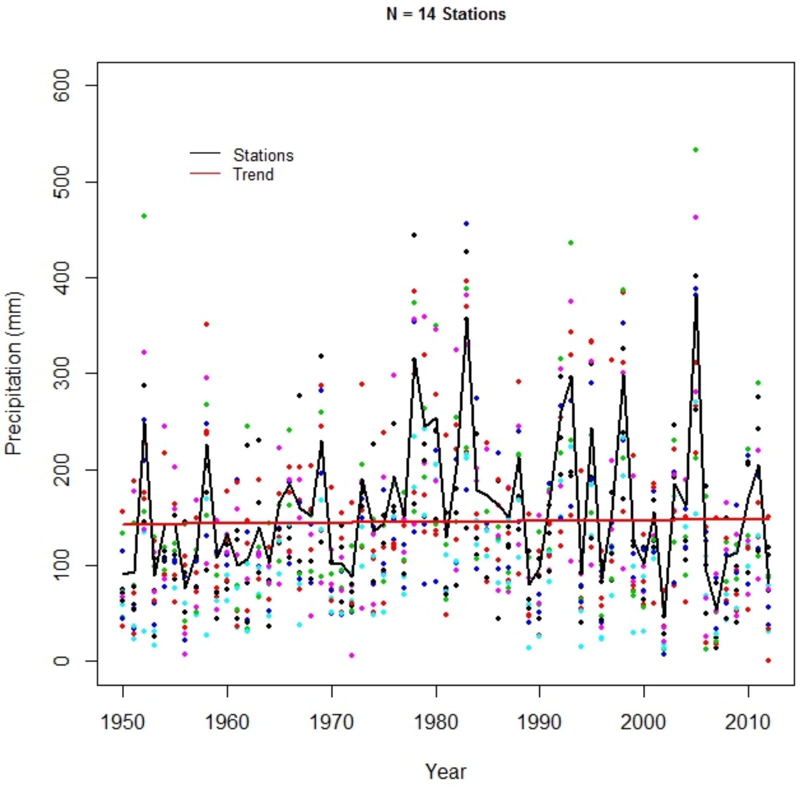
- Time series analysis (1972-2010)
  - Monthly number of fires and area burned
    - Fine temporal scale trend analysis
  - Annual number of fires and area burned
    - General patterns for forecasting
- But first we needed to understand patterns in precipitation and lightning





Temporal Variation in Precipitation Regime

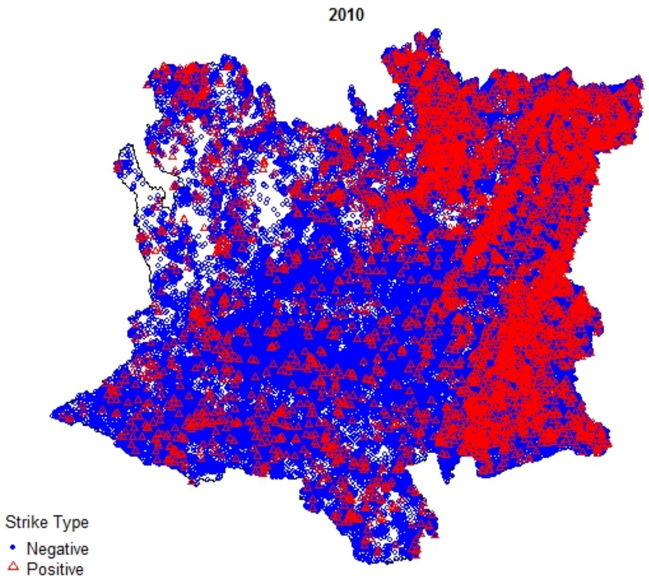
- Main Question
  - What is the ecoregional pattern of variability in precipitation?
  - Spatial variability within ecoregion
- Hereford (2006)
  - Monthly time series 1893 – 2001
    - N = 52 stations
    - Many outside ecoregion
    - Very patchy records
  - Dry periods (1893-1904, 1942-1975) sandwiched between wet periods (1905-1941, 1976-2001)
- Our analysis
  - Monthly time series 1950 – 2012
    - N = 29 stations parsed to 14 with near complete annual records
    - All within ecoregional boundary



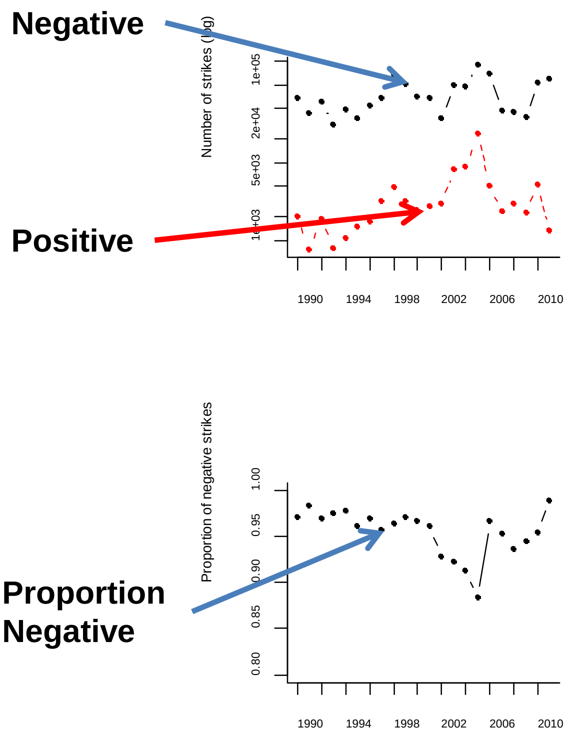
High variability but ***NO*** trend
One main pattern characterizes ecoregion
(Multivariate Autoregressive State-Space Model: MARSS)

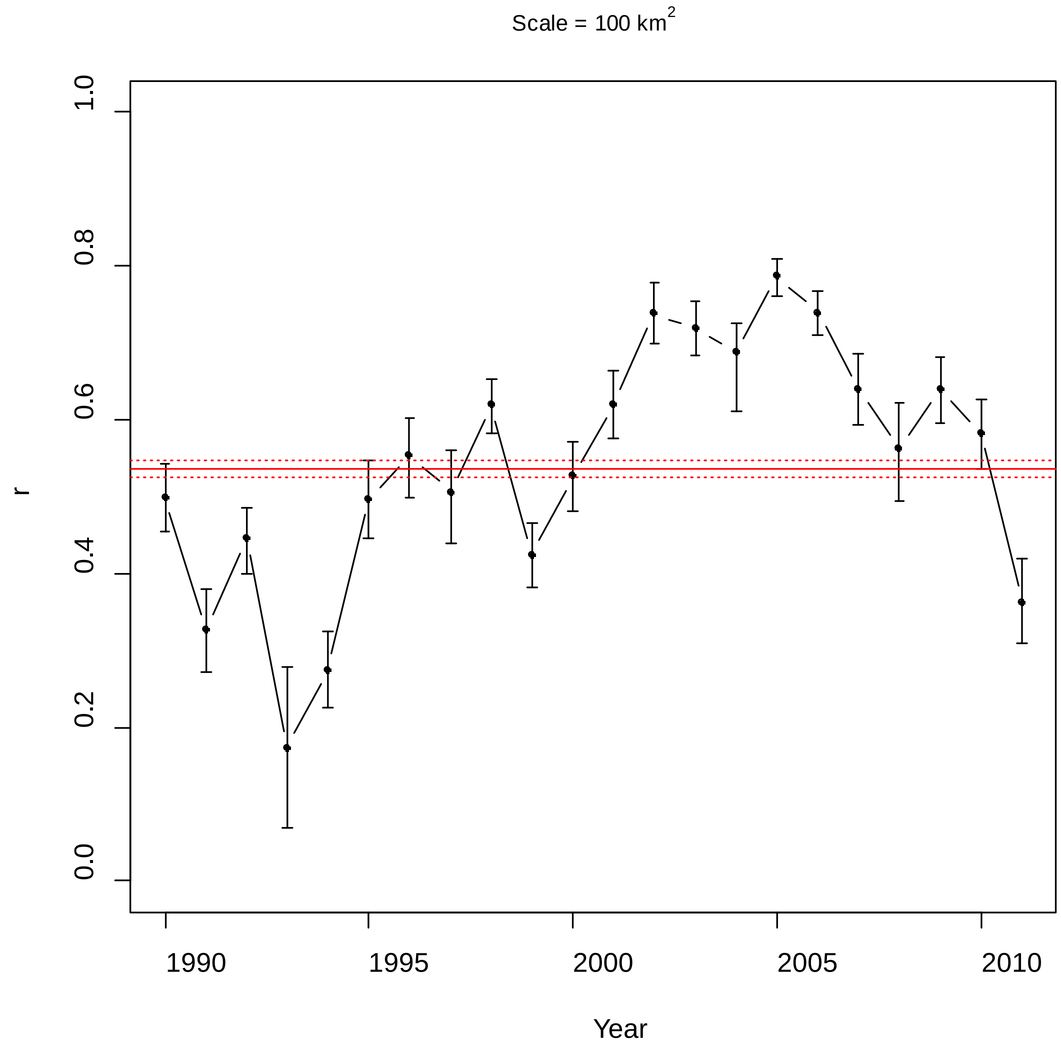
Spatio-temporal Variation In Ignition Patterns

- Lightning strike data (1990-2012)
  - N ≈ 1.8 million records
  - Negative strikes
    - Most strikes (90 – 95%)
    - “Short” duration (1 microsecond)
    - “Low” energy (30kA, 500 megajoules)
  - Positive strike
    - Low proportion (≈ 5%)
    - “Long” duration (20 microseconds)
    - High energy (300kA, 5000 megajoules)



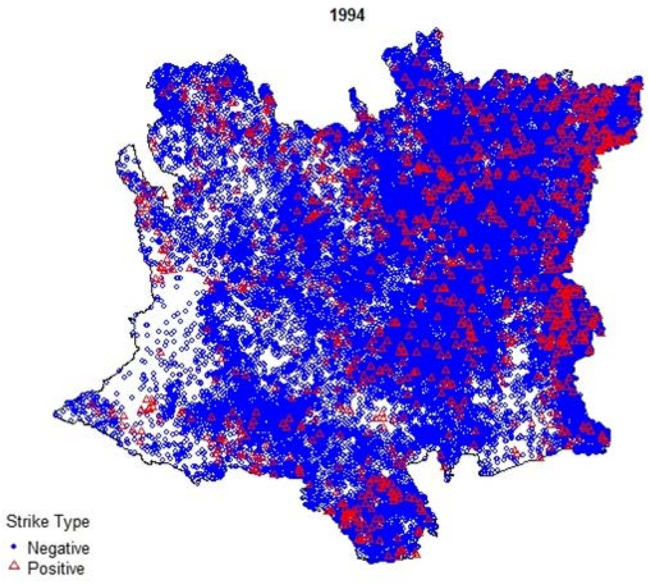
Spatio-temporal Variation In Ignition Patterns

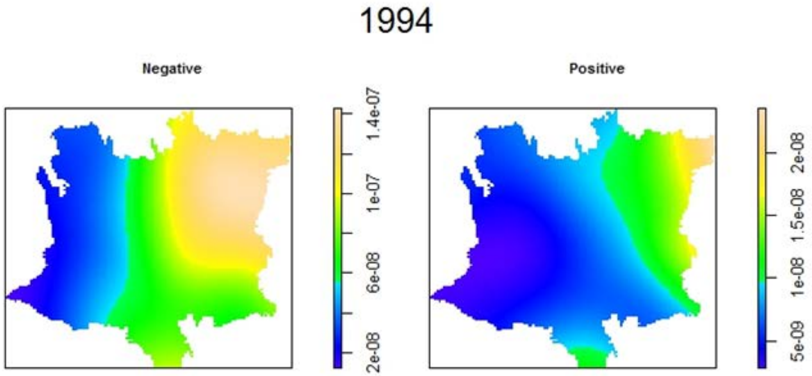




Cross-Correlation Coefficient; No CSR

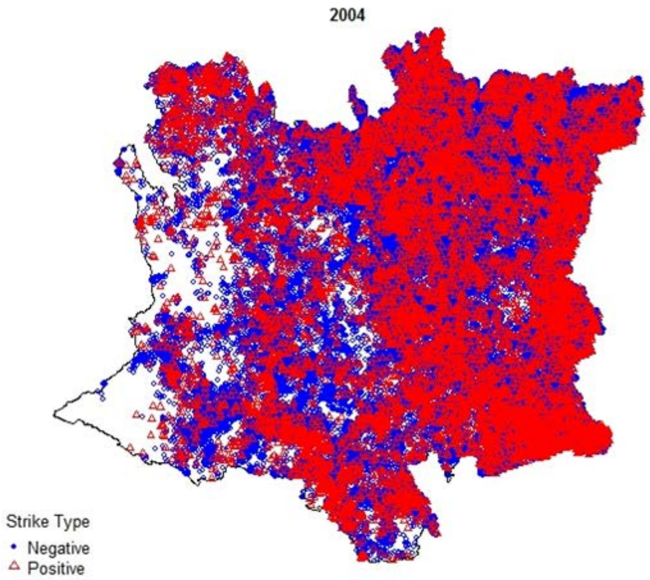
Spatio-temporal Variation In Ignition Patterns

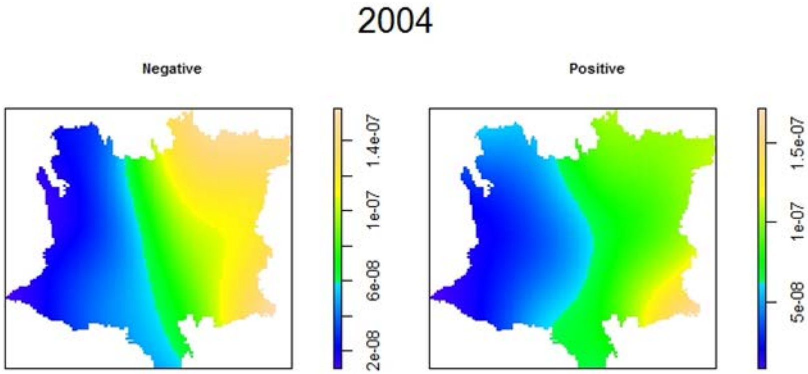




Dynamic Linear Model

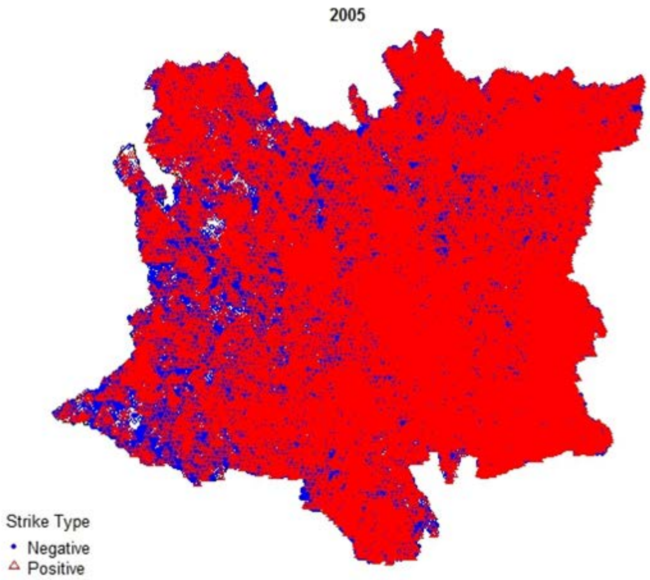
Spatio-temporal Variation In Ignition Patterns

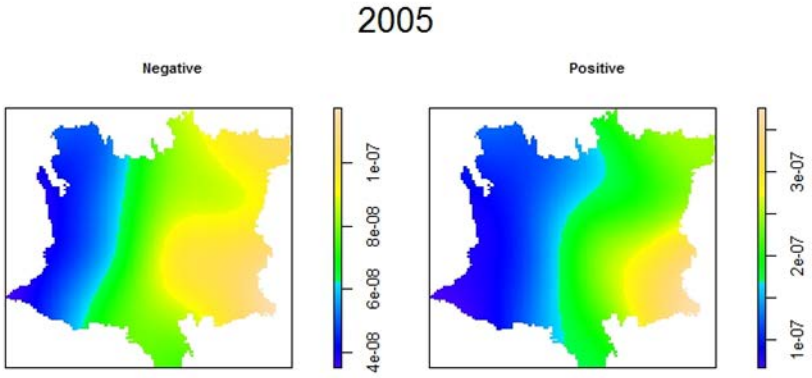




Dynamic Linear Model

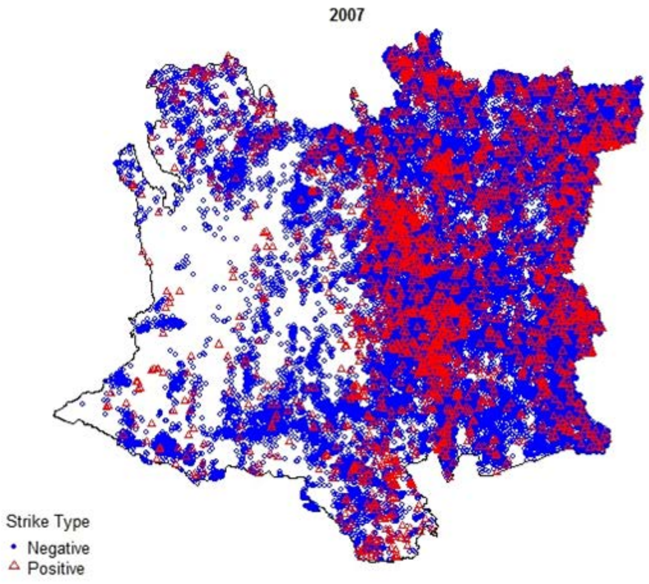
Spatio-temporal Variation In Ignition Patterns

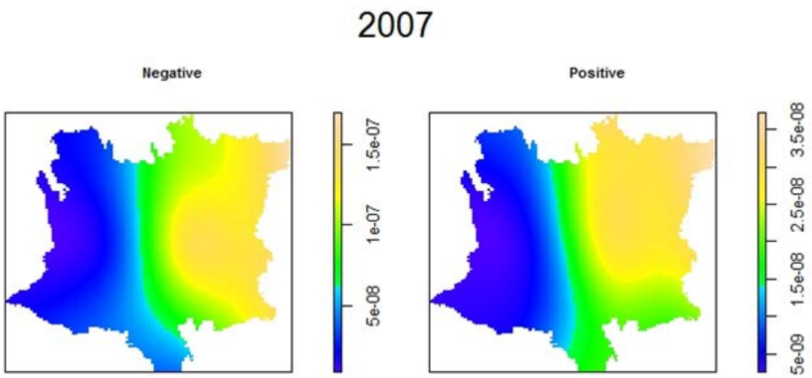




Dynamic Linear Model

Spatio-temporal Variation In Ignition Patterns

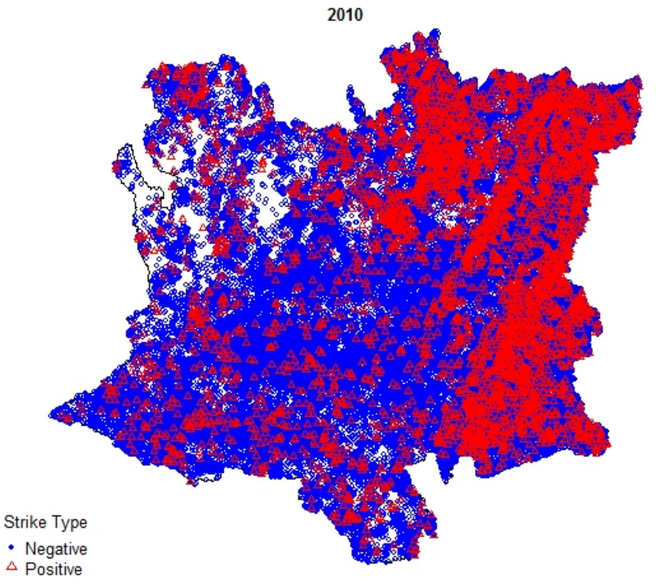




Dynamic Linear Model

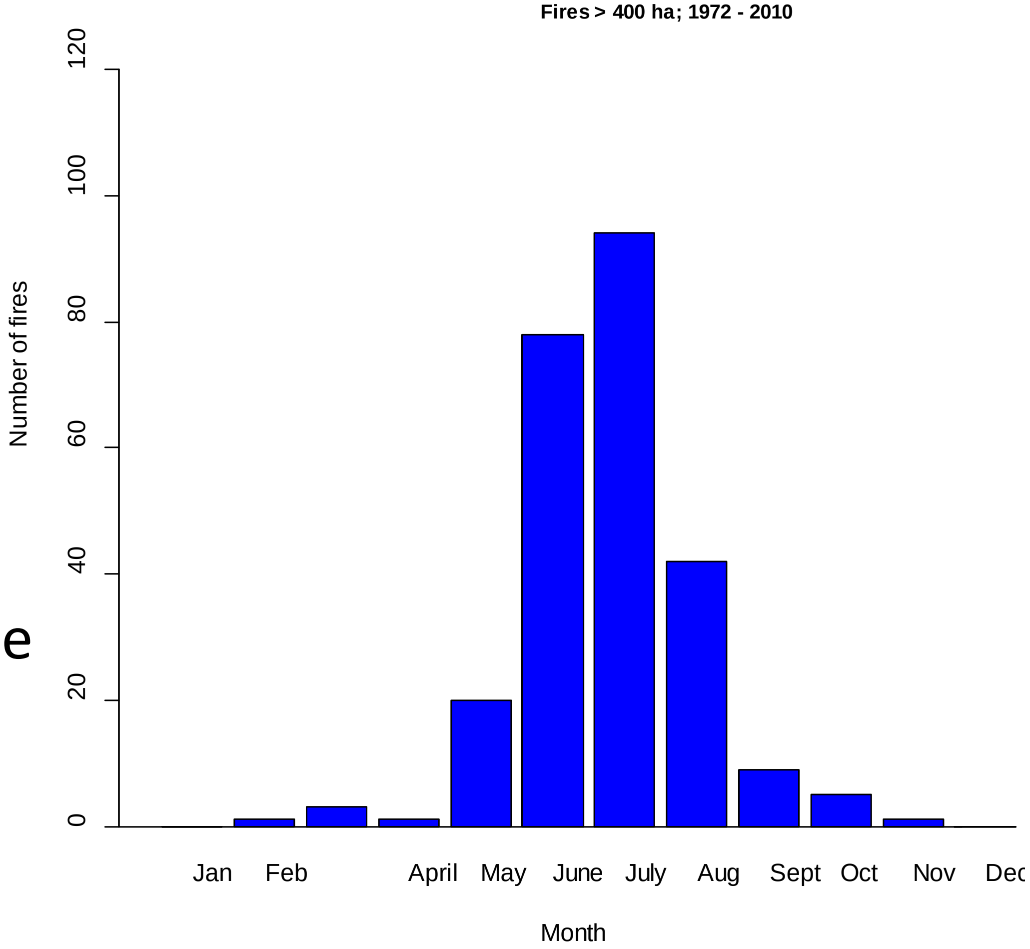
Spatio-temporal Variation In Ignition Patterns

- Summary of patterns
  - No temporal trend in number of negative strikes
  - Increase in number and proportion of positive strikes 1993-2005
  - Increase in spatial correlation of negative and positive strikes 1993-2005, followed by decrease 2006-2012
  - ***Strike intensity "jumps" around spatially in different years***
  - ***Central and west Mojave have much lower strike intensity than east Mojave***



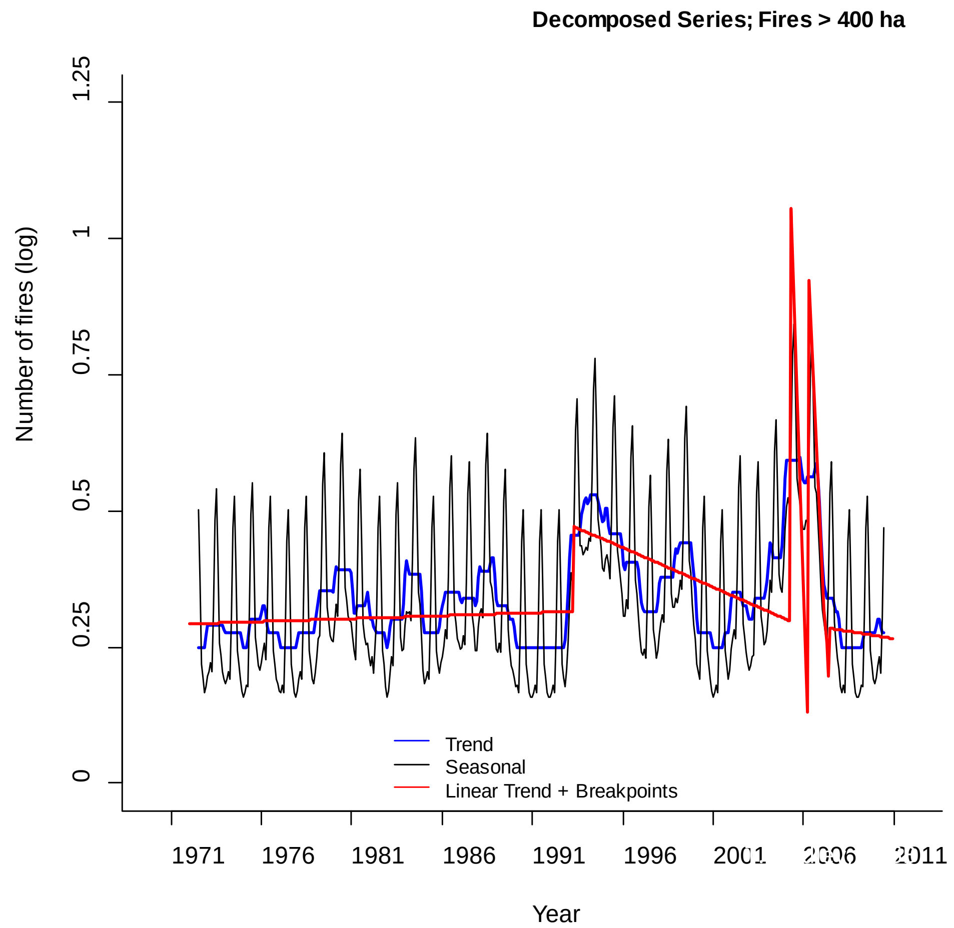
Temporal Patterns In Fire Occurrence

- When does fire occur in the Mojave?



Temporal Patterns In Fire Occurrence

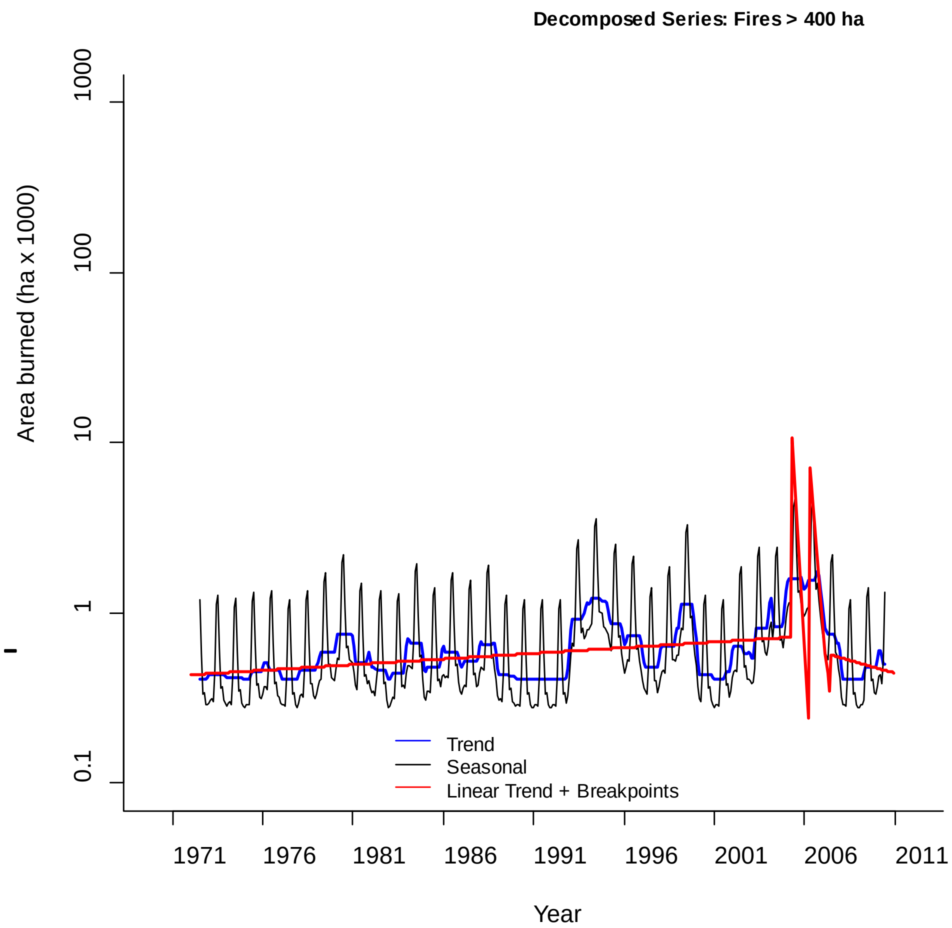
- Has there been a trend in number of fires?
  - Yes, but…
  - Not linear
  - Punctuated by “leaps” in two sets of years



Dynamic Linear Breakpoint Model

Temporal Patterns In Fire Occurrence

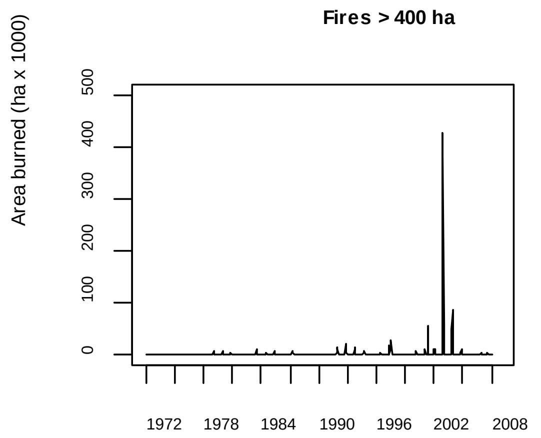
- Has there been a trend in area burned?
  - Yes, but…
  - Not linear
  - Punctuated by “leap” in 2005-2006

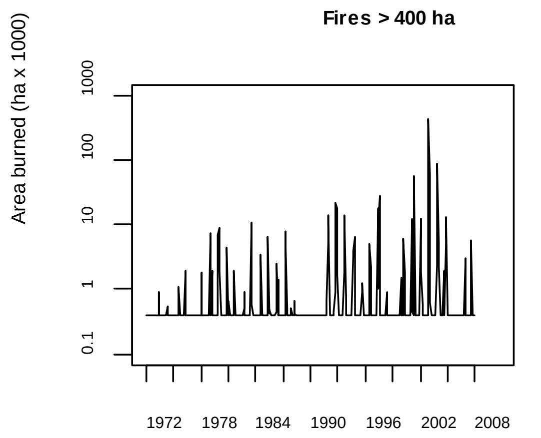


Dynamic Linear Breakpoint Model

Temporal Patterns

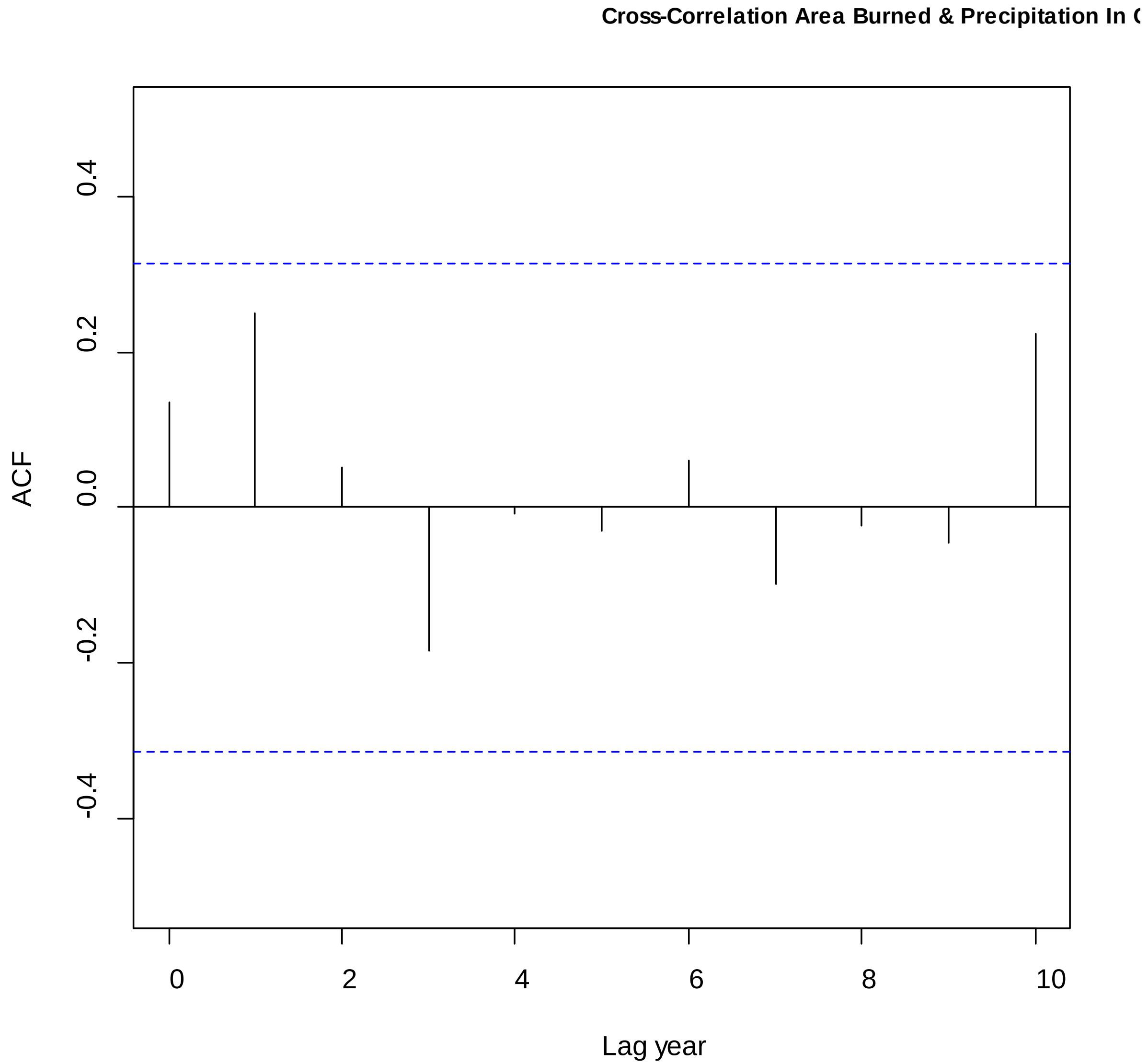
- Main Questions – Set 2
  - Could we use the data to generate short-term forecasts of:
    - Area burned
    - Number of fires
  - 1 - 2 years ahead
  - Ecoregional scale





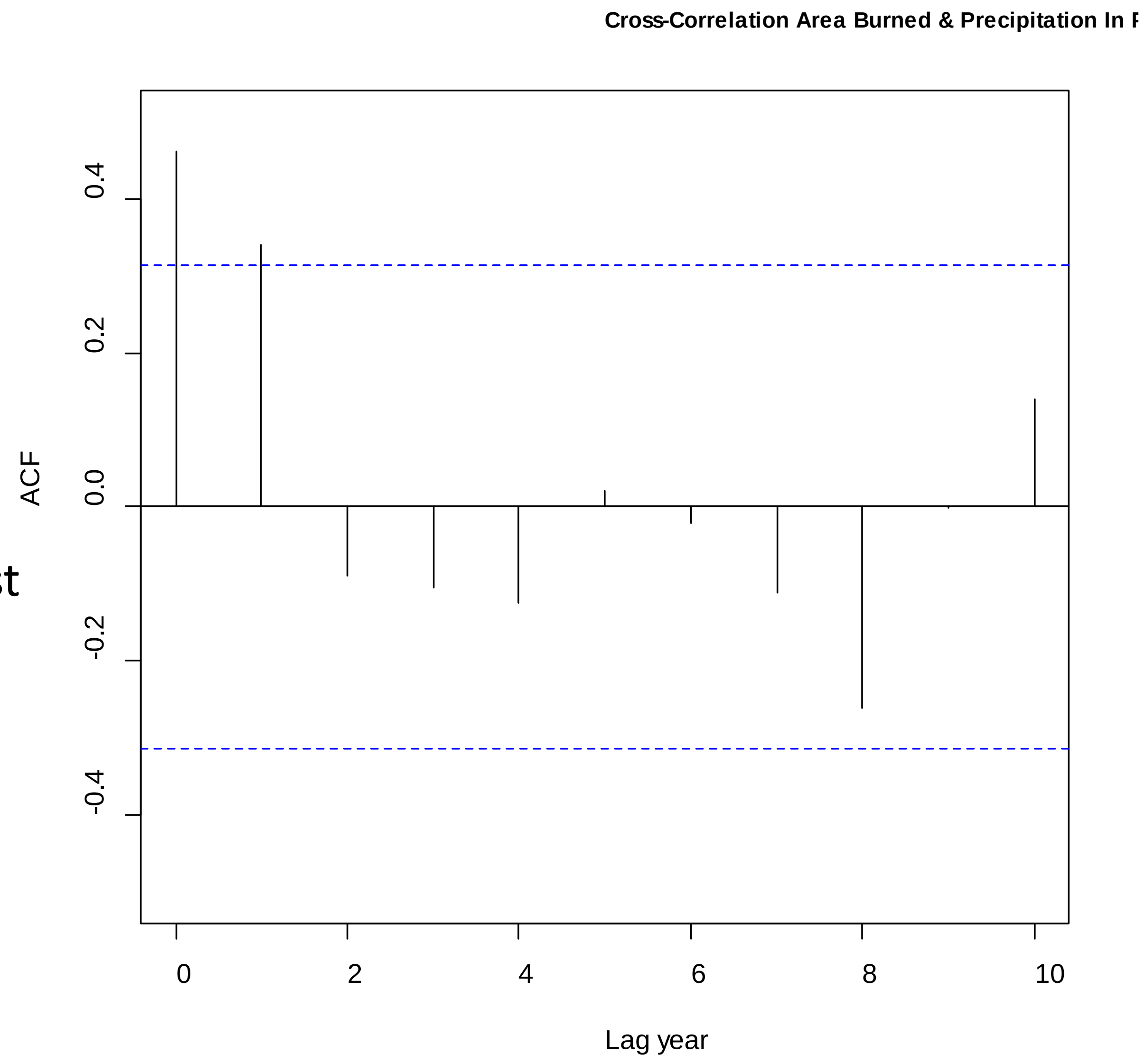
Temporal Patterns In Fire Occurrence

- What is useful for predicting how much area and how many burns will occur?
  - NOT precipitation in the current year
  - NOT lightning



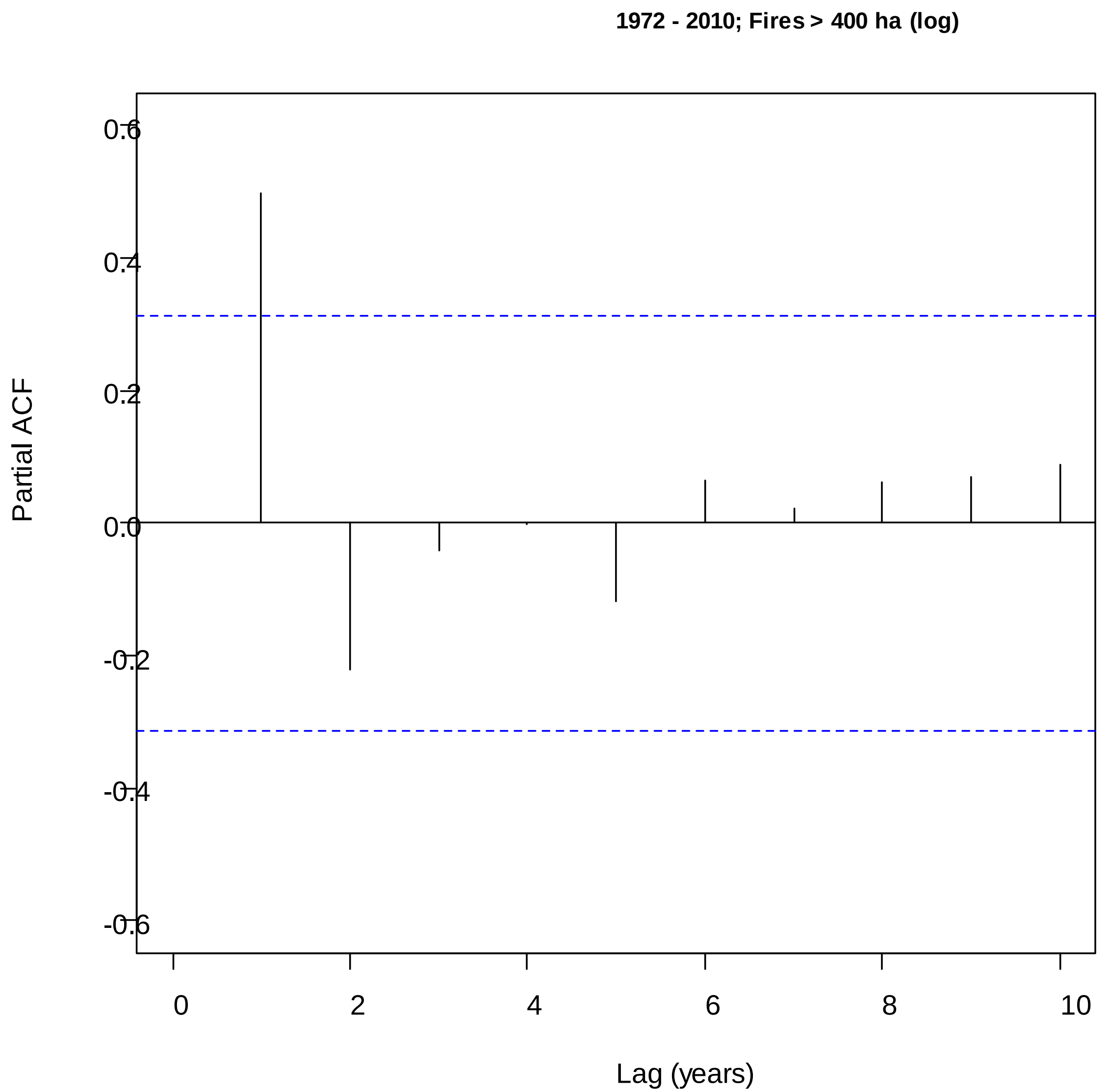
Temporal Patterns In Fire Occurrence

- What is useful for predicting how much area and how many burns will occur?
  - Precipitation in the last 6 or 18 months

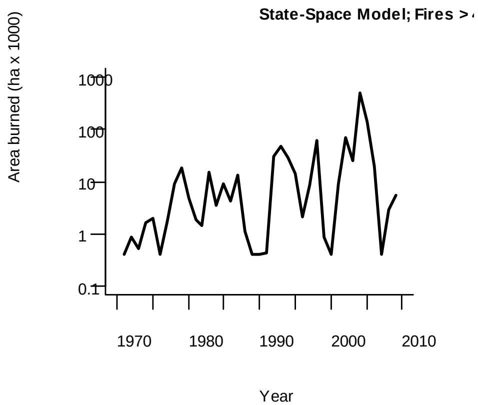


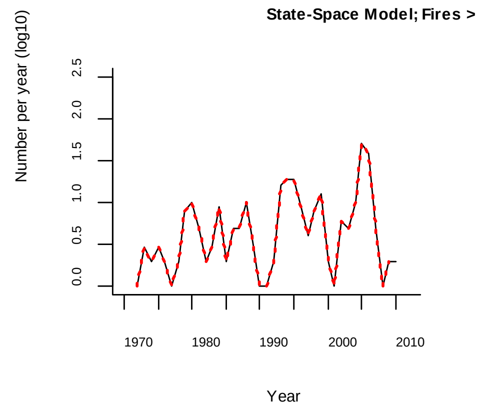
Temporal Patterns In Fire Occurrence

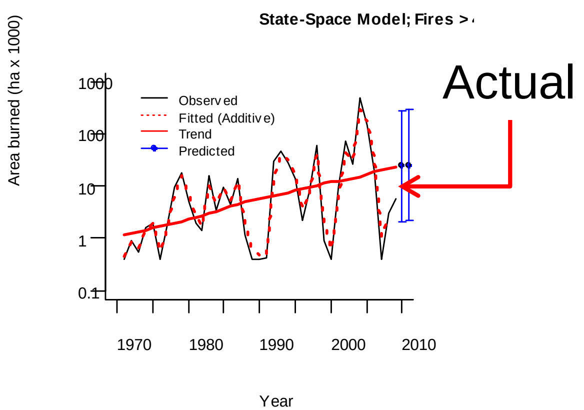
- What is useful for predicting how much area and how many burns will occur?
  - Their own short term history!
  - 1-year lag

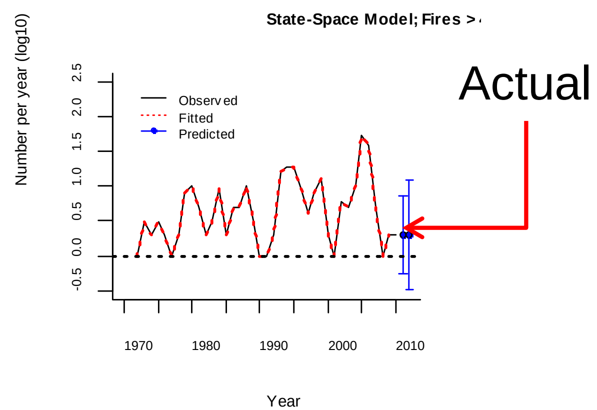


Looking A Little Bit Ahead





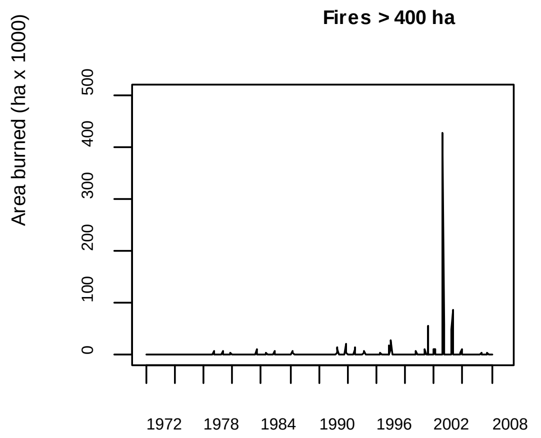


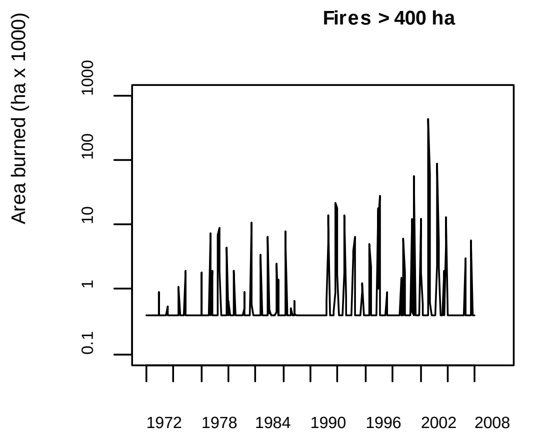


Successful 1-year forecasts of number of fires and area burned based on previous year burning and precipitation in previous year

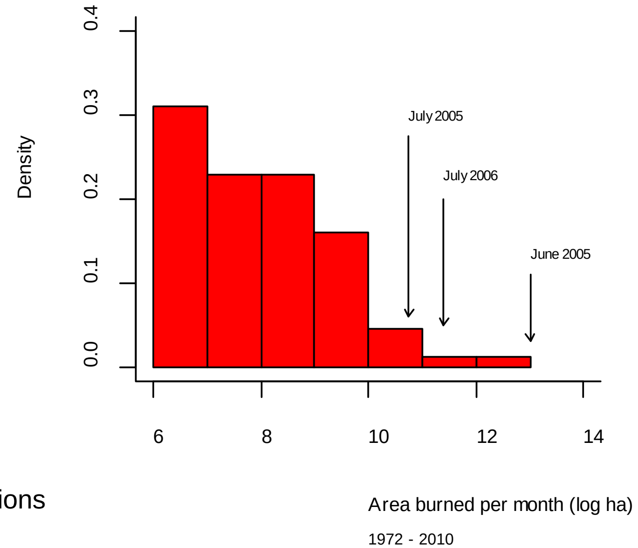
Temporal Patterns

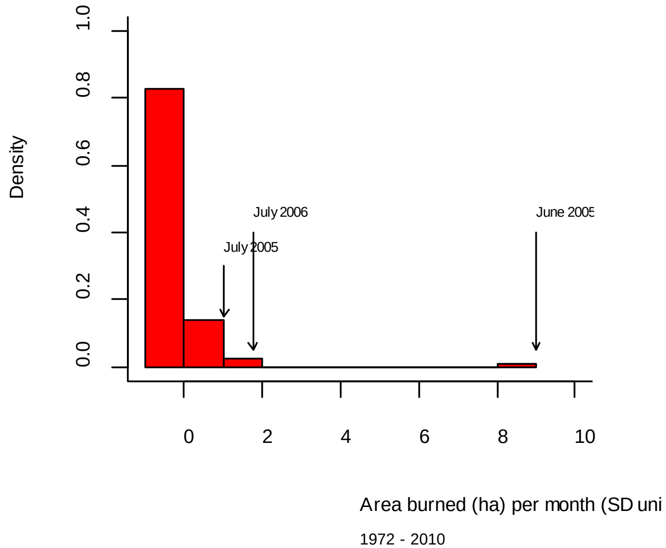
- Main Questions – Set 3
  - How rare were 2005 and 2006 fire seasons?
  - Could we estimate how frequently these types of years might happen?
  - Ecoregional scale





How Rare Of Events Were The 2005 & 2006 Fire Seasons?

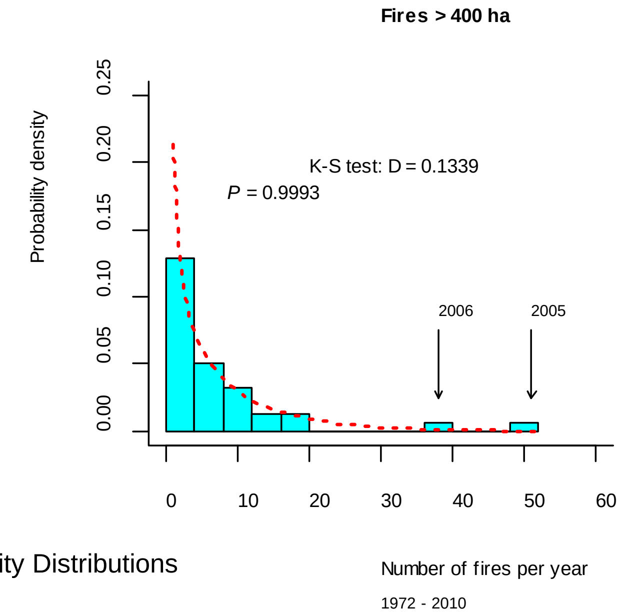


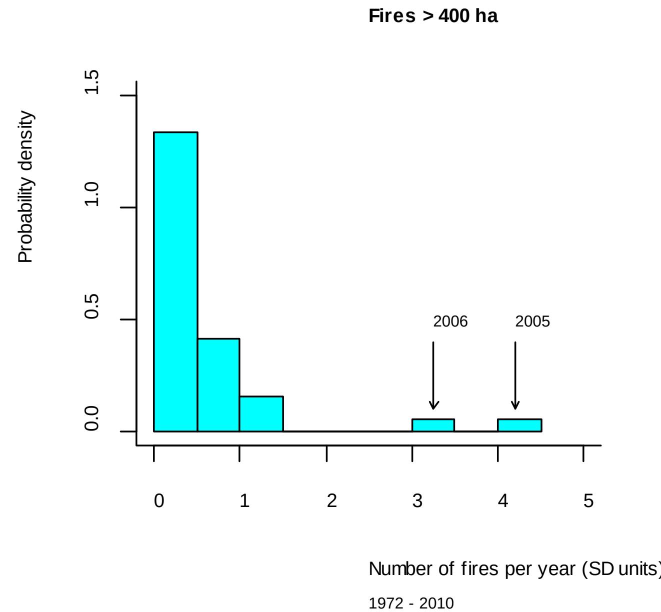


Gamma Probability Distributions

- VERY!
  - Statistically, June 2005 should not have happened

How Rare Of Events Were The 2005 & 2006 Fire Seasons?



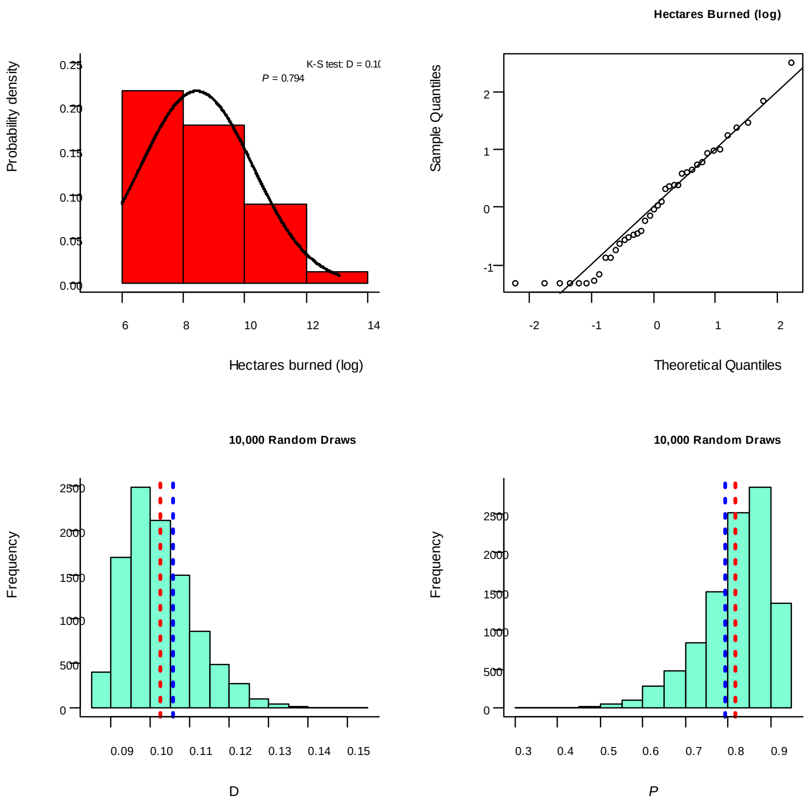


Negative Binomial Probability Distributions

- VERY!
  - Statistically, June 2005 and July 2006 occurring back-to-back should not have happened

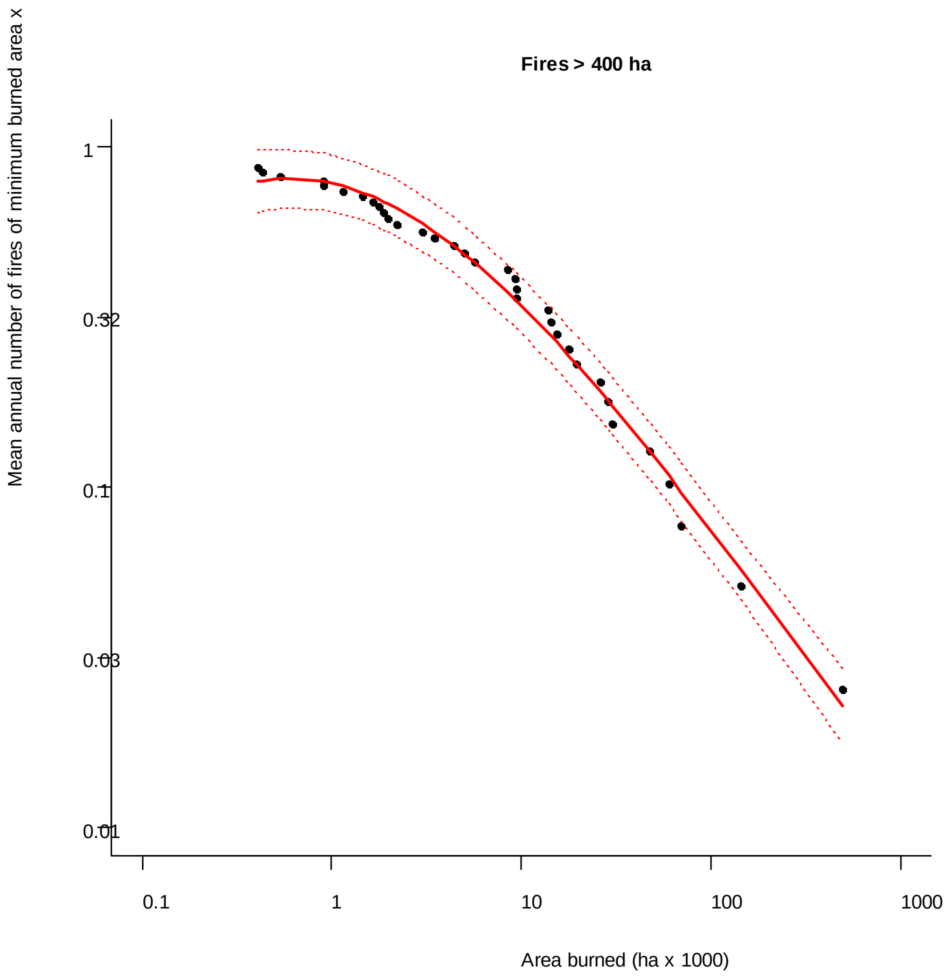
How Often Might These Rare Events Occur?

- Well…it depends
  - Theoretical probability distributions suggest every 500 – 1000 years (or more)
  - Assumes distribution of events remains relatively constant over time



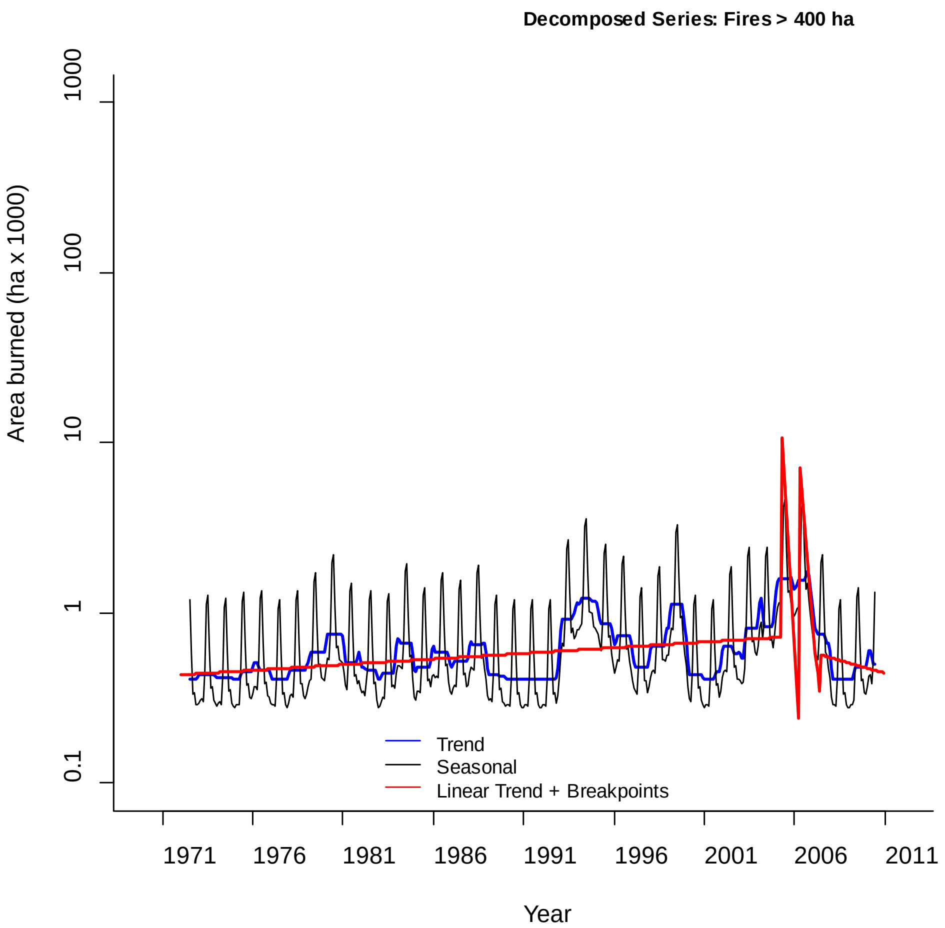
How Often Might These Rare Events Occur?

- Well…it depends
  - But empirically derived probabilities suggest every several decades or century (at the outside)
  - Assumes recent events are not anomalous and will be representative of future conditions
  - If this assumption has merit it implies years such as 2005 and 2006 will not be such rare events



Temporal Patterns In Fire Occurrence

- Summary
  - Number of fires and area burned have increased in the Mojave 1972-2010
  - Not a smooth increase
  - Irruptive pattern
    - Indication of state change?
  - Driven by precipitation but not ignition
  - Frequency of “rare events” could become more common



Bridging The Temporal And The Spatial

- When and where are the fires occurring?
  - Lightning was not a good predictor of temporal patterns of burning
    - Areas of concentration jump around so much
  - But averaging across time, there are clearly areas of lightning concentration
  - Guess where the burns are
  - But lightning also lines up with precipitation patterns
  - Ignition and precipitation!