Empirical Global Fire Regimes Identify Common Fire Relationships Across the Planet

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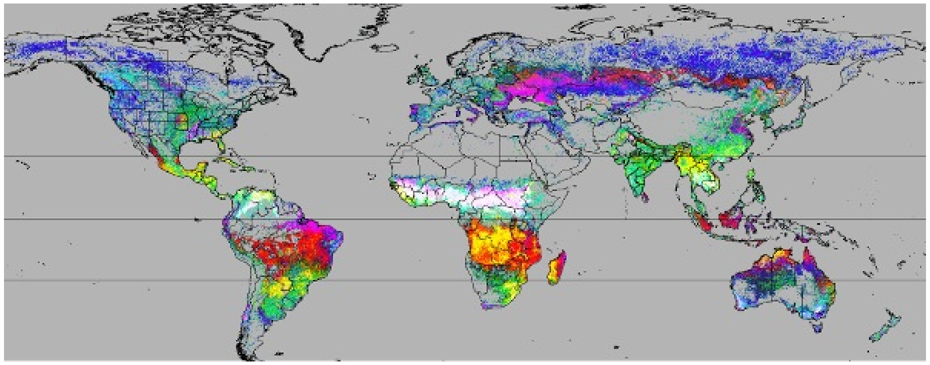


Slides available at
https://www.geobabble.org/~hnw/first/rubisco

Definition of Fire Regimes

A fire regime is the spatial pattern, frequency, and intensity of wildfires that prevail in an area over long periods of time. A fire regime describes the spatial and temporal patterns of fire on the landscape, and provides an integrative approach to identifying ecological impacts of fire at the landscape level.

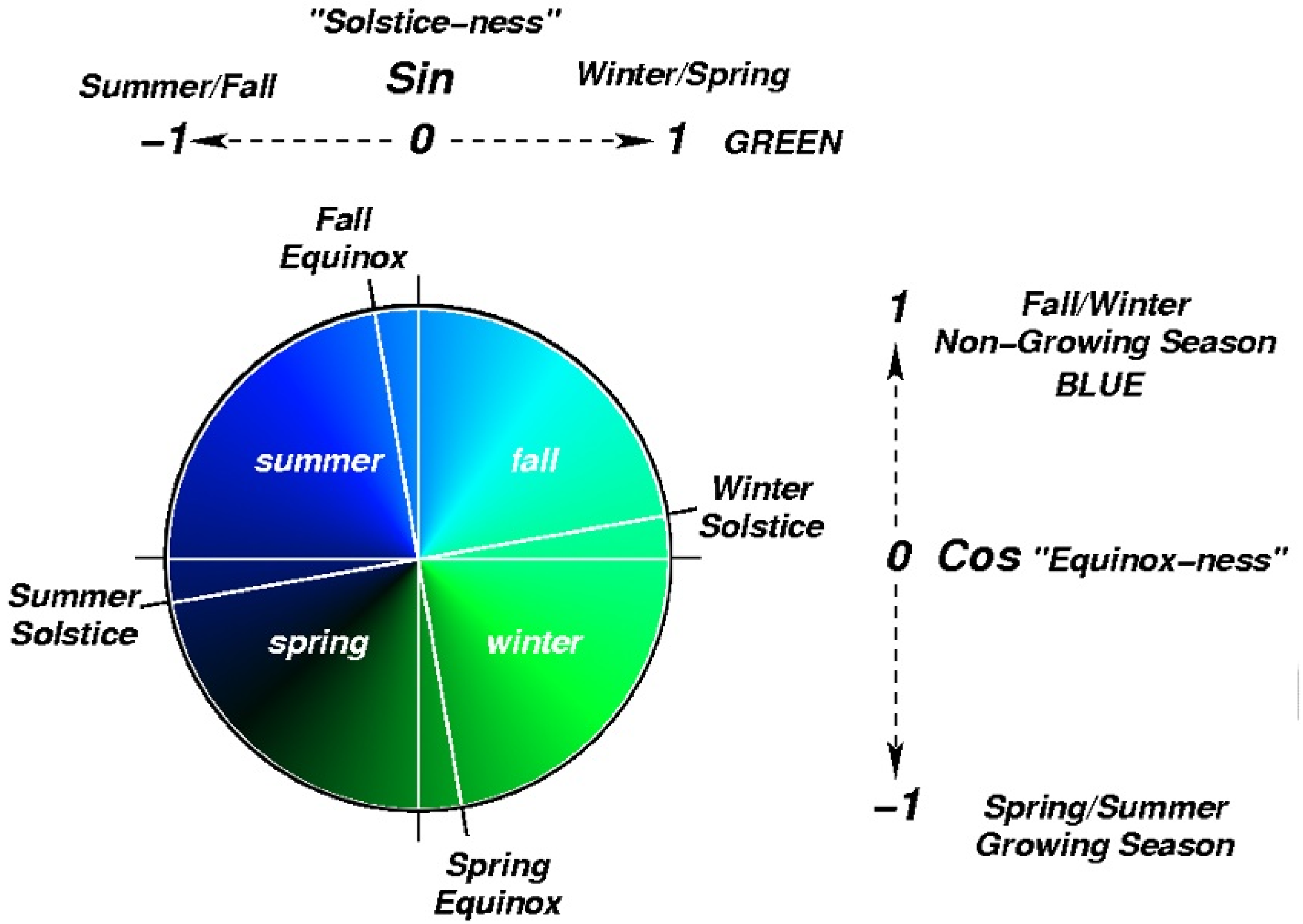
Important Components of Fire Regimes:

1. **Within-Year Fire Seasonality**
2. **Between-Year Fire Frequency**
3. **Fire Intensity**

Fire Regimes can be used in the same ways that Ecoregions are used, and are just as useful

Like Ecoregions, Fire Regime maps are often drawn by hand, using expert opinion, or sometimes by simple GIS intersection of vegetation and climate maps

Here we delineate Global Fire Regime maps empirically, using a statistical process of Multivariate Geographic Clustering



Northern and Southern Hemispheres experience seasons oppositely. We developed a new mathematical date-transform to synchronize seasons with respect to the date of greatest local solar declination. Fire hotspot dates were encoded as sine-cosine pairs to preserve the annual cycle. Using green for sine and blue for cosine represents the "Equinox-ness" and the "Solstice-ness" of the date, respectively.

Synchronizing Seasons Across Hemispheres

The same season happens roughly 180 days apart in northern and southern hemispheres

We add 91.25 days to temperate northern hemisphere hotspot dates, and subtract 91.25 days from temperate southern hemisphere dates, to "split the difference" between hemisphere seasons.

Within tropical latitudes, we calculate a continuous date correction, based on latitude, that decreases from 91.25 days at the Tropic of Cancer down to zero at the equator. We use a symmetrical inverse function in the southern tropics to go from zero back up to 91.25, seamlessly.

Because we split the seasonal difference between hemispheres, the annual cycle must be rotated 90 degrees earlier by one season to indicate the correct DOY on the clustered Global Fire Regime maps.

This Seasonal Synchronization Date Transform is the only way to let, say, summer fires cluster with summer fires, irrespective of the month they occurred.

Allows the same Global Fire Regimes to link up and bridge across both northern and southern hemisphere locations

A "Big Data" Empirical Approach to Global Fire Regimes

The two MODIS sensors make four overpasses per day, have a 1km resolution infrared thermal detector that can detect actively burning fire "hotspots" -- Used a supercomputer at Oak Ridge National Laboratory to analyze *more than 83 Million MODIS "hotspots"* detected over an 18 year period from 2002-2019 (Collection 6)

Summed all MODIS thermal detections within 10km global land cells using a Lambert Conformal Conic equal-area map projection

Calculated 21 higher-order derived variables describing the characteristics of the hotspot population within each 10km cell

Sines and Cosines were used to encode the "Solstice-ness" and "Equinox-ness" of dates for the top six Bi-Weeks, or two-week long intervals, containing the greatest number of fires. Only the rank order of the top six Bi-Weeks was used; actual fire frequency was not included.

Submitted the 21 fire characteristics to Multivariate Geographic Clustering to classify cells into similar Global Fire Regimes (GFRs) -- Seven different GFR maps were generated showing the most different 10, 20, 50, 100, 500, 1000, and 3000 Global Fire Regimes worldwide

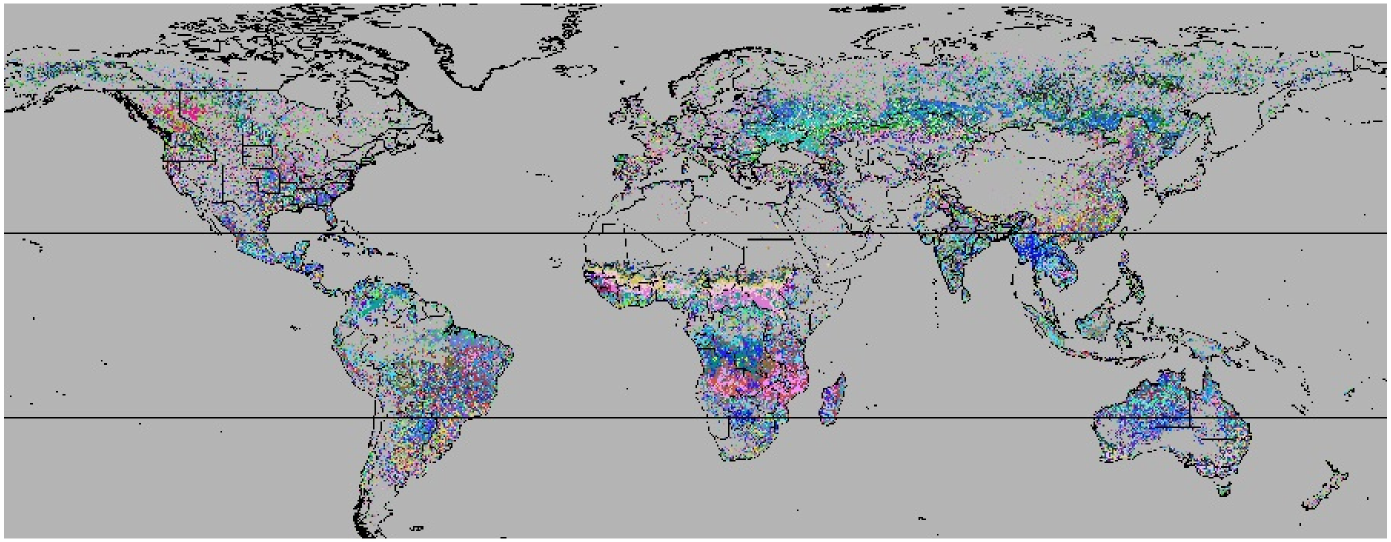
GFRs need not be spatially contiguous, and parts of a single GFR could be widely separated in geographic space

MODIS "Hotspot" Variable Name	21 MODIS "Hotspot" Fire Characteristics
	Within-Year Fire Seasonality
bw1sin	Sine of Date of Maximum Fire Frequency for Bi-Week #1, Indicating "Solstice-ness"
bw1cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #1, Indicating "Equinox-ness"
bw2sin	Sine of Date of Maximum Fire Frequency for Bi-Week #2, Indicating "Solstice-ness"
bw2cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #2, Indicating "Equinox-ness"
bw3sin	Sine of Date of Maximum Fire Frequency for Bi-Week #3, Indicating "Solstice-ness"
bw3cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #3, Indicating "Equinox-ness"
bw4sin	Sine of Date of Maximum Fire Frequency for Bi-Week #4, Indicating "Solstice-ness"
bw4cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #4, Indicating "Equinox-ness"
bw5sin	Sine of Date of Maximum Fire Frequency for Bi-Week #5, Indicating "Solstice-ness"
bw5cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #5, Indicating "Equinox-ness"
bw6sin	Sine of Date of Maximum Fire Frequency for Bi-Week #6, Indicating "Solstice-ness"
bw6cos	Cosine of Date of Maximum Fire Frequency for Bi-Week #6, Indicating "Equinox-ness"
burnsbi	Length of Longest Continuous "Run" of Bi-Weeks with fire in this 10km cell
unbrnbi	Length of Longest Continuous "Run" of Bi-Weeks without fire

	in this 10km cell
	Between-Year Fire Seasonality
numyrsw2	Number of Years with two or more **MODIS** "Hotspots" in this 10km cell
runburns	Length of Longest Continuous "Run" of Years with fire in this 10km cell
rununbrn	Length of Longest Continuous "Run" of Years without fire in this 10km cell
	Fire Intensity
meantemp	Mean Temperature of **MODIS** "Hotspots" in this 10km cell
maxtemp	Maximum Temperature of **MODIS** "Hotspots" in this 10km cell
mintemp	Minimum Temperature of **MODIS** "Hotspots" in this 10km cell
numhspts	Number of **MODIS** "Hotspots" in this 10km cell

GFRs=Global Fire Regimes

100 Global Fire Regimes - Random Colors



The 100 Most-Different Global Fire Regimes, colored with Random Colors.

Random colors accentuate the borders, the edges between GFRs.

Gray areas do not have enough fires to define a "Fire Regime"

But it is hard to see much detail at this global scale ...
Would have been even harder with 3000 GFRs ...

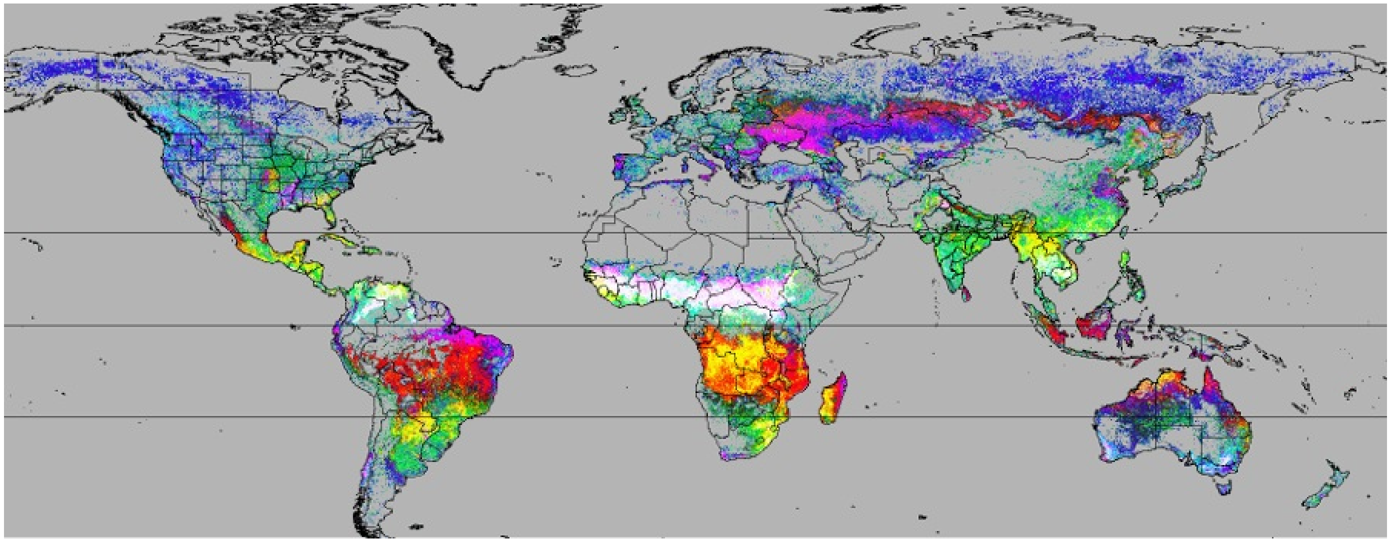
Principal Component Factor Loadings for MODIS "hotspot" Characteristics Used to Statistically Delineate Global Fire Regimes. Yellow highlight indicates the Principal Component having the greatest loading for each of the 21 variables. Runs of Bi-Weeks burning, Number of Years with fire, Runs of Years with fire, Maximum Temperature of burn, and Number of "Hotspots" per cell load on Factor 1, interpreted as "Repeat Burnability." Runs of Years not burning and Minimum Temperature of burn loaded negatively on this "Repeat Burnability" Factor 1. Sines and Cosines of dates for each of the top six Bi-Weeks loaded on Factor 2 and Factor 3, respectively, interpreted as "Solstice-ness" and "Equinox-ness" for dates of "Within-Year Fire Seasonality". Fire frequency counts during each Bi-Week were not included, only the rank order and date. Runs of Bi-Weeks not burning loaded negatively on Factor 2, "Solstice-ness," indicating less likelihood of long runs of unburned Bi-Weeks during Winter/Spring. Mean Temperature of fire hotspots showed no preferred Factor loading, unlike Max and Min.

MODIS "Hotspot" Variable Name	Rotated Factor Pattern, First Three Principal Components		
	Factor 1	**Factor 2**	**Factor 3**
	Within-Year Fire Seasonality		
bw1sin	0.05690	0.84426	-0.00683
bw1cos	-0.00455	0.01093	0.78642
bw2sin	0.02060	0.84823	0.02057
bw2cos	-0.03076	0.01343	0.78811
bw3sin	-0.00518	0.82768	0.04217
bw3cos	-0.04566	0.01229	0.76897
bw4sin	0.00415	0.78211	0.06910
bw4cos	-0.06717	0.02758	0.72738
bw5sin	0.02724	0.70154	0.08167
bw5cos	-0.08218	0.03298	0.68151
bw6sin	0.04469	0.60702	0.06984
bw6cos	-0.10576	0.06783	0.61143
burnsbi	0.82608	0.11633	-0.27689
unbrnbi	0.38140	-0.54920	0.25199
	Between-Year Fire Frequency		
numyrsw2	0.95445	0.14845	-0.12325

runburns	0.93046	0.15147	-0.10319
rununbrn	-0.92507	-0.14432	0.13148
		Fire Intensity	
meantemp	0.14626	-0.04672	-0.07122
maxtemp	0.38976	-0.14682	-0.03699
mintemp	-0.48266	0.04835	-0.07209
numhspts	0.33918	0.01127	0.04697

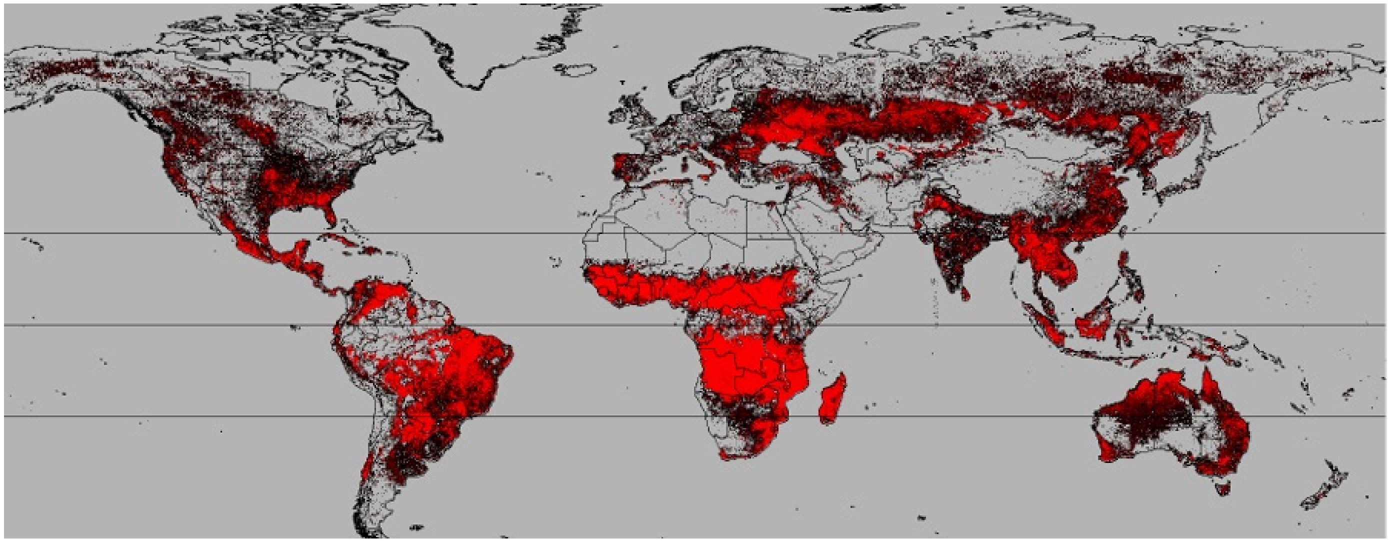
GFRs=Global Fire Regimes. SAS PROC FACTOR used with Equamax rotation

3000 Global Fire Regimes - Similarity Colors



The 3000 Most-Different Global Fire Regimes, colored with Similarity Colors. Now the map makes a lot more visual sense, even at this global scale. Similarity Colors show similar mixtures or combinations of the 21 fire conditions within each GFR, but completely hide the borders between GFRs. Redness shows "Repeat Burnability" characteristics, and green-blue-ness shows "Seasonality" characteristics. White and brighter areas are large levels of all three colors, and dark colors are lower levels.

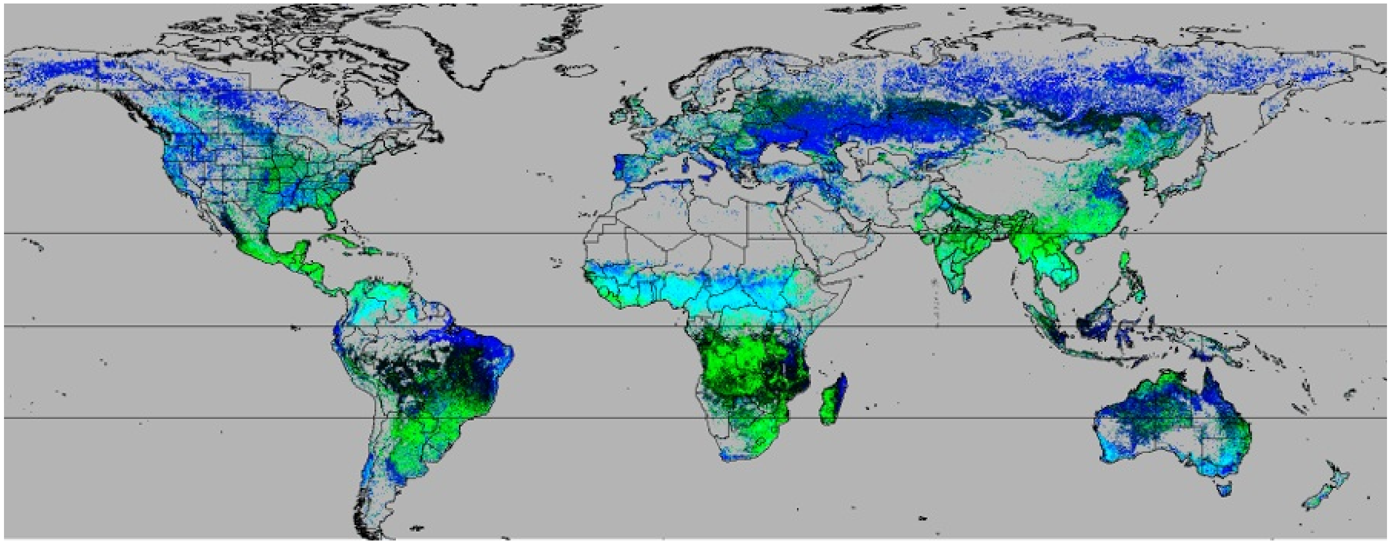
3000 Global Fire Regimes - Repeat Burnability Colors



The 3000 Most-Different Global Fire Regimes, colored with Red-ONLY Repeat Burnability Colors. This is the RED part of the Similarity Colors ONLY, and the black-to-red color shows the relative likelihood for intense and repeated fire, both within and between years.

This is the same underlying 3000 GFR map as before, only the Similarity Colors are different.

3000 Global Fire Regimes - Within-Year Seasonality Colors



The 3000 Most-Different Global Fire Regimes, colored with Green-Blue ONLY Annual Seasonality Colors. This GREEN and BLUE part of the Similarity Colors shows the seasonal timing of fire during the year.

Blue = summer fire max

Cyan = fall fire max

Green = winter fire max

Black = spring fire max

Shows common seasonality, despite the alternating seasons across hemispheres

This is the same underlying 3000 GFR map as before, only the Similarity Colors are different.

A Purely Empirical Result

We did not manually draw the regions nor manually select the colors used for these maps

We did not force the interpretable statistical loading of the 21 fire characteristics onto the top three Factor Scores

Global Fire Regimes were delineated and colored statistically, based entirely on quantitative data

All 21 fire variables were derived from a single, consistent data source, all MODIS hotspot observations, 2002-2019

Other than selecting the 21 constructed input variables, few expert opinions were employed

The methods are repeatable; anyone starting with these data using these methods would obtain identical results

Transparent; all data are quantitative and open to inspection

Most Global Fire Regimes are Shared, Few are Unique

96% of the 3000 GFRs are shared between N and S Hemispheres (so the Seasonal Date Transform works!)

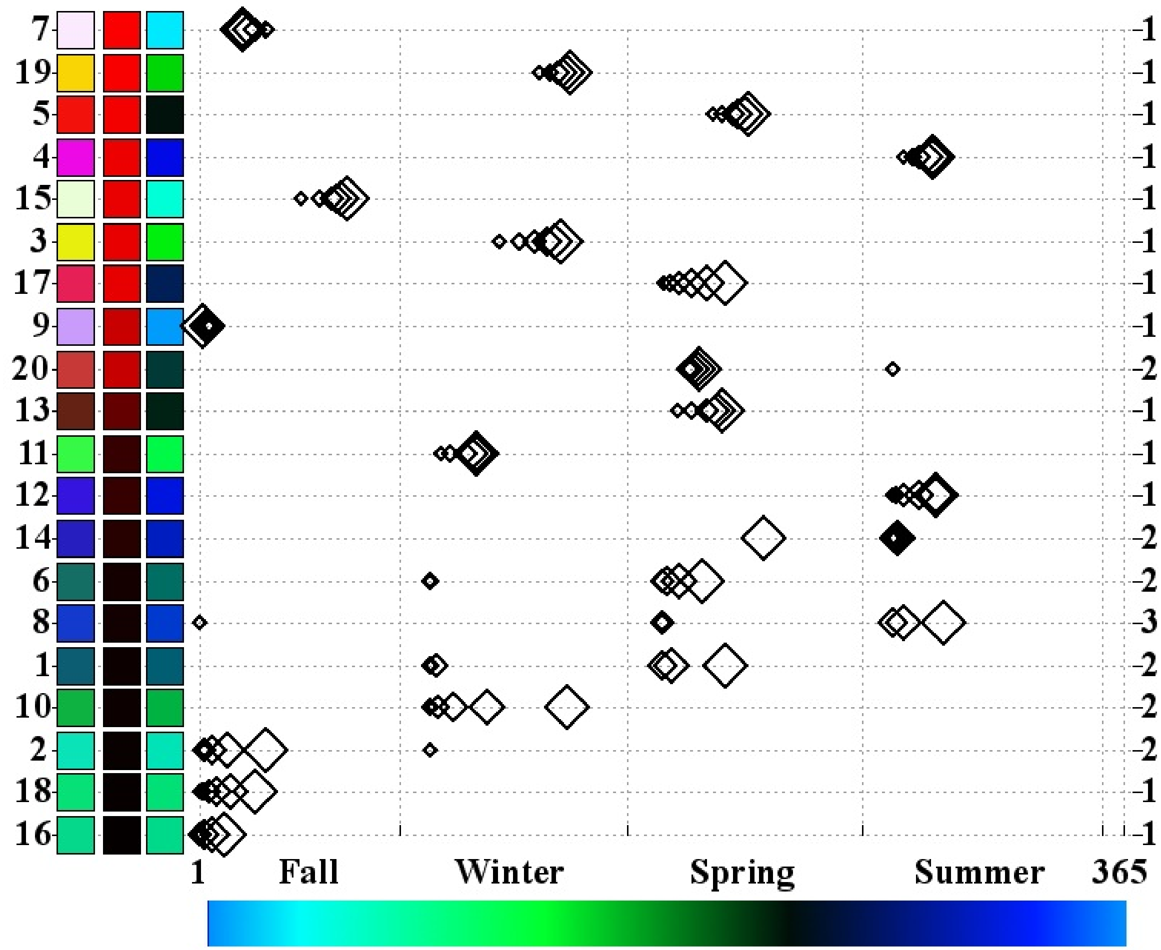
Greater land area leads to more unique GFRs in the Northern Hemisphere (88) than in the Southern Hemisphere (22)

97% of the 3000 GFRs are shared between Eastern and Western Hemispheres

72 GFRs are unique to the larger Eastern Hemisphere, none are only in the Western Hemisphere

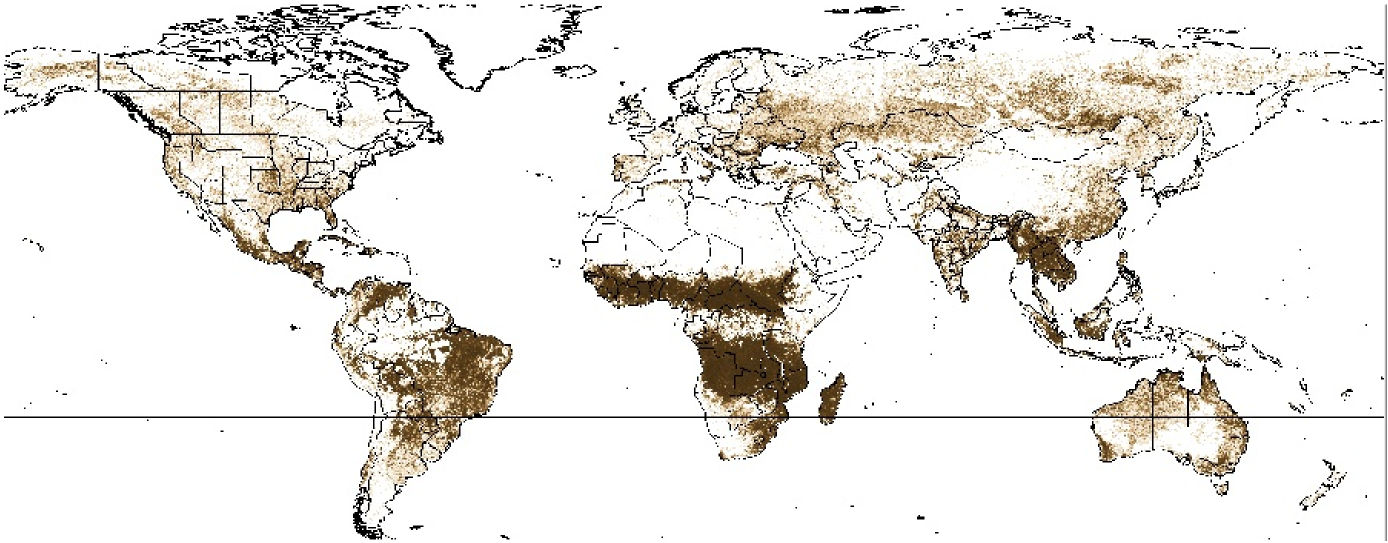
Most of the seven continents contain NO unique GFRs. Africa has 22 unique GFRs, and Asia has one that is unique

World Fire is more alike than different!



Seasonality Characteristics of the 20 Most-Different Global Fire Regimes. GFR cluster numbers at left. Leftmost color column is **Similarity Colors, from the Principal Components**. Middle color column shows only the **RED component**, which is **"Repeat Burnability,"** sorted from most to least. Right column shows only **BLUE and GREEN components**, which is **"Seasonality."** The annual timeline shows dates for the **top six biweeks having greatest fire**, the largest diamond is the top fire biweek date. The number at the right shows **how many statistically distinct fire modes this GFR has.**

Strength of Seasonality for 3000 Global Fire Regimes



Strength of Fire Seasonality. Darker colors show areas where the six highest fire frequency biweeks are strongly synchronized, so that fires occur near a single date. This map also strongly resembles a map of GFRs having one or two annual maximum frequency modes. Areas of strongest fire seasonality correspond well with the Koppen climate map for Tropical monsoonal dry winter (Aw) climates. In these areas, strong seasonal precipitation patterns tightly constrain fires to occurring within one or two narrow date ranges each year.

These Similarity Colors look impressive, but how do we know these GFRs actually work?
How would they be used?

Manually made 10 "Location Groups" of GFRs -- to demonstrate interpretability and useablity

Picked a global location having a uniform and a unique Similarity Color

Then manually selected and collected multiple GFRs from this area to form a "Location Group" -- like supervised "training"

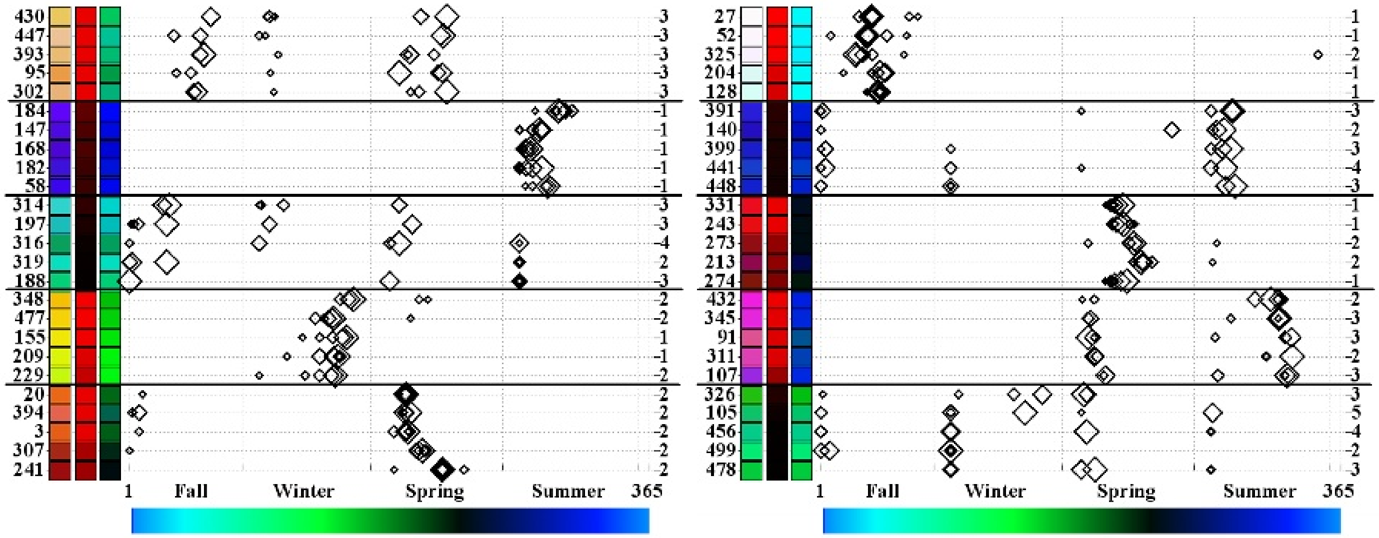
Made all other GFRs transparent and invisible, only showed the GFRs in this "Location Group" across the planet

See where else in the world is also part of this same "Location Group"

Is there a single, common fire ecology interpretation that fits all of these areas?

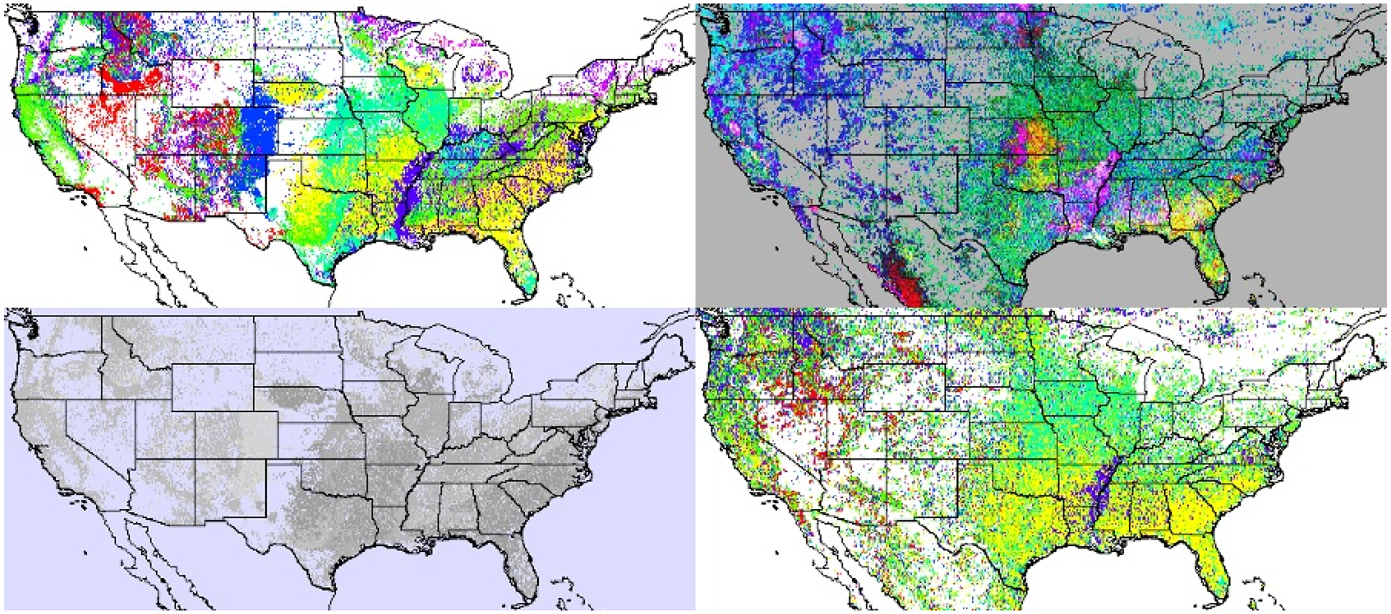
Yes, there is!

Seasonality for Ten "Location Groups" of Global Fire Regimes

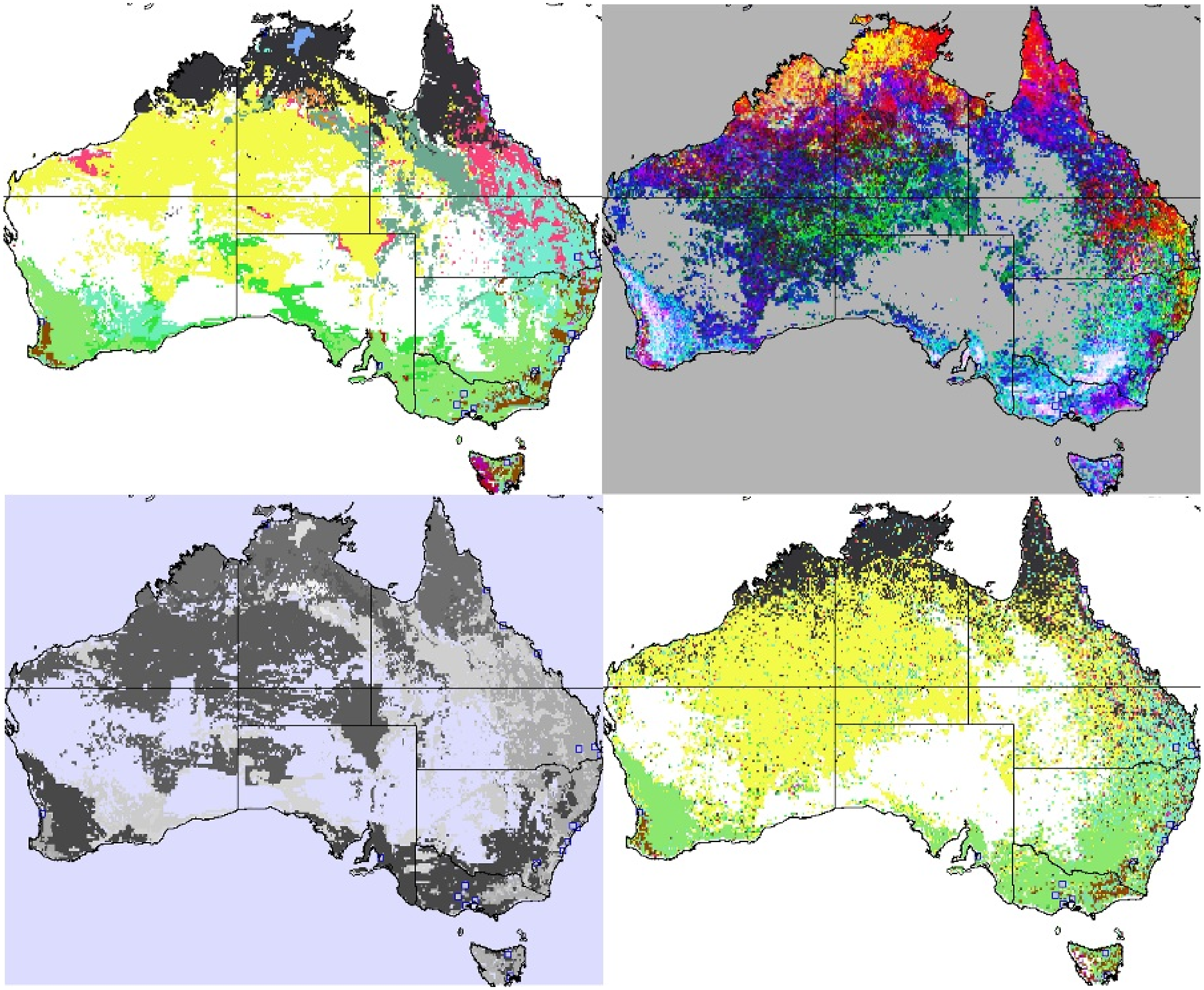


Five typical annual seasonal timelines are shown from each of the ten GFR "Location Groups" described earlier. Each "Location Group," separated by a horizontal line, shows a consistent but distinct pattern of fire seasonality. Some dates are tight, others show greater variability. GFR groupings were formed using the full distribution of all six biweeks. This figure can also be used as a master legend to show seasonality for the global maps.

Comparing 3000 GFRs with Forest Service LANDFIRE CONUS Fire Regime Groups



Mapcurves Goodness-of-Fit (GOF) is 25.1 between the two maps in the top row, after masking out four Fire Regime Groups (II-B, IV-A, V-A, and V-B) having little overlap with GFRs. Lower right map shows GFRs reclassed to resemble LANDFIRE as well as possible. Lower left map shows where darker grays are greater GOFs for each LANDFIRE Fire Regime Group. Maps agree throughout the Eastern US, but GOFs decrease somewhat in the Western US, especially in the southern Central Plains. Expert Fire Regime maps only exist for a couple of continents, but GFRs are global in extent.



Murphy et al. (2013) mapped "Fire Regime Niches" for Australia. Mapcurves Goodness-of-Fit (GOF) is 28.5 between the two maps in the top row, after deleting 3 Fire Regime Niches for which there were no GFR classifications. Lower right map shows how well the GFR map can be made to resemble the Fire Regime Niches map by reclassifying groups of GFRs. Lower left map shows darker grays for greater GOFs. Agreement is good across most of Australia, slightly lower in eastern Australia and Tasmania.

Conclusions -- Global Fire Regimes can Direct and Facilitate Transfer of Fire Knowledge and Understanding

96% of Global Fire Regimes are Shared across different hemispheres of the Earth -- Few are Unique to particular areas only

GFRs can be used to make inferences about the spatial extents over which fire findings might hold true

Like ecoregions, Global Fire Regimes can direct and facilitate the transfer of fire knowledge, research, and understanding within the same or similar GFRs

The Seasonality Synchronization Date Transform is universal -- The same Global Seasonality-Synchronizing Date Transform equation can also work to synchronize ANY date-based phenological or seasonal events between Northern and Southern Hemispheres

For More Information...

- ***These slides are available on the web at:***

  https://www.geobabble.org/~hnw/first/rubisco

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