May 18, 2006, New Orleans

Satellite-derived PM2.5 Emissions from Wildfires for Air Quality Forecast




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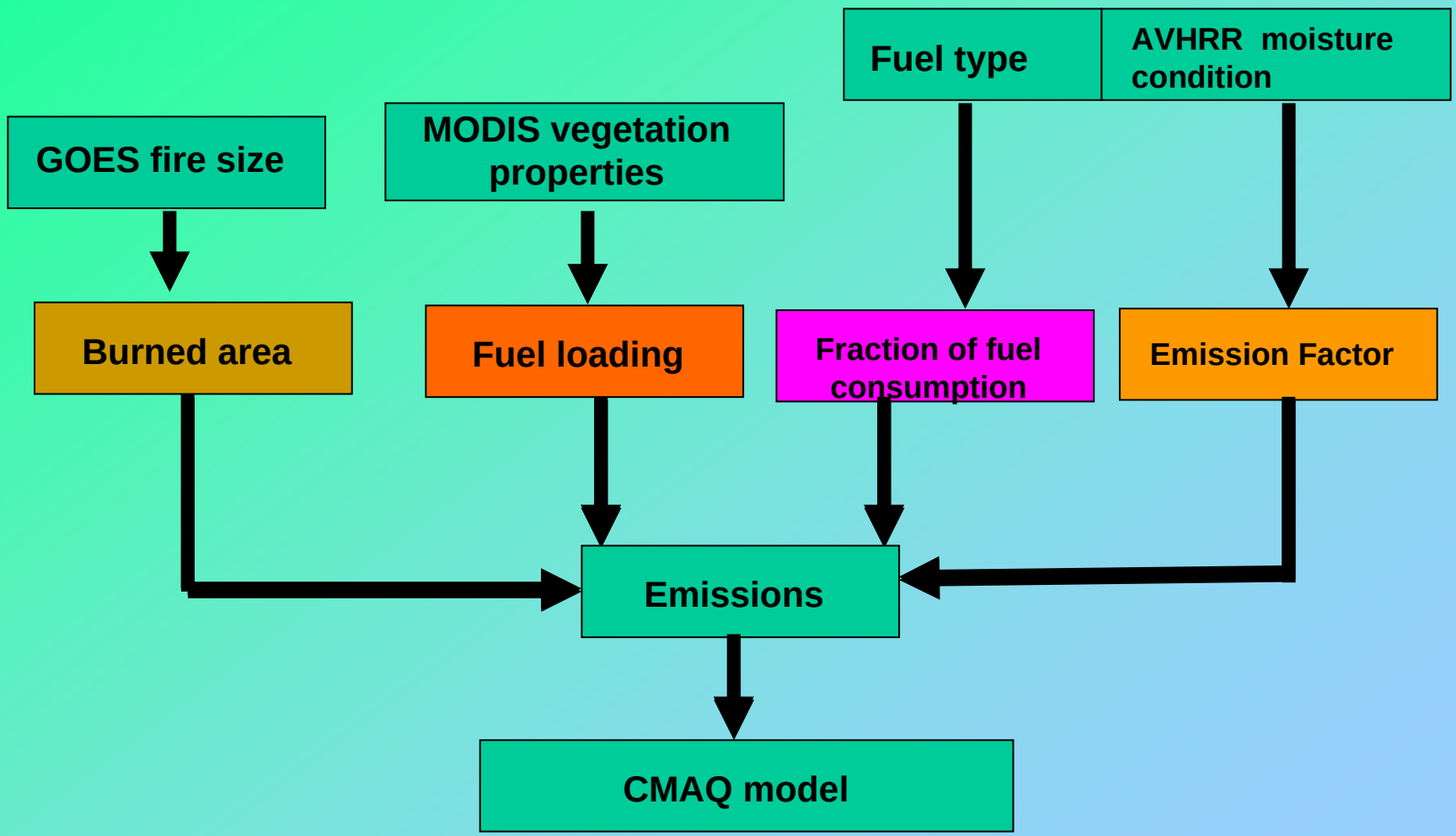
Outline

1. Fuel loading dataset derived from MODIS data
2. AVHRR NDVI-controlled combustion and emission factors
3. GOES fire sizes
4. PM2.5 emissions across the continental USA
5. Summary

Modeling Emissions from Biomass Burning



Model of Biomass Burning Emissions

Standard formula (Seiler and Crutzen, 1980):

$$E = AMCF \qquad (1)$$

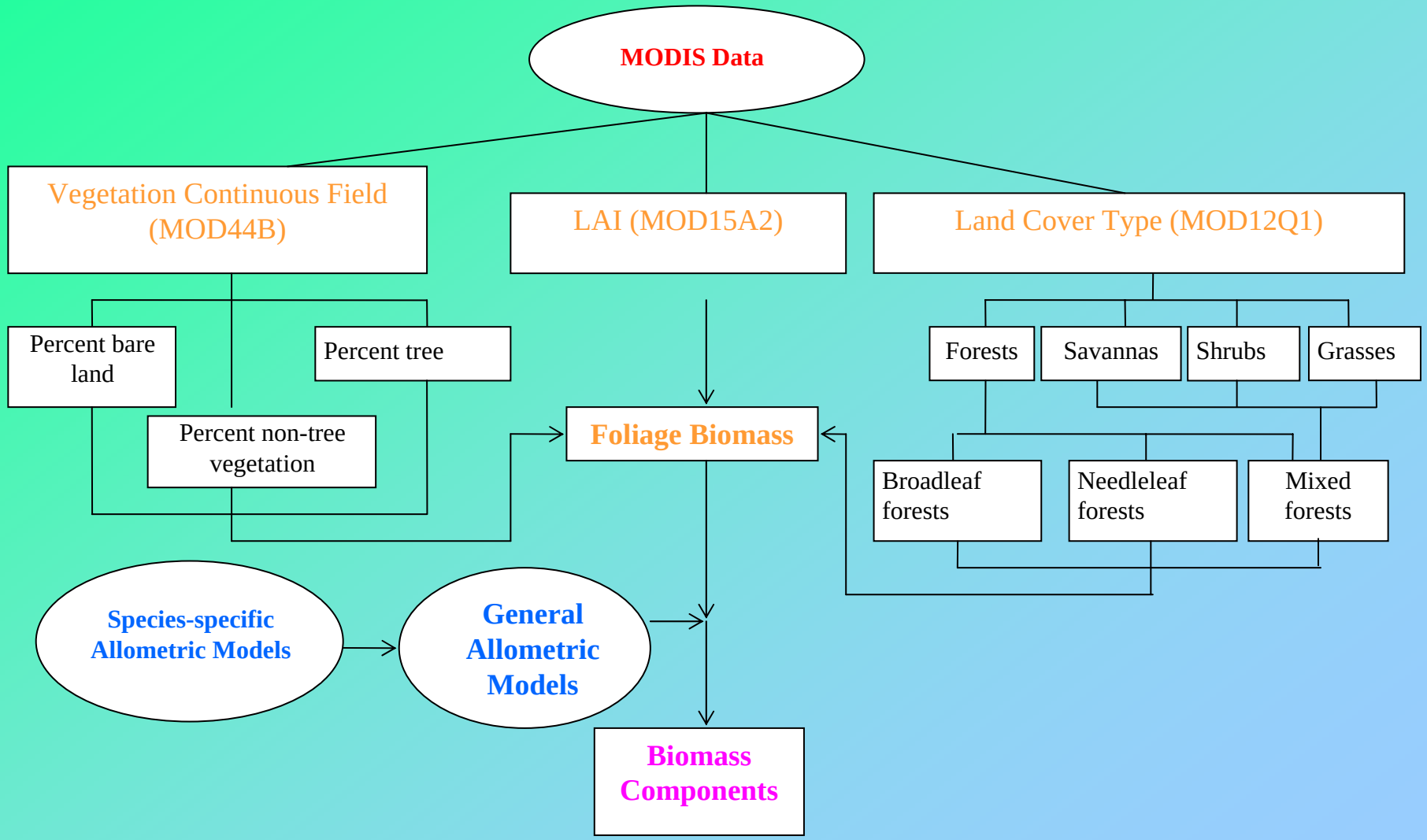
E---biomass burning emissions (kg)
A---burned area (km^2)
M--biomass density/fuel loading ($kg.km^{-2}$)
C--fraction of combustion
F--fraction of emission

Spatial-temporal-distributed formula:

$$E = \sum_{k=1}^{K} \sum_{l=1}^{L} \sum_{j=1}^{J} \sum_{i=1}^{I} A_{ijkl} M_{ijk} C_{ijkl} F_{ijkl} \qquad (2)$$

i and *j* define the fire (pixel) locations
l is the fuel type
k is the time period

Biomass (Live Fuel) Estimates from Generalized Allometric Models and MODIS Data



Foliage-Based Allometric Model

$$M_c = \alpha_1 M_f^{\beta_1} \qquad (3)$$

M_c – Branch biomass or aboveground biomass in a tree (kg)

M_f -- foliage biomass

α_1, β_1 -- coefficients.

Foliage Biomass Derived from LAI

Leaf mass (*Mf*) (kg C/m^2) is calculated using the formula (Heinsch et al., 2003):

$$M_f = LAI/SLA \qquad (4)$$

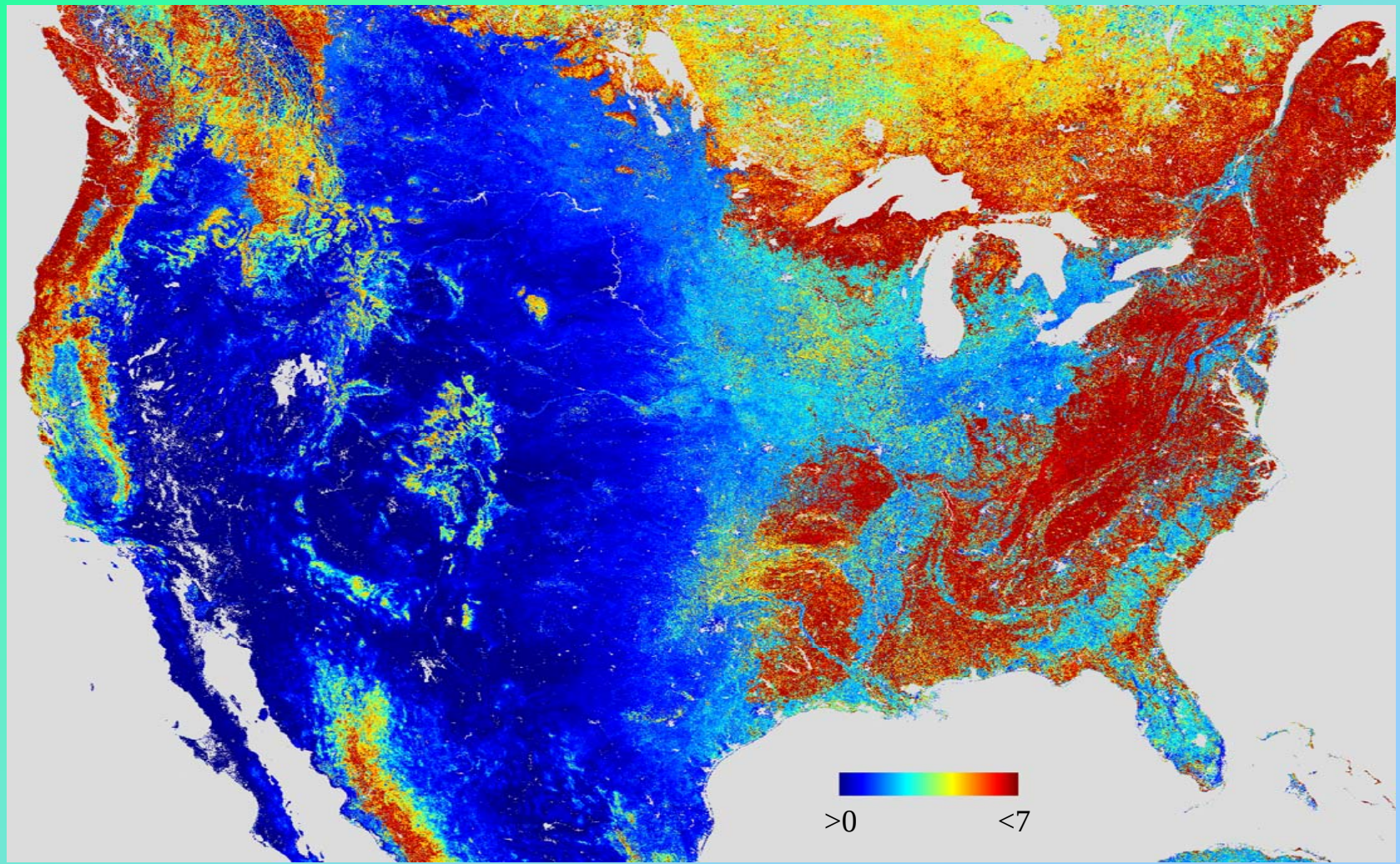
SLA—the specific leaf area (projected leaf area Kg^{-1} leaf C) for a pixel, which is obtained from a look-up table.

LAI--the leaf area index, obtaining from MODIS LAI product.

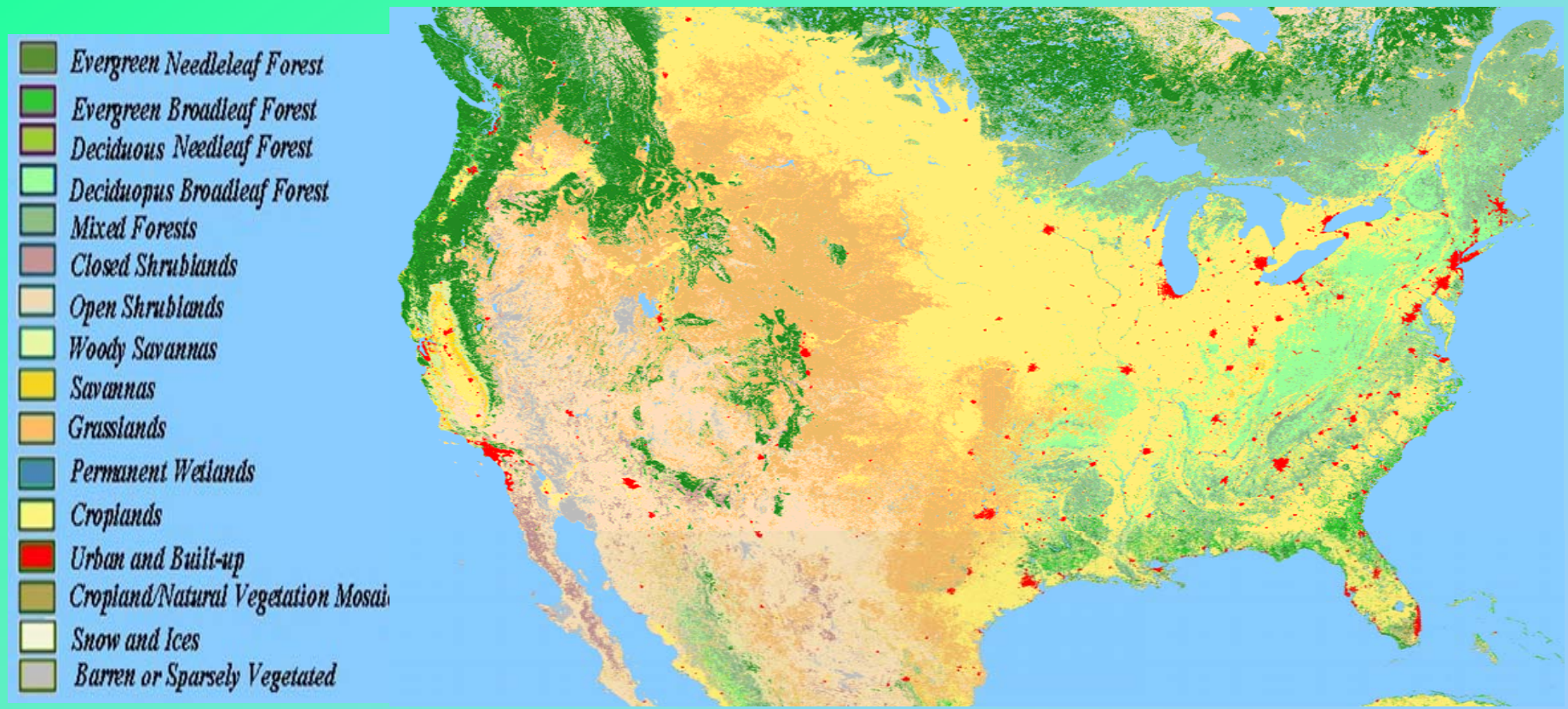
Forest LAI value in sub-pixel is calculated using LAI product, land cover product, and percent tree product.

MODIS Land cover type	SLA
Evergreen Needleleaf Forest (ENF)	21.1
Evergreen Broadleaf Forest (EBF)	23.3
Deciduous Needleaf Forest (DNF)	31
Deciduous Broadleaf Forest (DBF)	26.2
Mixed Forest (MF)	21.5
Grassy woodland (WL)	33.8
Wooded Grassland (Wgrass)	33.8
Close shrub (Closed Shrubland)	12
Open shrub (Open Shrubland)	19
Grass (Grasslands)	40
Crop (Croplands)	36

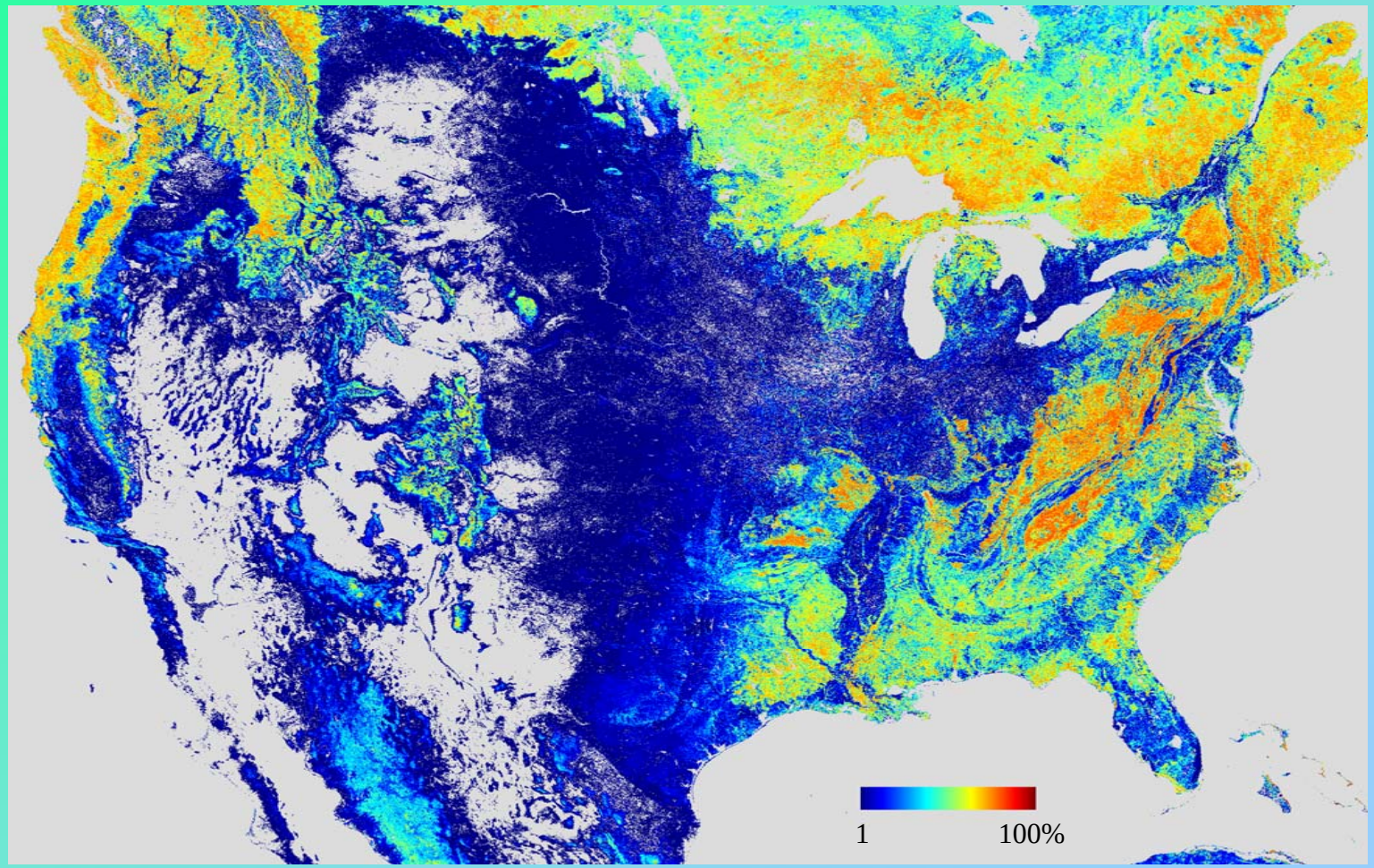
Maximum monthly MODIS LAI in 2002



MODIS Land Cover

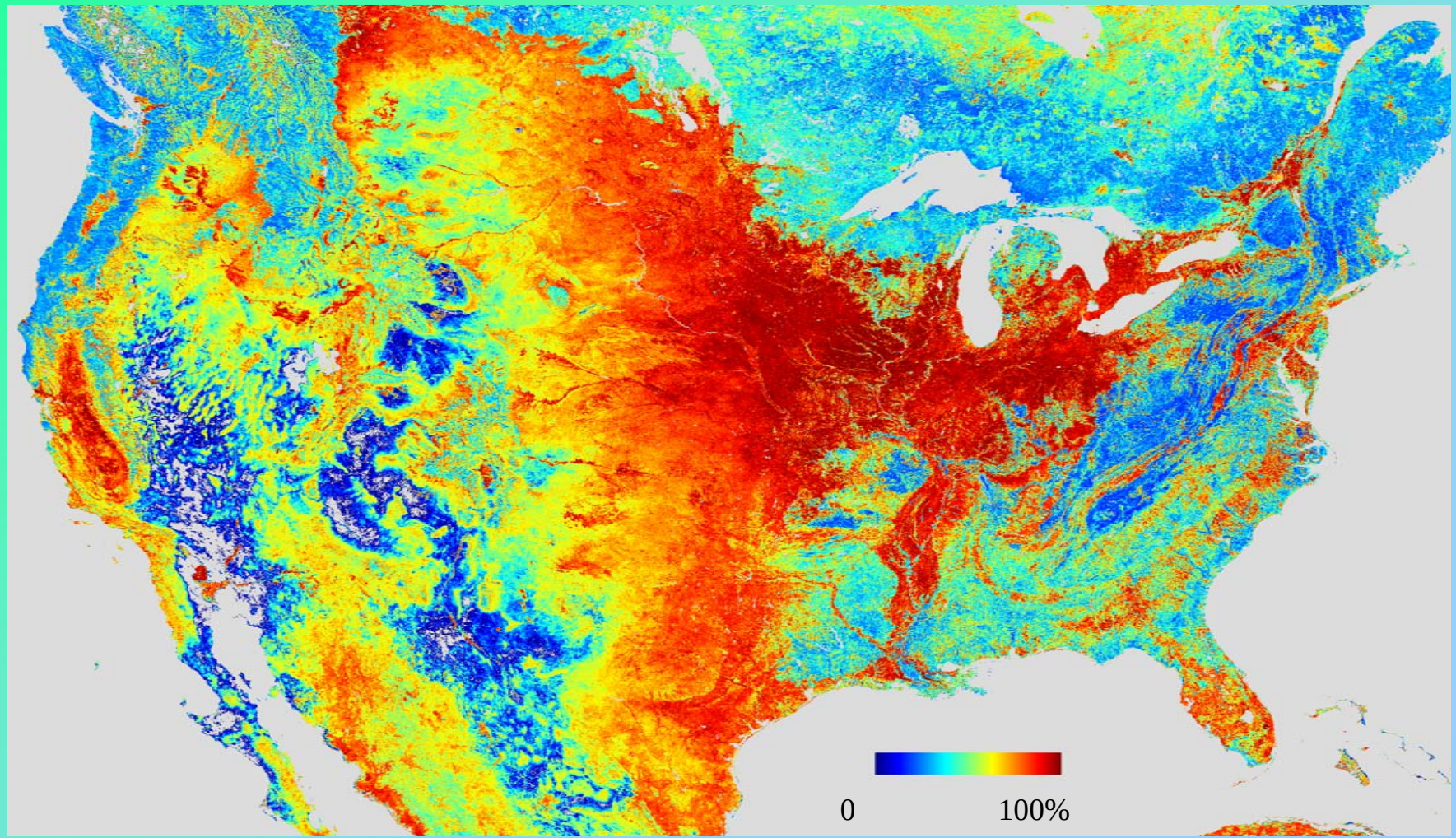


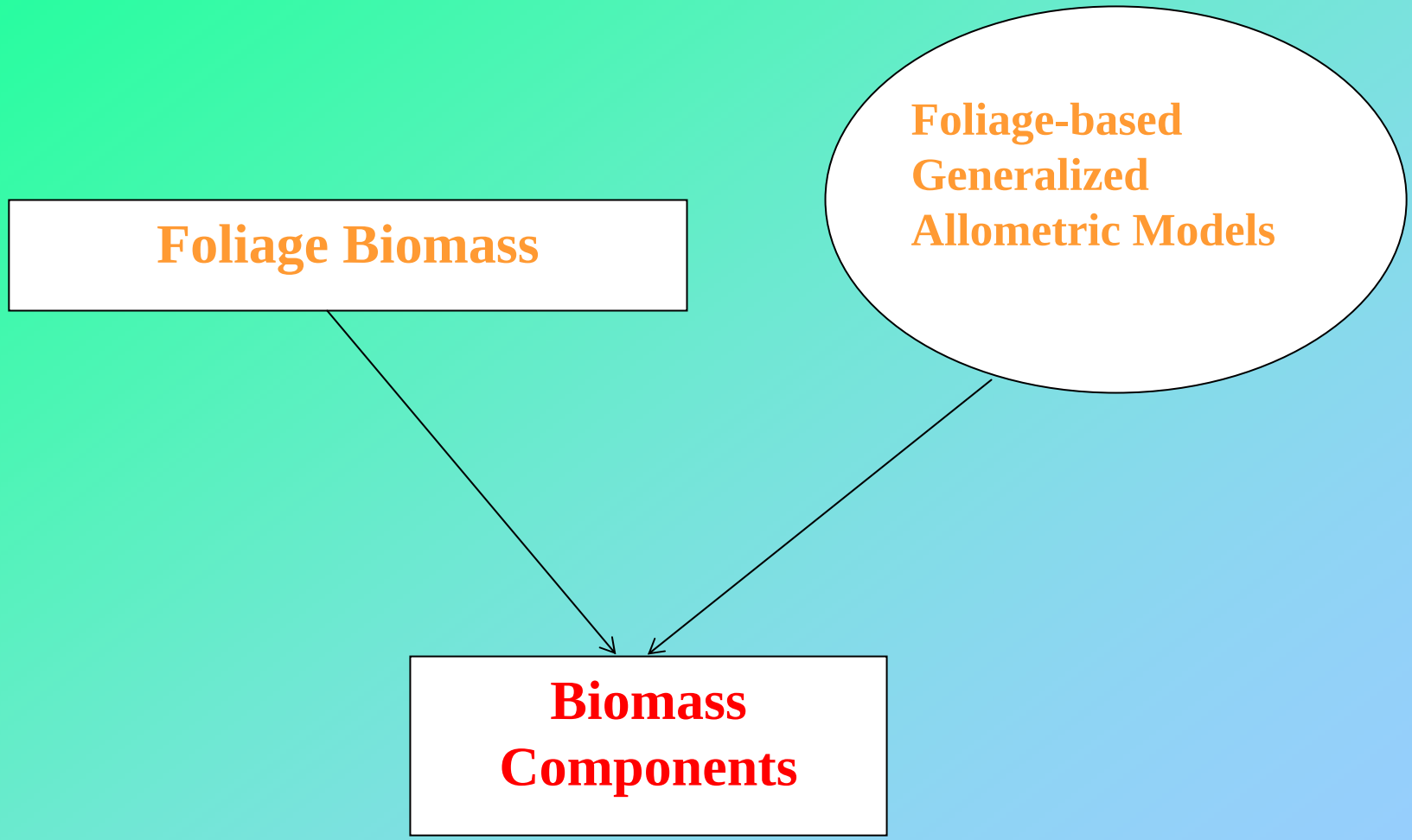
MODIS Percent Tree Cover



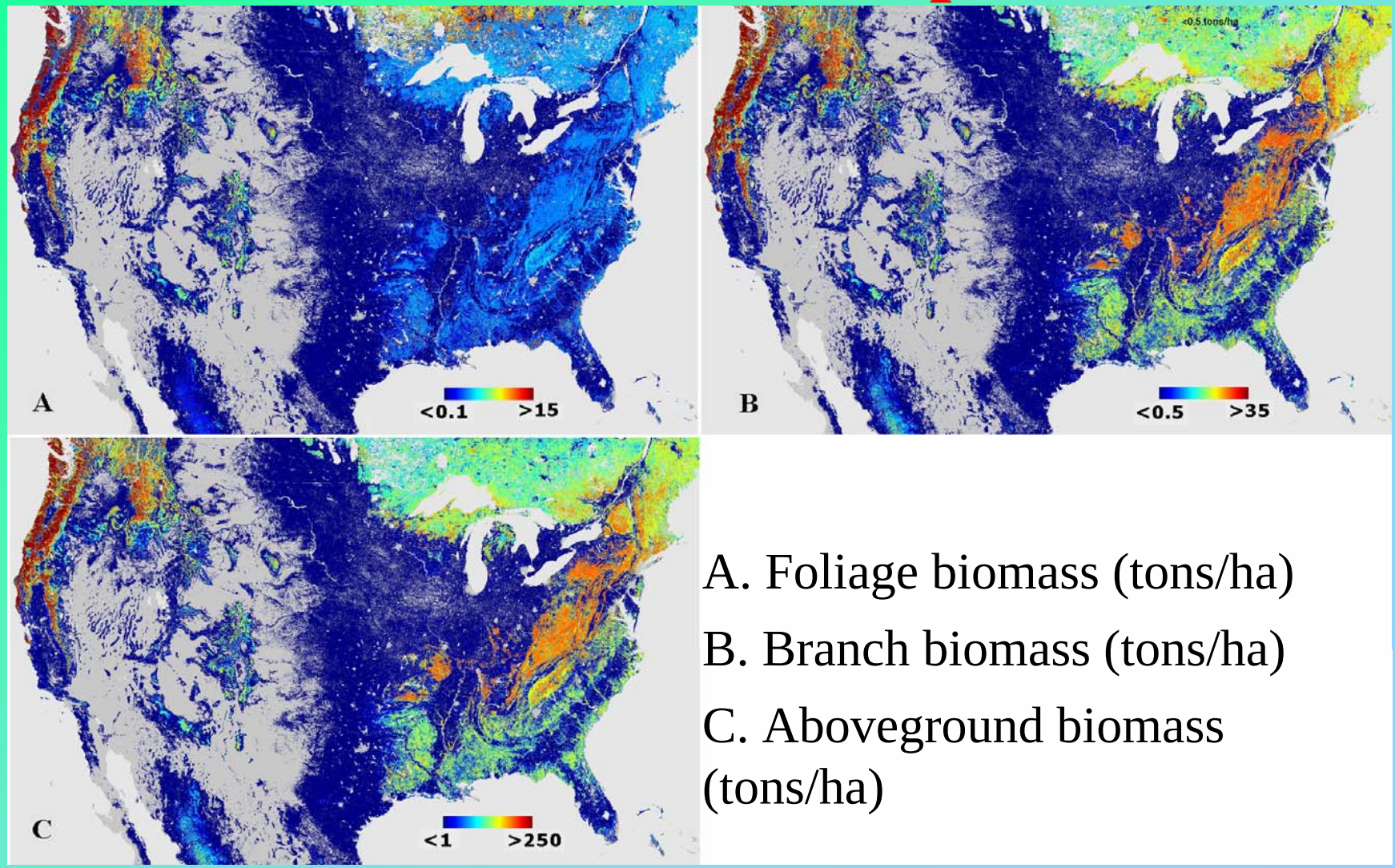
MODIS Percent Nontree Vegetation

(shrubs, crops, and herbaceous)




Foliage Biomass
Foliage-based
Generalized
Allometric Models
Biomass
Components

Tree Biomass Components



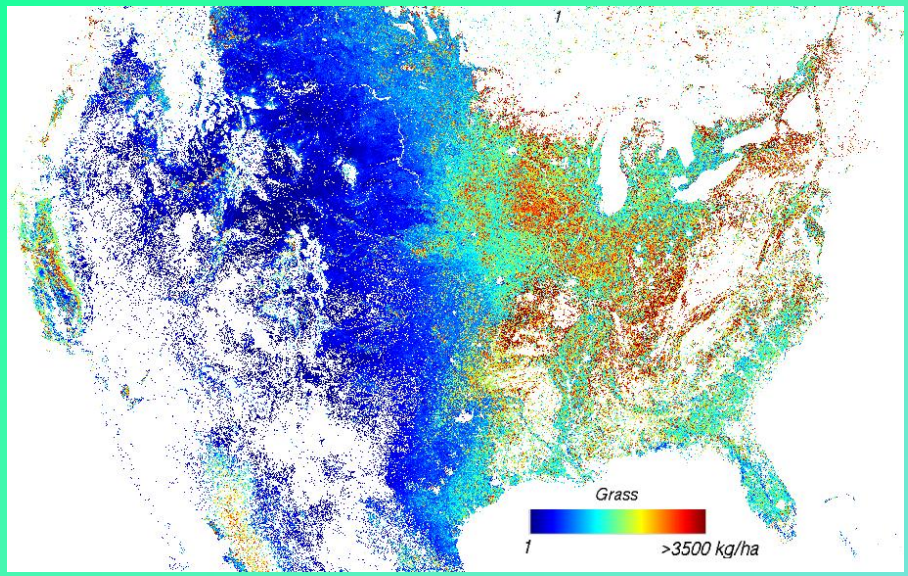
A. Foliage biomass (tons/ha)

B. Branch biomass (tons/ha)

C. Aboveground biomass (tons/ha)

Zhang, X., and S. Kondragunta (2006), Estimating forest biomass in the USA using generalized allometric models and MODIS land products, *Geophysical Research Letter*, 33, L09402, doi:10.1029/2006GL025879.

Biomass in Shrubs and Grasses

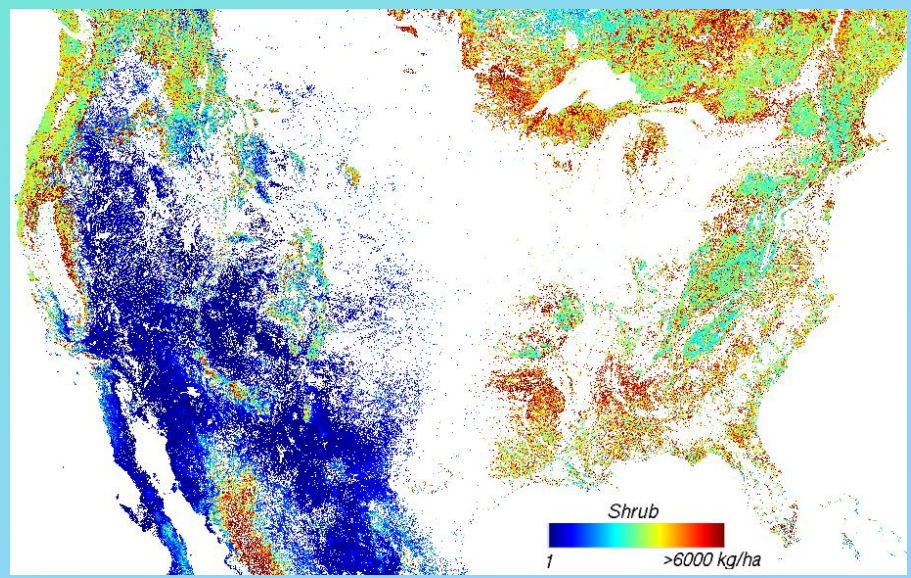


Grass biomass

Total Shrub biomass

$$M_s = 1.09 - 0.02161 V_c + 0.001078 V_c^2$$

(5)



Litter or CWD Estimated Using Land Cover Type and Percent Vegetation Cover

$$M_l = M_{lf} V_{cf} + M_{ls} V_{cs} \qquad (6)$$

M_l— litter or CWD density in a pixel

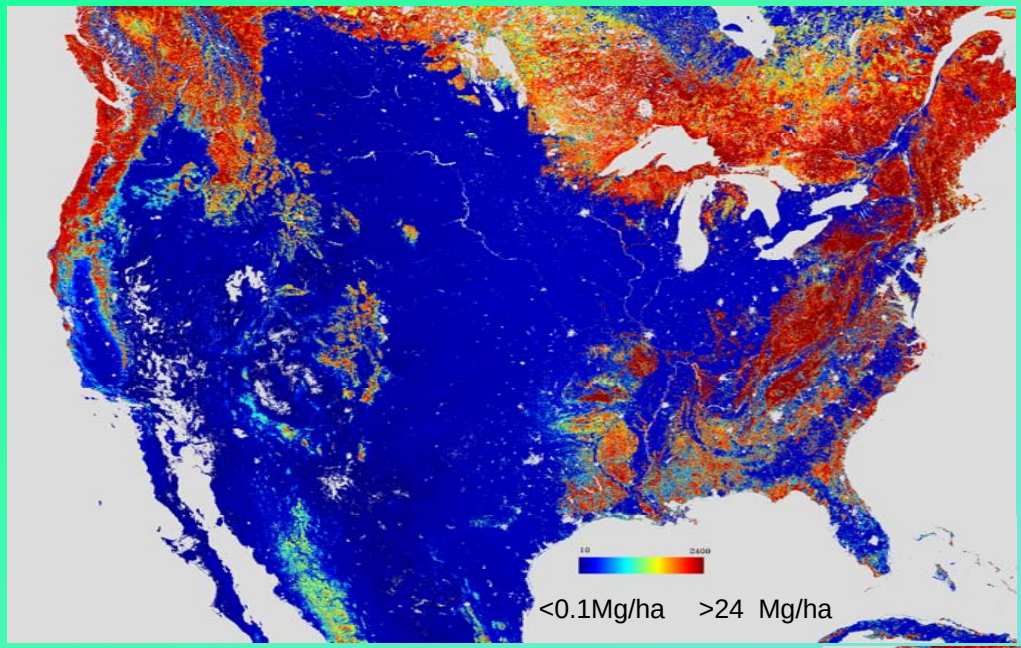
M_{lf} -- litter or CWD density (kg/m^2) for forests changing with forest types

M_{ls}--average litter or CWD density (kg/m^2) in shrubs and grasses

V_{cf} -- tree cover

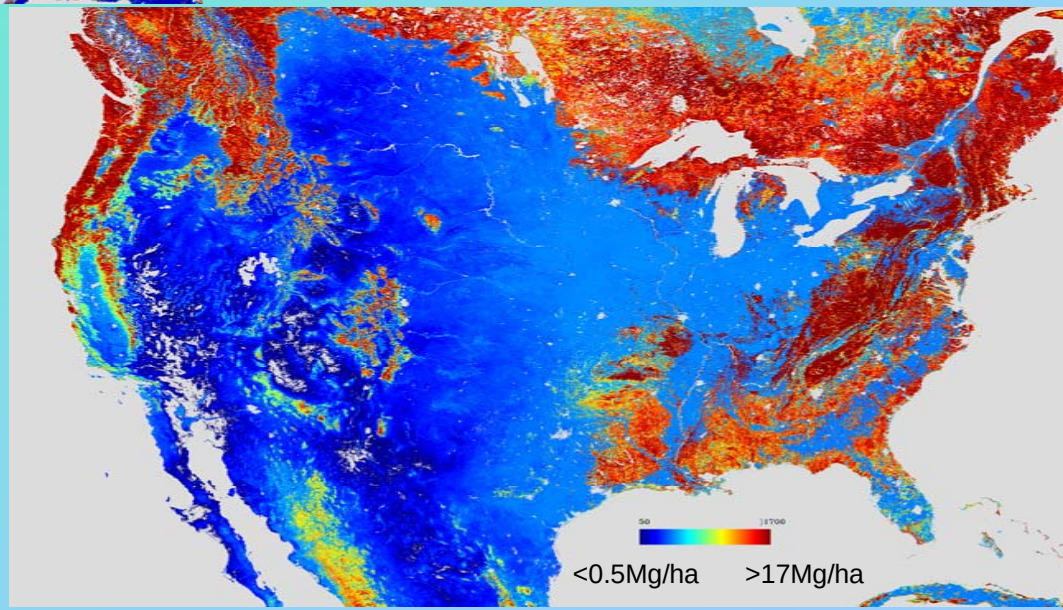
V_{cs} --the non-forest vegetation cover

Fuel Loading from MODIS
— Litter and coarse woody detritus



CWD

Litter



Fuel Moisture Category Factor (MCF) for Determining Combustion and Emission Factors

Moisture Category Derived from AVHRR Global Vegetation Index (4km)

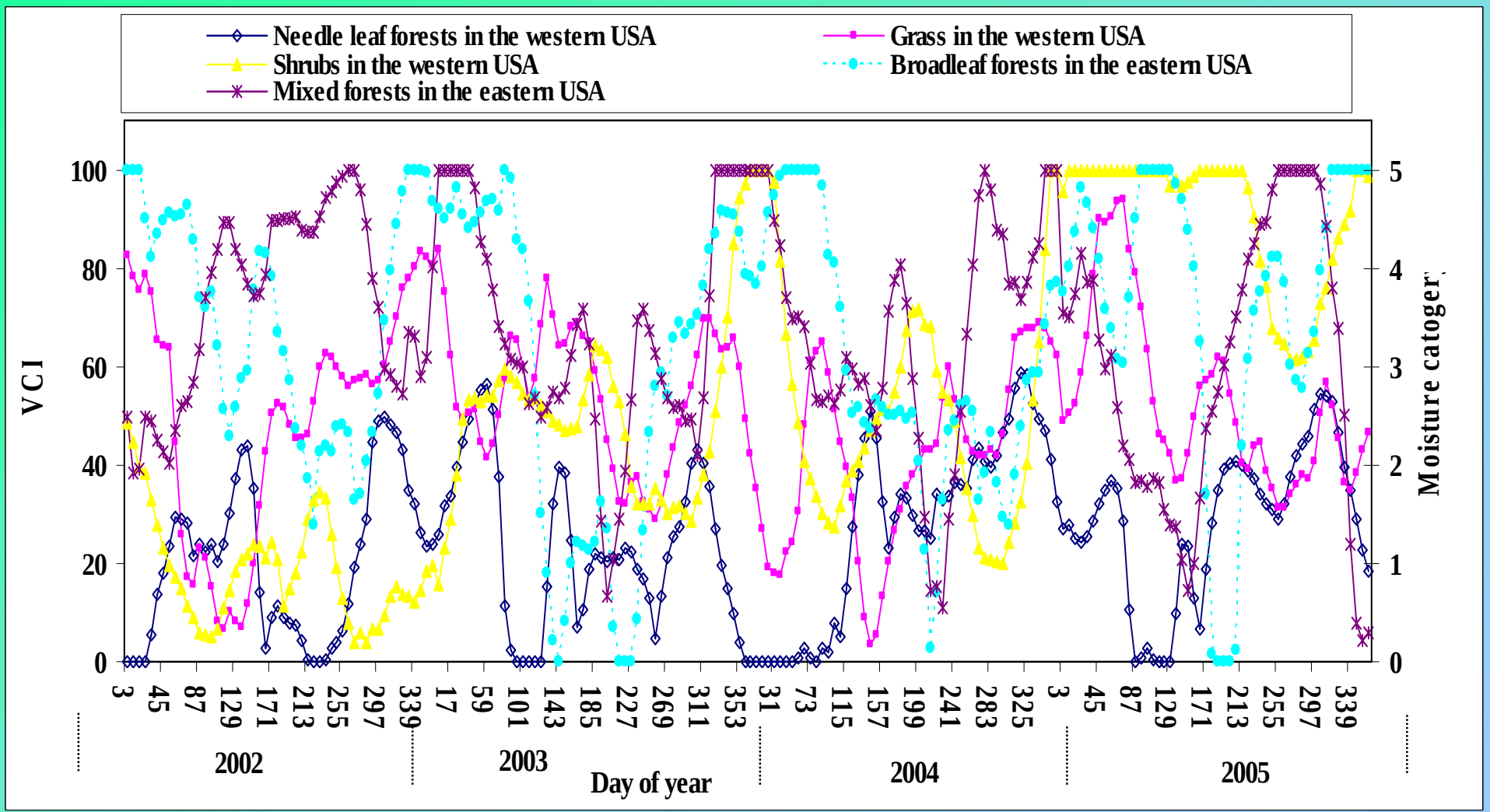
Vegetation health condition (VCI) index (Felix Kogan, 1997) :

$$VCI=100(NDVI-NDVI_{min})/(NDVI_{max}-NDVI_{min}) \quad \text{-------(7)}$$

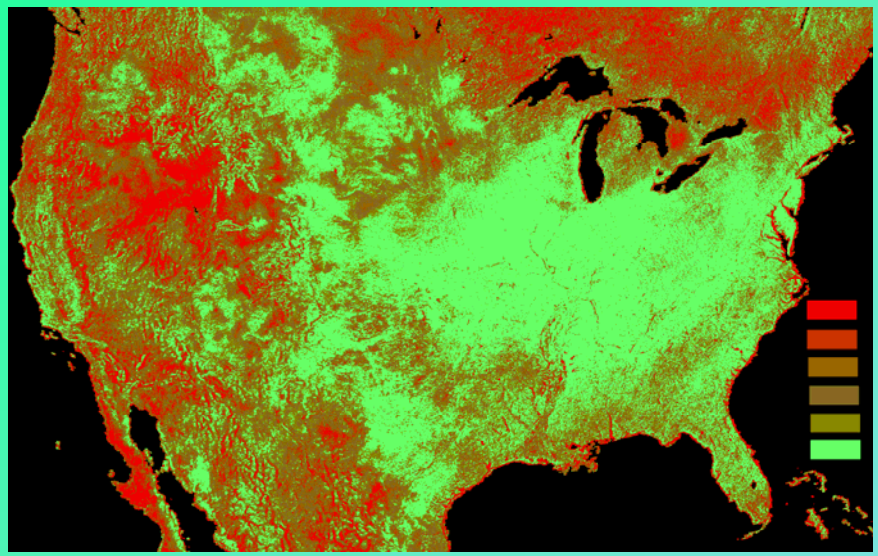
NDVI—Normalized Difference Vegetation Index in a week

$NDVI_{max}$ and $NDVI_{min}$ in a pixel are the weekly maximum and minimum values from1985 to 2005

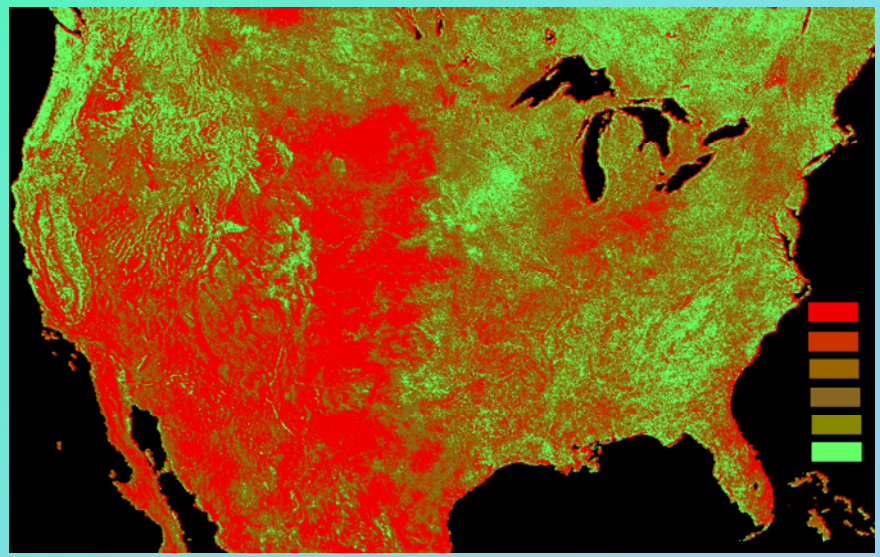
Temporal Variation in Moisture Category



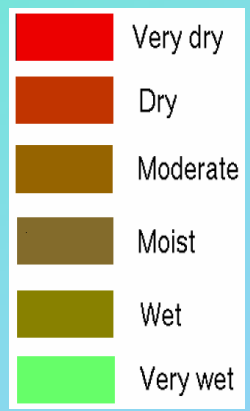
Moisture Category
--derived from AVHRR VCI



Early January in 2002



Early July in 2002



Moisture Category Factor --mcf

Moisture category	Canopy	Shrub	Grass	CWD
Very dry	0.33	0.25	0.125	0.08
Dry	0.5	0.33	0.25	0.12
Moderate	1	0.5	1	0.15
Moist	2	1	2	0.22
Wet	4	2	4	0.31
Very wet	5	4	5	0.75

From Fire Emission Production Simulator (FEPS)

Fuel Combustion Factor

Consumed fractions of tree canopy, shrub, grass (Anderson et al., 2004)

$$LC_L = 100*(1-e^{-1})^{mcf} \qquad (8)$$

LC_L --percent of fuel loading consumed for fuel type canopy, shrub, and grass, respectively

mcf—moisture category factor

The combustion factor for litter was assumed to be 100%.

Combustion factor for CWD:

$$C_w = 0.6(0.31+(0.03*(0.31-mcf))) \qquad (9)$$

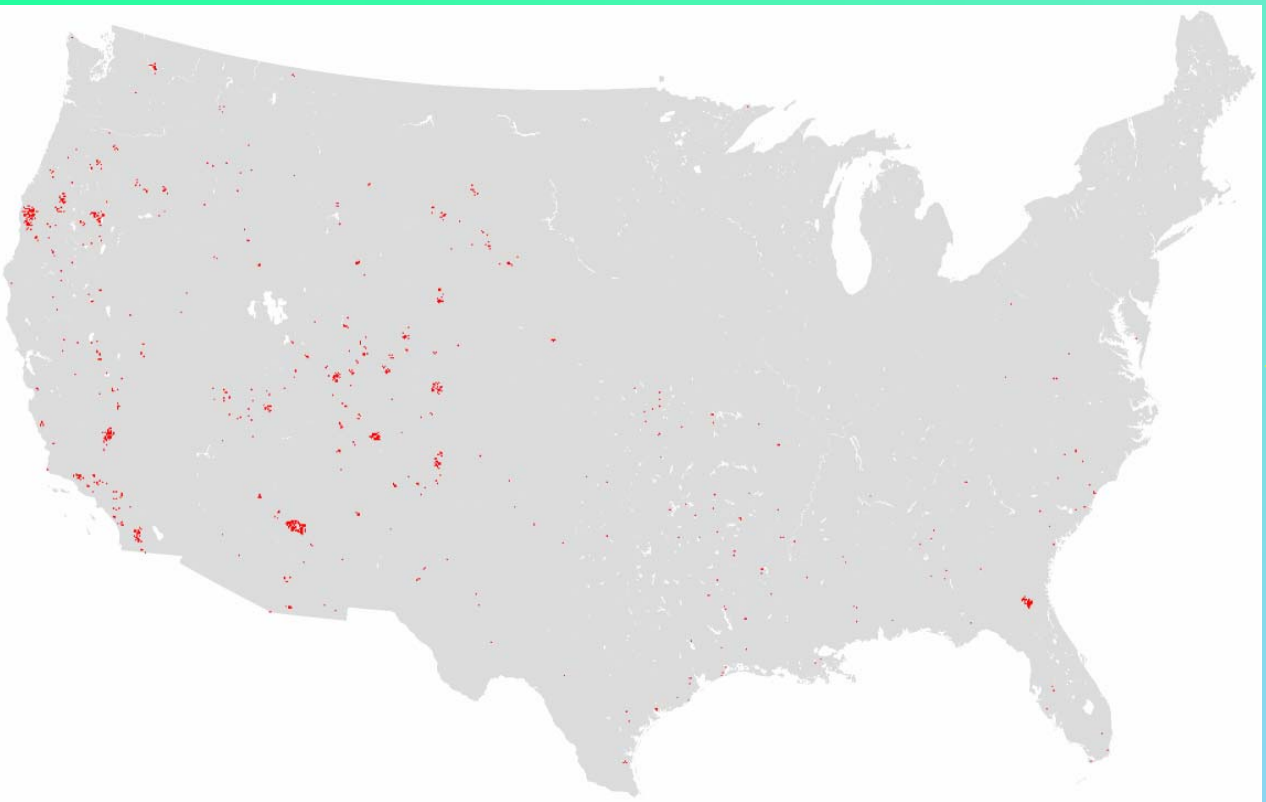
Anderson et al. 2004 Fire Emission Production Simulator (FEPS) User's Guide (version1.0)

PM2.5 Emission Factor (lb/ton)

	Wet PM2.5	Moderate PM2.5	Dry PM2.5
Litter, w	7.9	7.9	7.9
Wood 1-3”	11.9	11.9	11.9
Wood >3”	22.5	18.3	16.2
Herbs and shrubs	21.3	21.3	21.3
Canopy	21.3	21.3	21.3

Anderson et al. 2004 Fire Emission Production Simulator (FEPS) User’s Guide (version1.0)

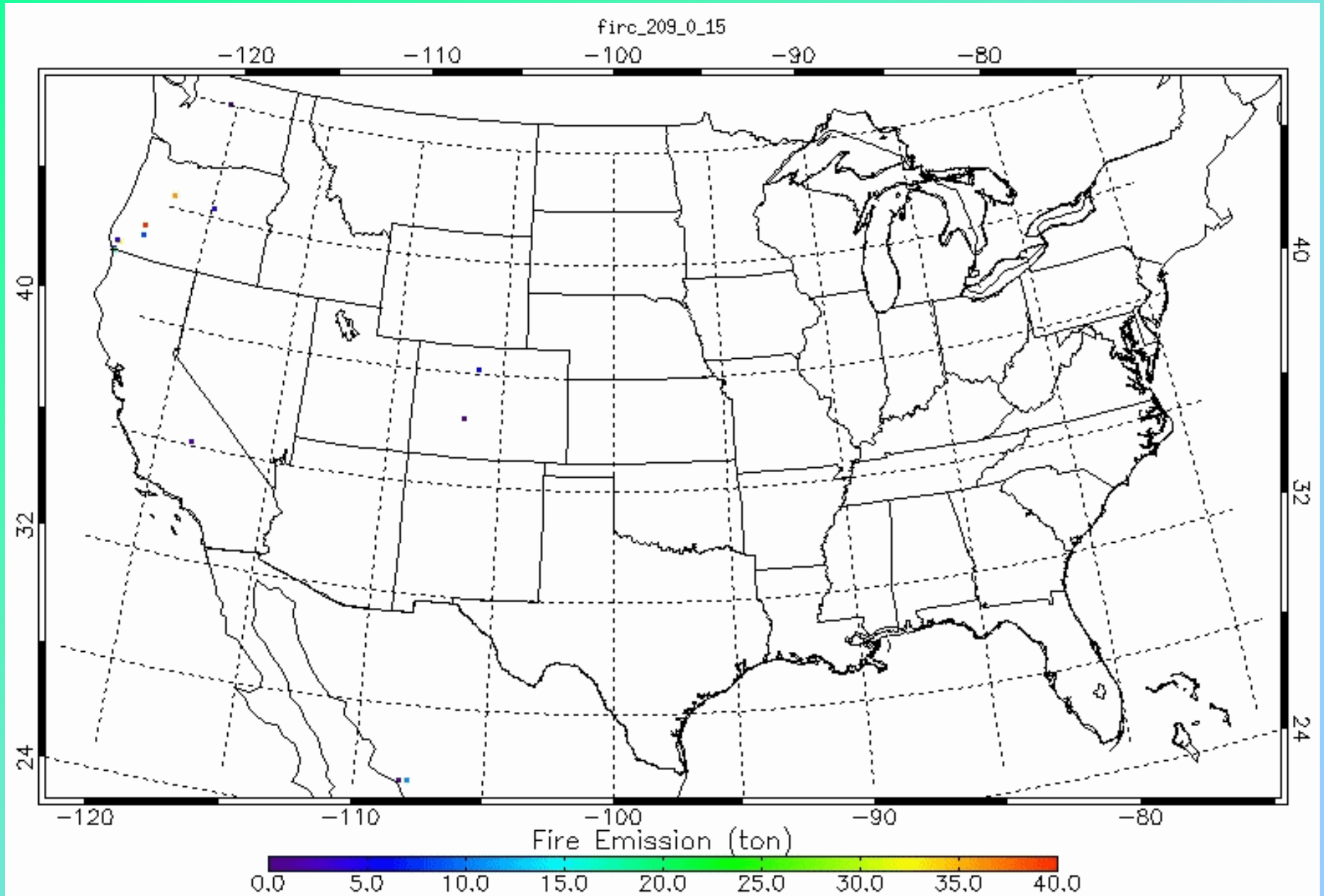
GOES Fire Size



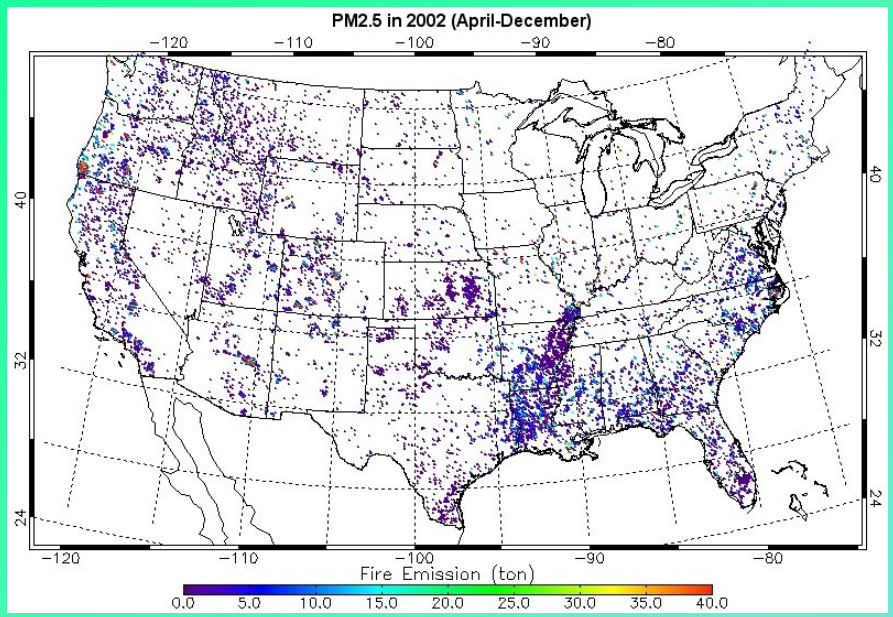
- Spatial resolution: 4km
- Temporal resolution: 30min
- Instantaneous fire sizes in subpixels detected from 3.9 µm and 10.7 µm infrared bands

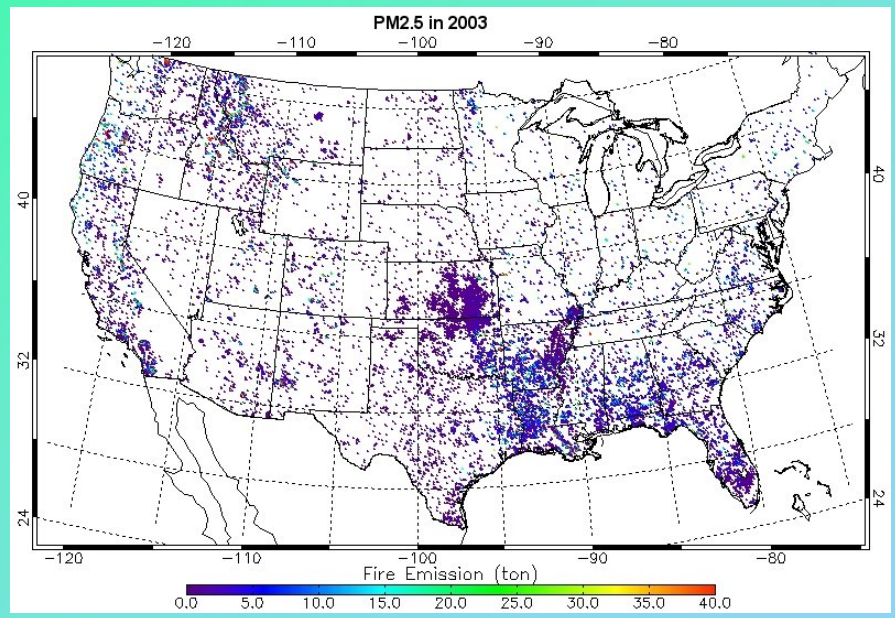
Fire occurrences detected from GOES satellite in 2002

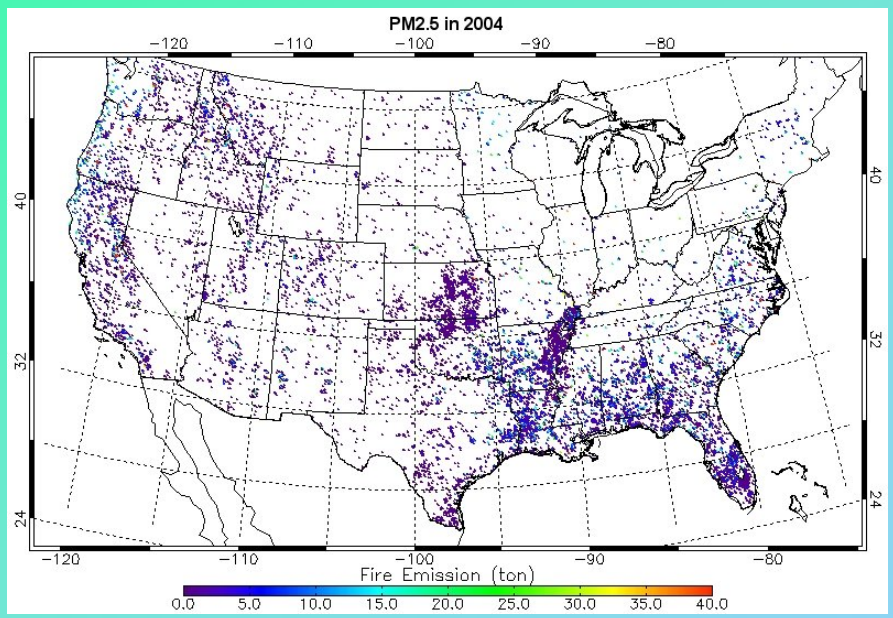
Half-hourly PM2.5 Emissions

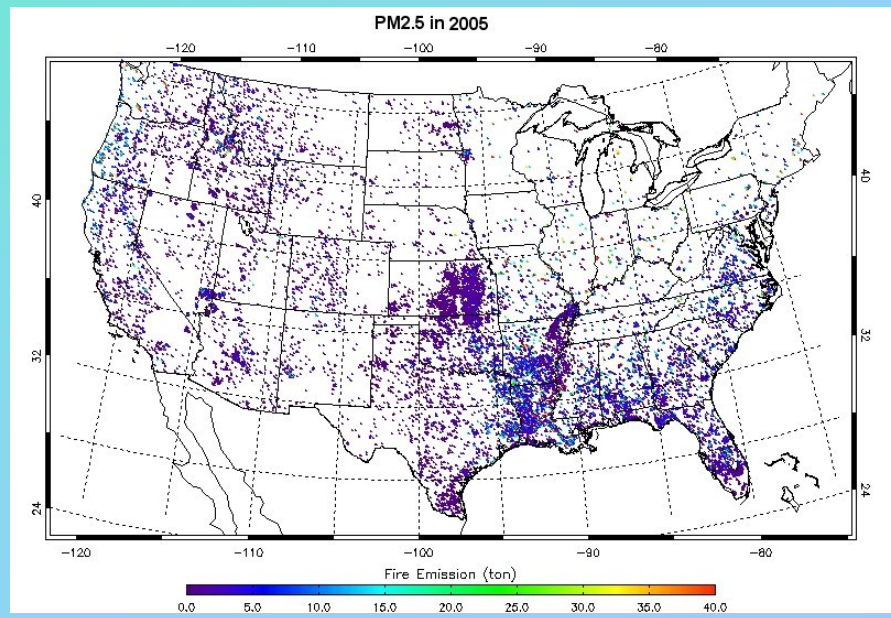


Annual PM2.5 Emissions

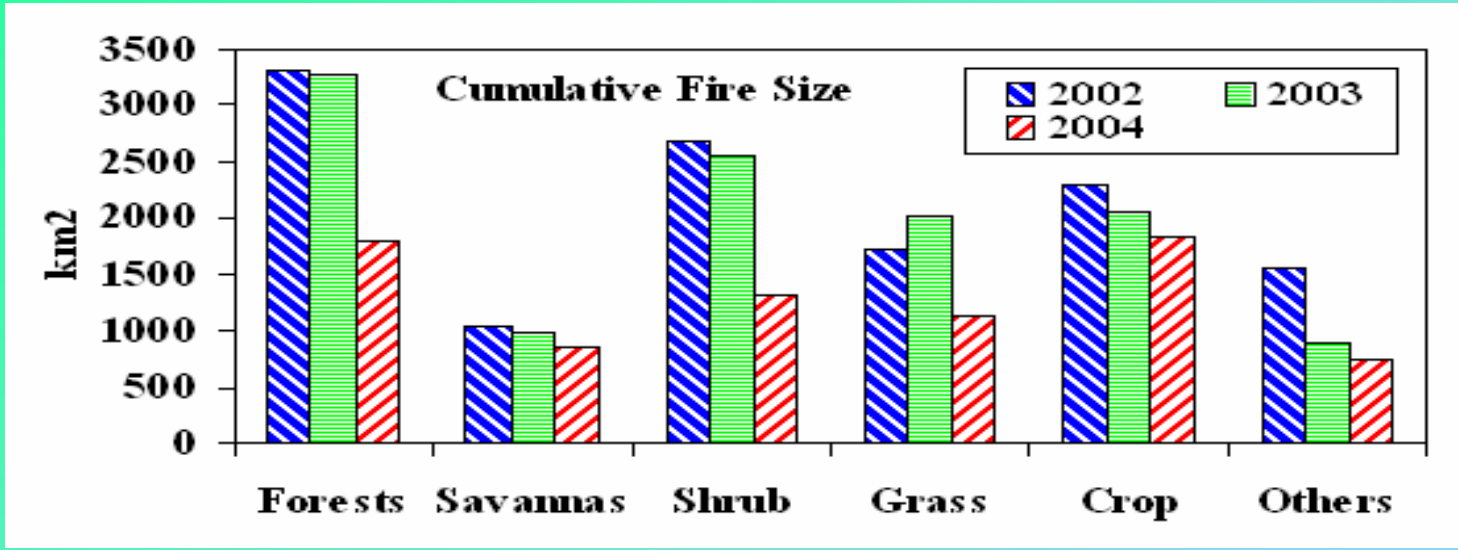


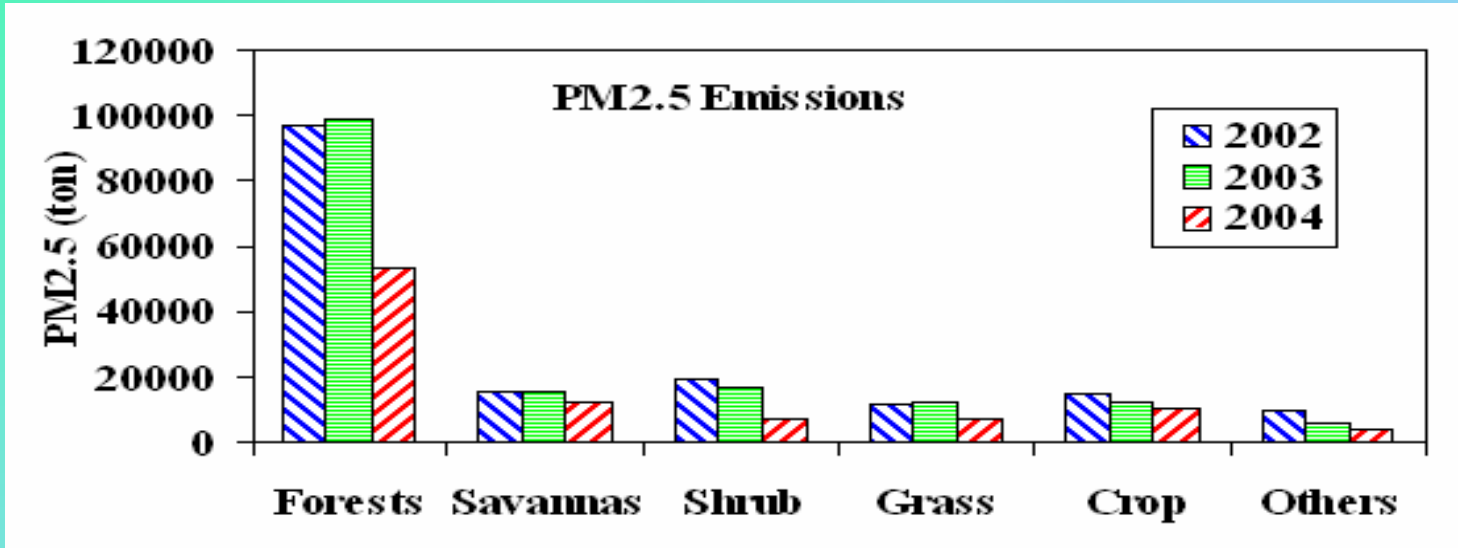




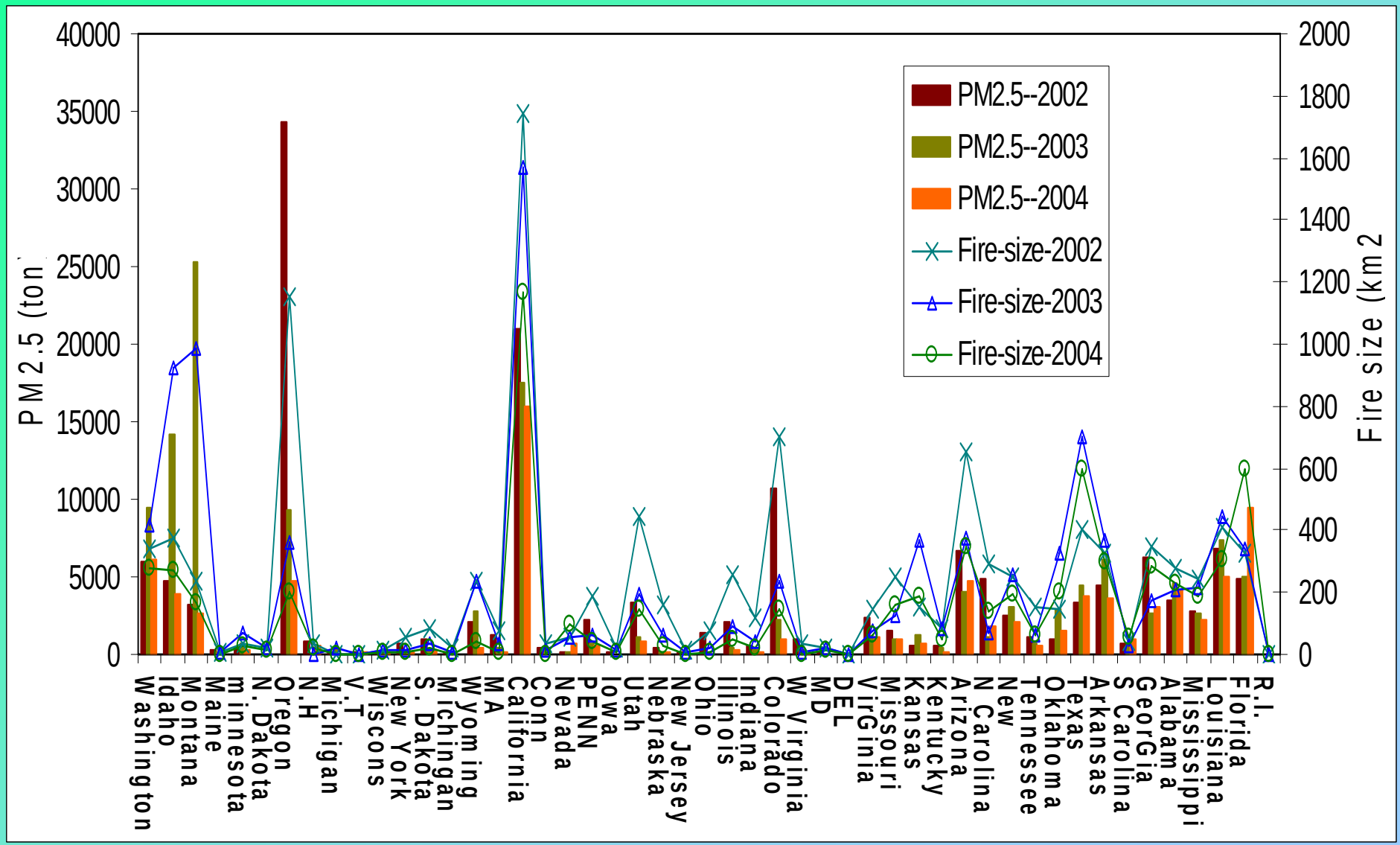


Variation in GOES Fire and PM2.5 Emission with Land Cover Type



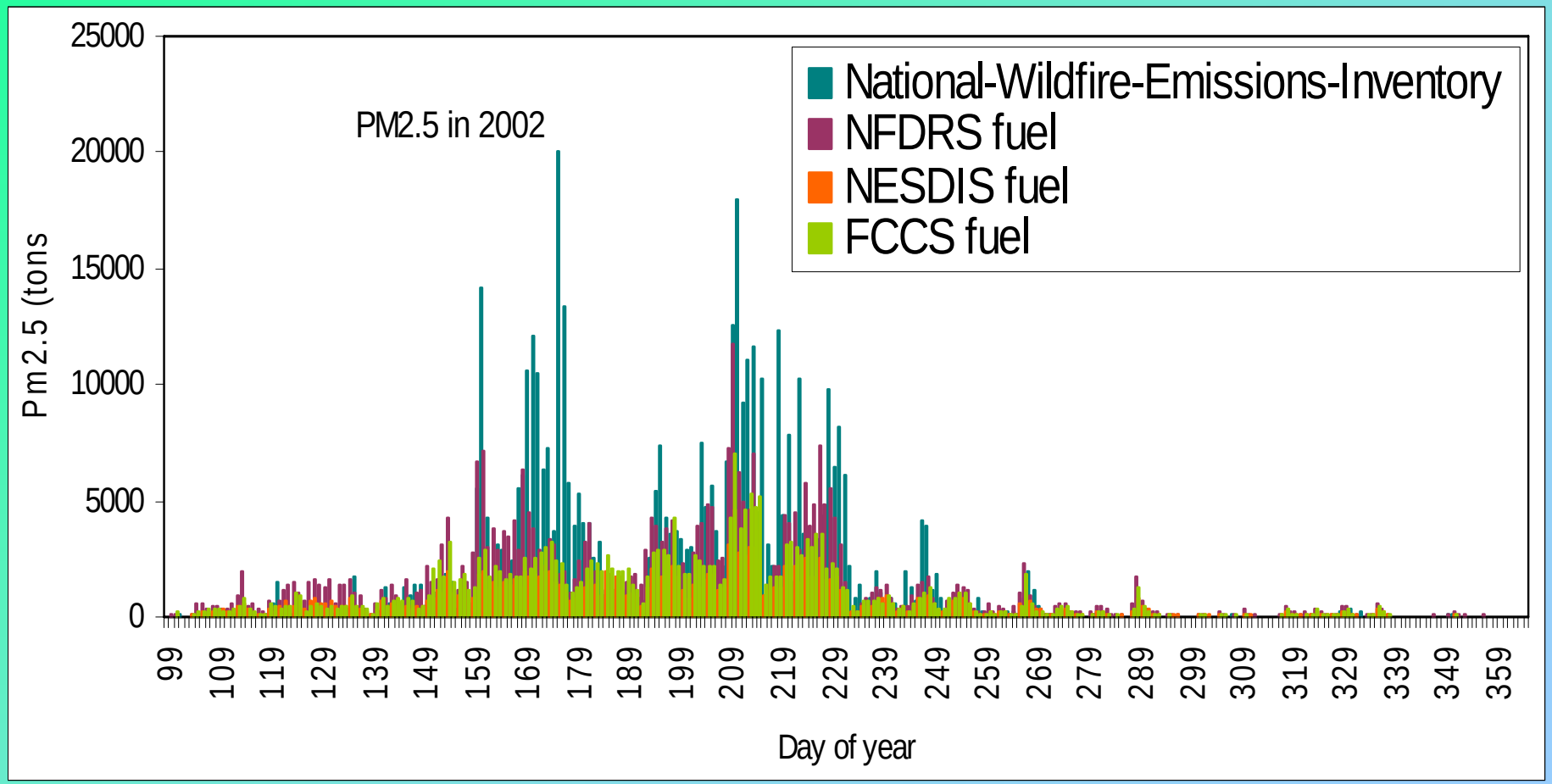


PM2.5 Emissions in Each State



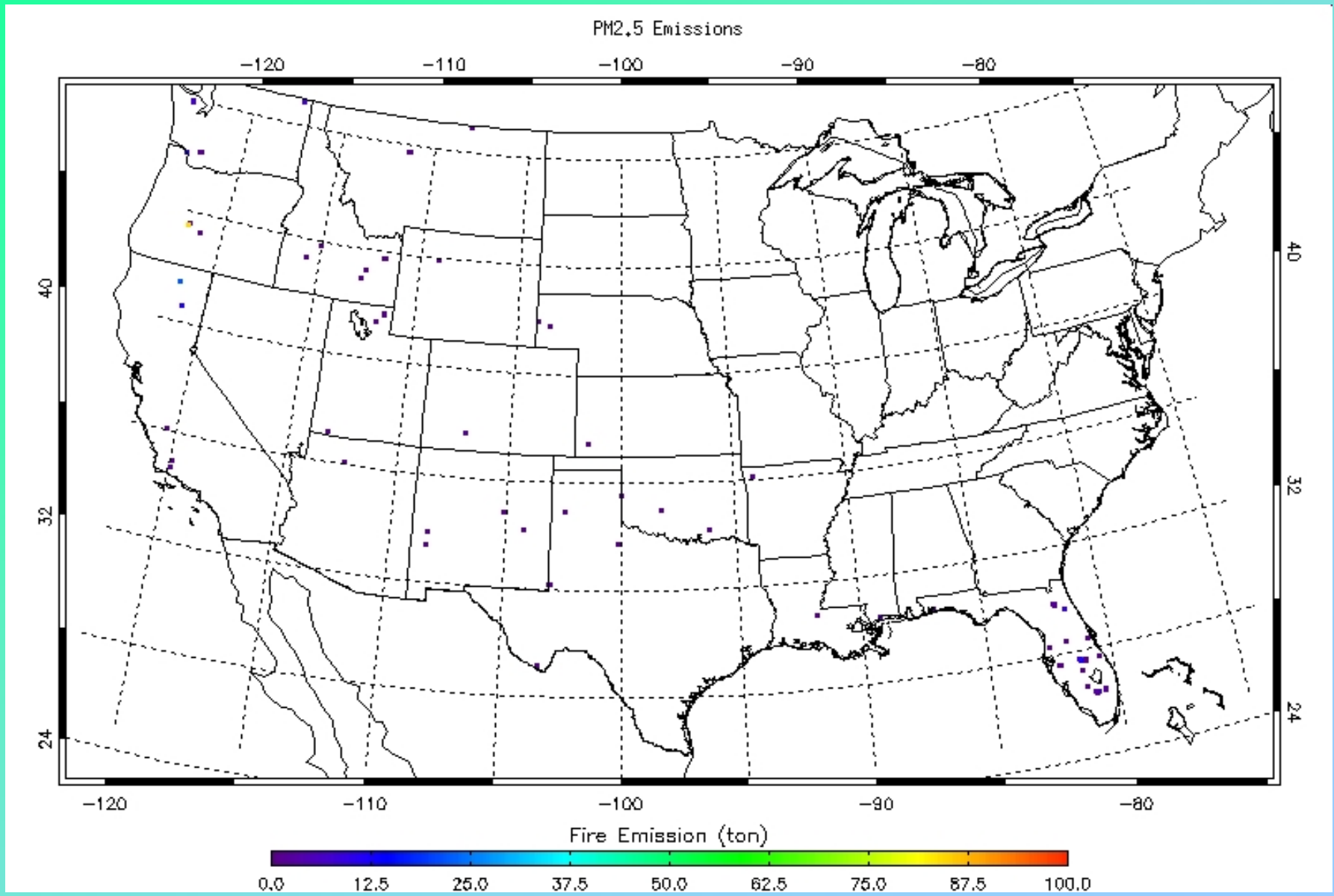
Comparison of Daily Emissions

--April-December 2002



Near Real Time Emission

(May 15, 2006)



Summary

- MODIS data combined with foliage-based allometric models provide a robust tool to establish fuel loading data over a large domain. This dataset is easy to update.
- PM2.5 emissions vary greatly with ecosystems, state, season, and year.
- Instantaneous fire size from GOES satellite is not the same as burned areas. Effort is needed to accurately retrieve burned areas from satellite-based fire sizes.
- Future work will derive reasonable burnt areas by investigating GOES fire size, MODIS fire counts, AVHRR fire counts, and national inventory burned areas in spatial and temporal patterns.


THANK YOU

Litter and Coarse Woody Detritus (CWD)

Litter pool and CWD pool modified from Matthews et al. (1997).

MODIS Land cover type	Litter (kg/m^2)	CWD pool (kg/m^2)
Evergreen Needleleaf Forest (ENF)	2.175	3.14
Evergreen Broadleaf Forest (EBF)	1.5	1.76
Deciduous Needleaf Forest (DNF)	0.85	1.6
Deciduous Broadleaf Forest (DBF)	0.85	1.6
Mixed Forest (MF)	1.67	2.2
Grassy woodland (WL)	0.63	0.176
Wooded Grassland (Wgrass)	0.63	0.176
Cshrub (Closed Shrubland)	1.24	1.21
Oshrub (Open Shrubland)	1.24	1.21
Grass (Grasslands)	0.3625	0.06
Crop (Croplands)	0.3625	0.06
Non forest vegetation (average from shrub and grass)	0.5019	0.1657

Fire size comparison between GOES data and NEI in 2002