# Fire Contributions to Contemporary Changes in the Global Carbon Cycle and Climate System

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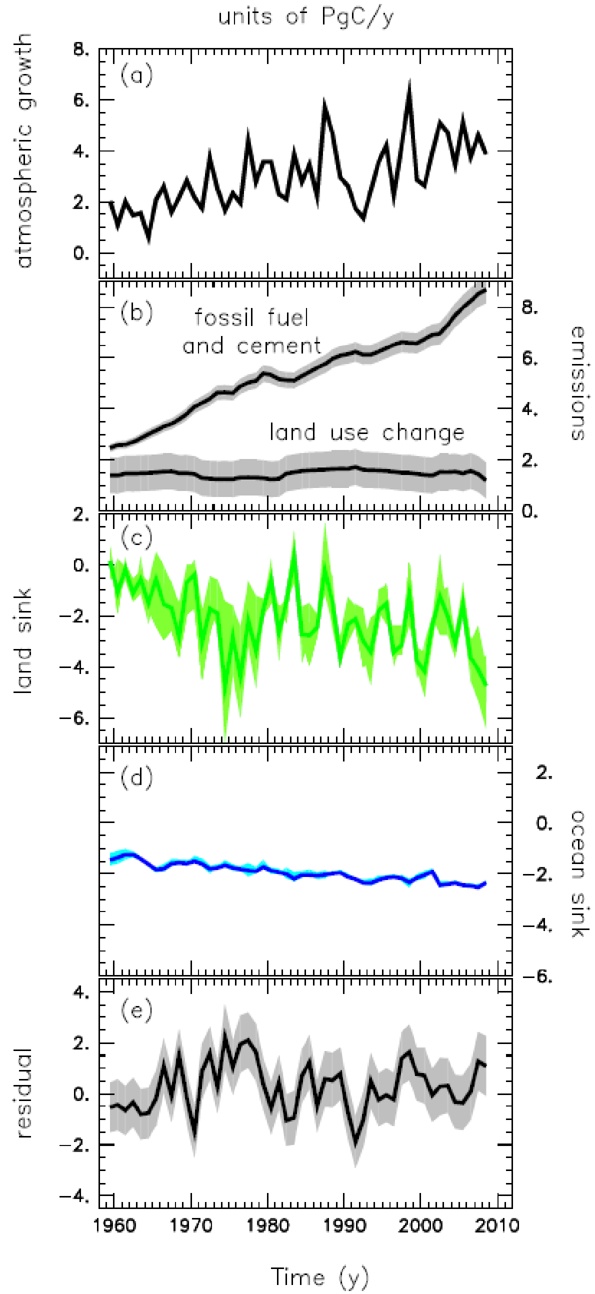
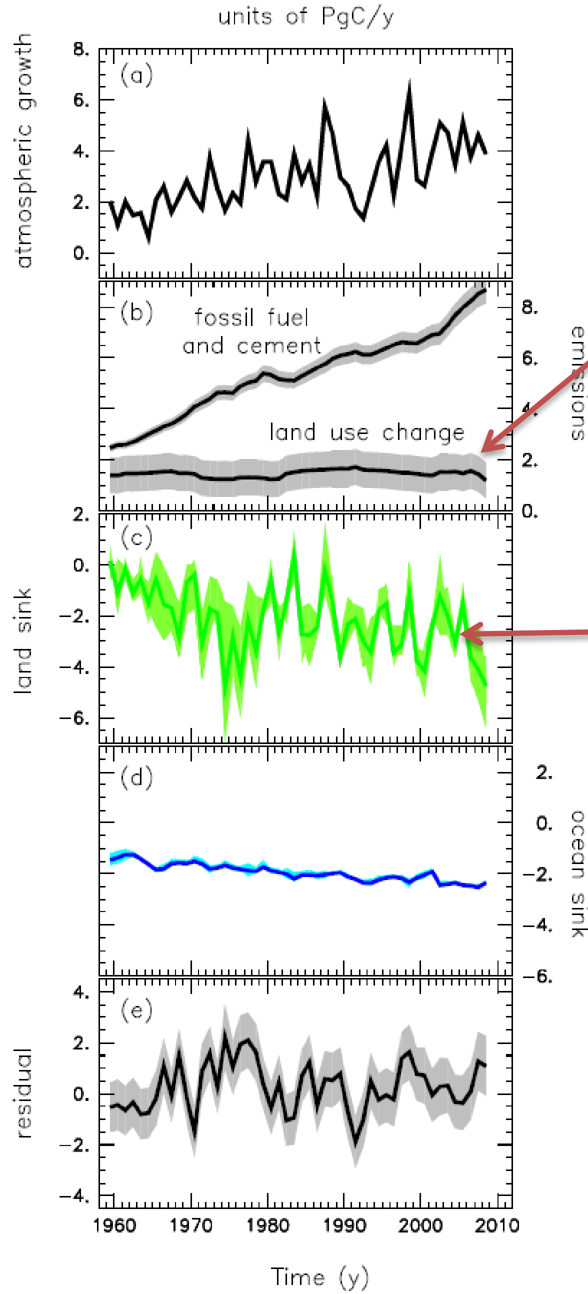
# Recent Changes in the Global Carbon Cycle




Le Quere et al., 2009
Nature Geosciences

# Recent Changes in the Global Carbon Cycle



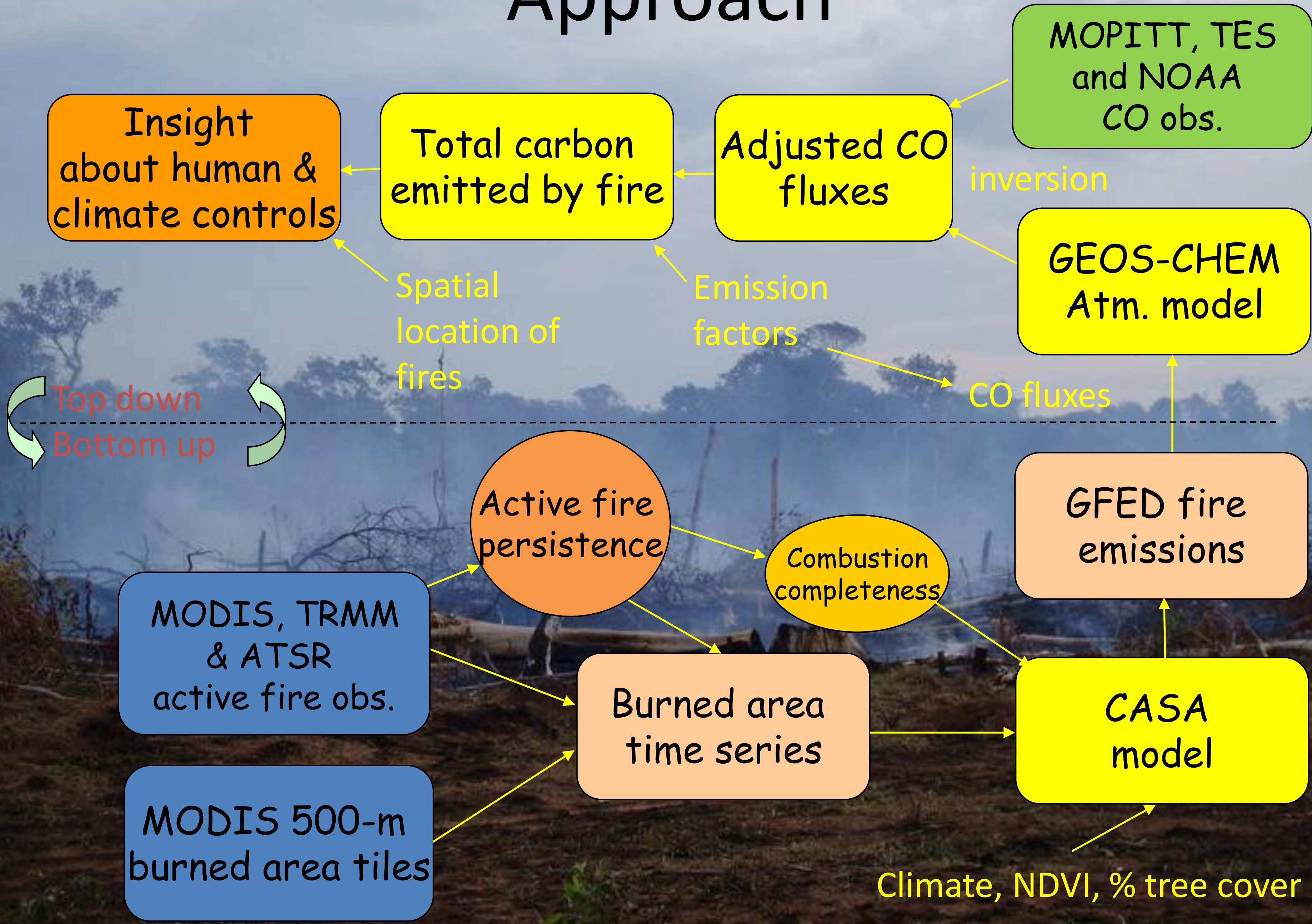

Why study fires?

1. Direct measure of deforestation
2. May play an important role in climate-ecosystem feedbacks
3. Changes in fire regime can contribute to long-term carbon sources and sinks
4. Climate forcing includes multiple pathways, including black carbon, $CH_4$, aerosols, albedo, and $O_3$

# NASA's Earth Observing System satellites (Terra, Aqua, Aura) have transformed our understanding of global fires

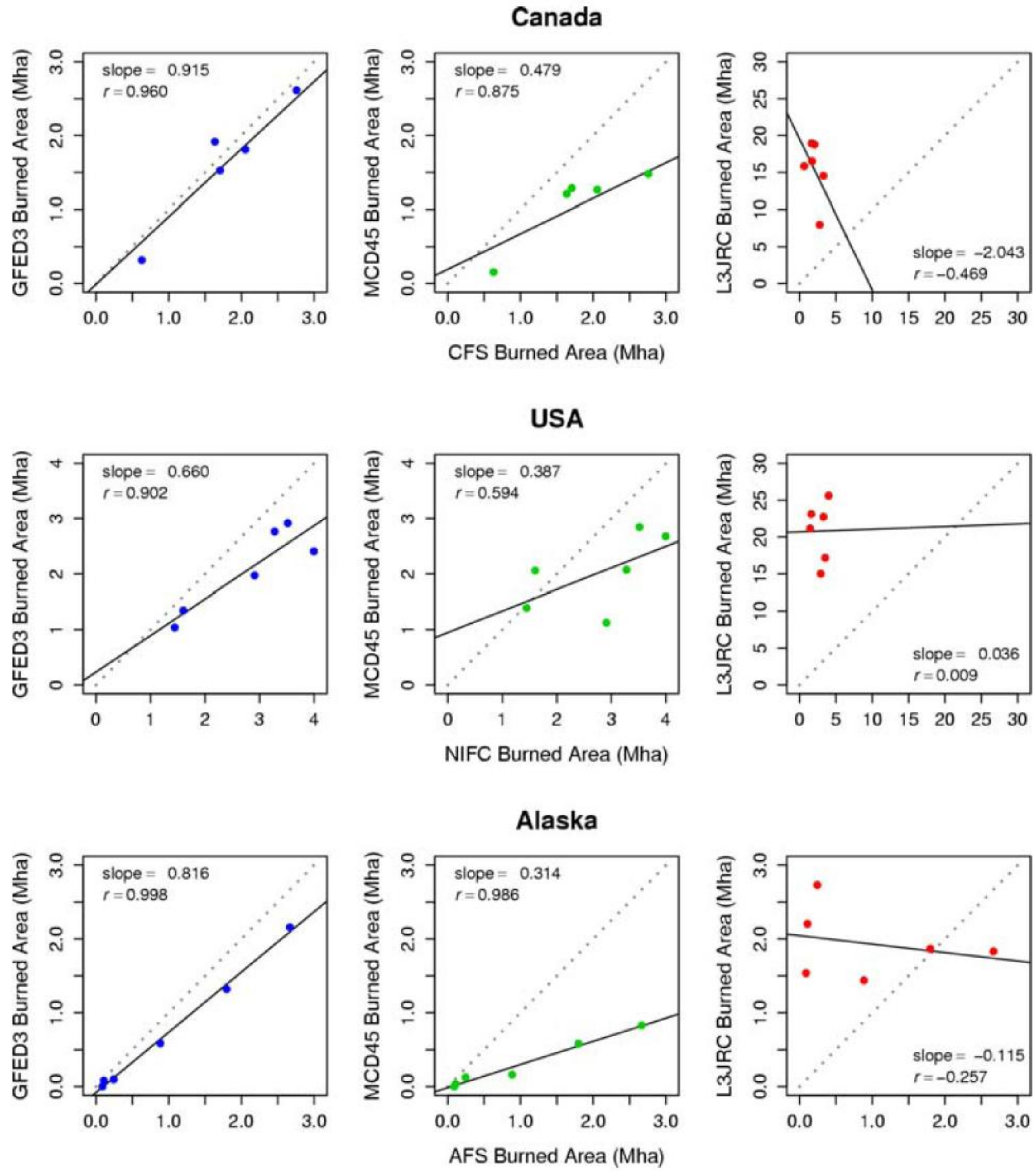
- Wall-to-wall 500m monthly burned area observations now available from two algorithms
  – Roy et al. (2005, 2008) MODIS collections 5 and 6 products
  – Giglio et al. (2009, 2010) direct broadcast and 'GFED' burned area
- Active fire observations provide insight about fire processes
  – Agricultural intensification leads to greater fire use in the deforestation process (Morton et al., 2008)
- Column CO observations from MOPITT, AIRS, and TES provide top-down constraints on fire emissions
- Multi-angle MISR observations are currently being used to systematically retrieve plume heights from different biomes
  – Injection heights critically determine fire aerosol effects on climate, ecosystems, and human health
- Combined with TRMM VIRS and ESA's ATSR active fire records, we now have a 14+ year time series of global burned area and fire emissions
  – Has substantially improved our understanding of the sensitivity of fires to climate, human, and ecosystem factors

# Approach

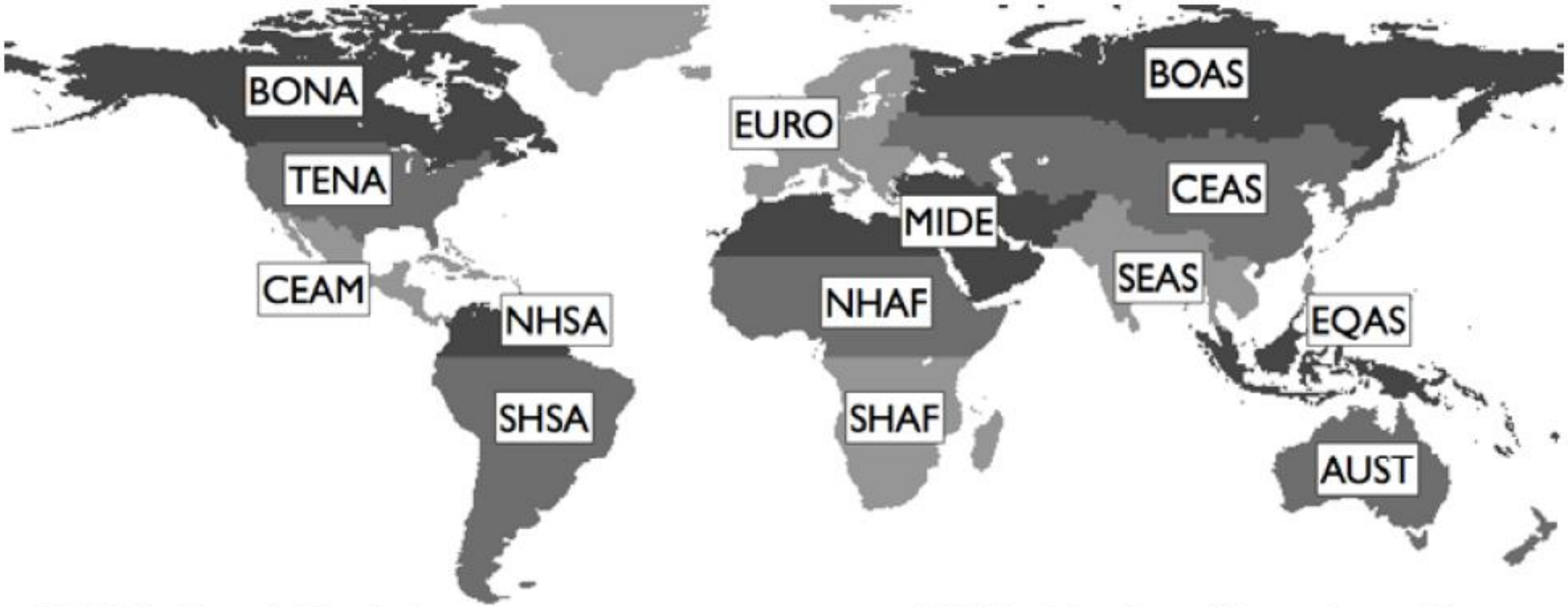

MOPITT, TES and NOAA CO obs.
Insight about human & climate controls
Total carbon emitted by fire
Adjusted CO fluxes
inversion
GEOS-CHEM Atm. model
Spatial location of fires
Emission factors
CO fluxes
Top down
Bottom up
Active fire persistence
Combustion completeness
GFED fire emissions
MODIS, TRMM & ATSR active fire obs.
Burned area time series
CASA model
MODIS 500-m burned area tiles
Climate, NDVI, % tree cover

# Global burned area

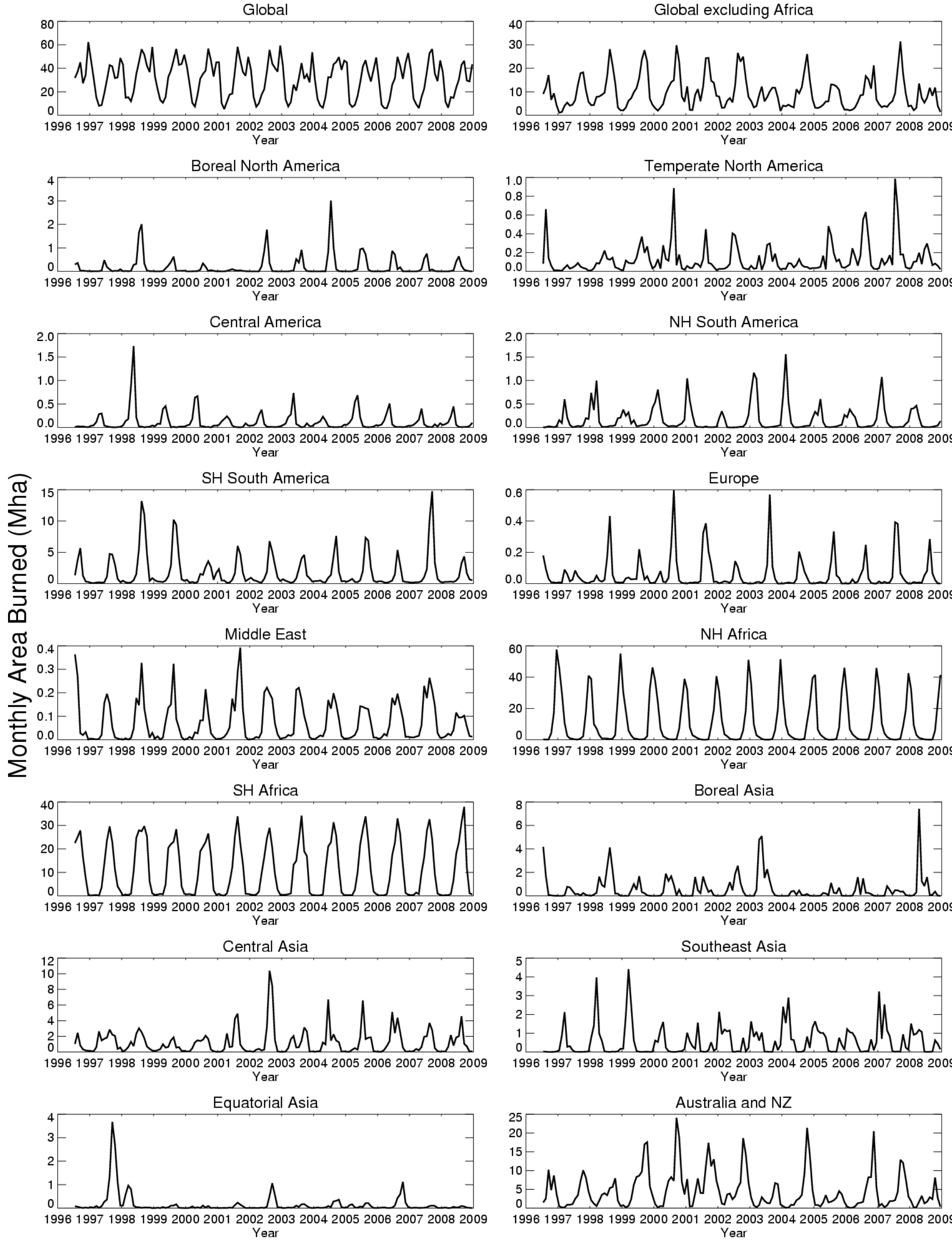
- Where available, we use 500-m burned area maps produced by a change detection algorithm with surface reflectance from MODIS
- Burned area extended to other periods and area by relating this burned area product in each region to active fire detections from MODIS, VIRS, and ATSR instruments



# Regions of analysis




| | |
|---|---|
| BONA | Boreal North America |
| TENA | Temperate North America |
| CEAM | Central America |
| NHSA | Northern Hemisphere South America |
| SHSA | Southern Hemisphere South America |
| EURO | Europe |
| MIDE | Middle East |
| NHAF | Northern Hemisphere Africa |
| SHAF | Southern Hemisphere Africa |
| BOAS | Boreal Asia |
| CEAS | Central Asia |
| SEAS | Southeast Asia |
| EQAS | Equatorial Asia |
| AUST | Australia and New Zealand |

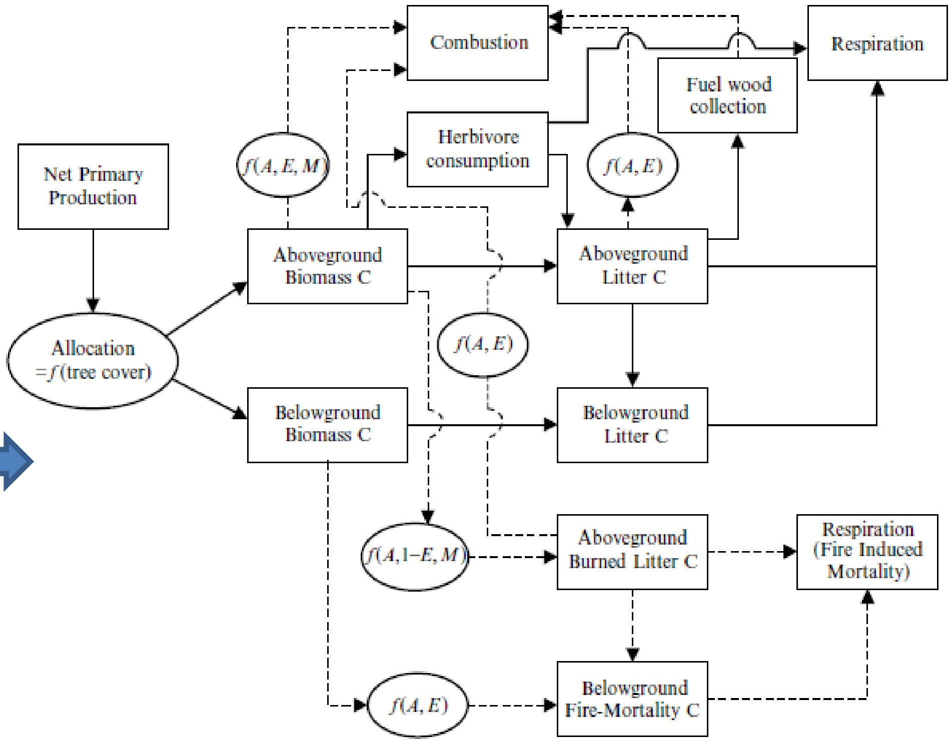

Monthly Area Burned (Mha)
Global
Global excluding Africa
Boreal North America
Temperate North America
Central America
NH South America
SH South America
Europe
Middle East
NH Africa
SH Africa
Boreal Asia
Central Asia
Southeast Asia
Equatorial Asia
Australia and NZ
Year
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009

# From burned area to emissions

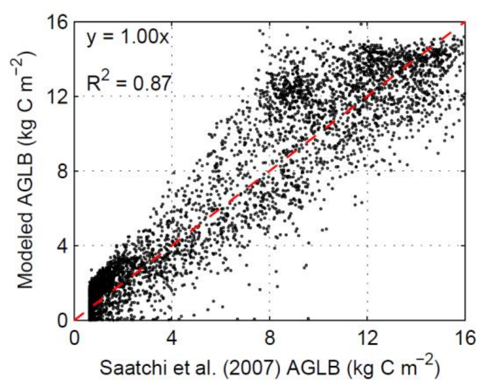
- E = AB *FL* CC *EF

  - high uncertainty (> 50%)
  - medium uncertainty (25-50%)
  - low uncertainty (< 25%)

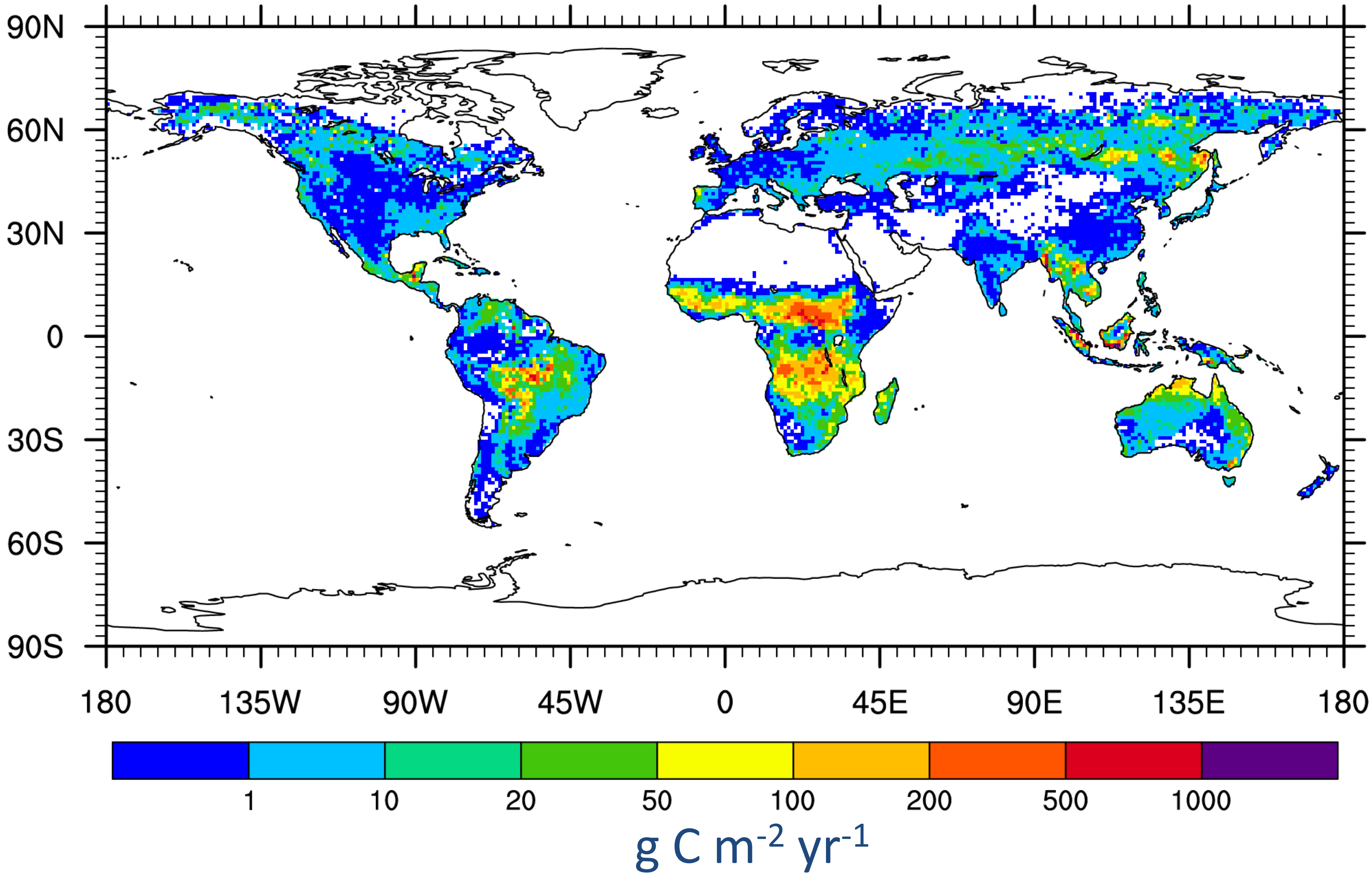
- Emissions obtained from a biogeochemical model




- Driven by satellite observations
  - fAPAR -> primary production
  - fractional tree cover
  - Maps of peat areas
- Includes a representation of peat and organic soil burning
- Allocation optimized to match tropical aboveground biomass inventories (Saatchi et al., 2007)

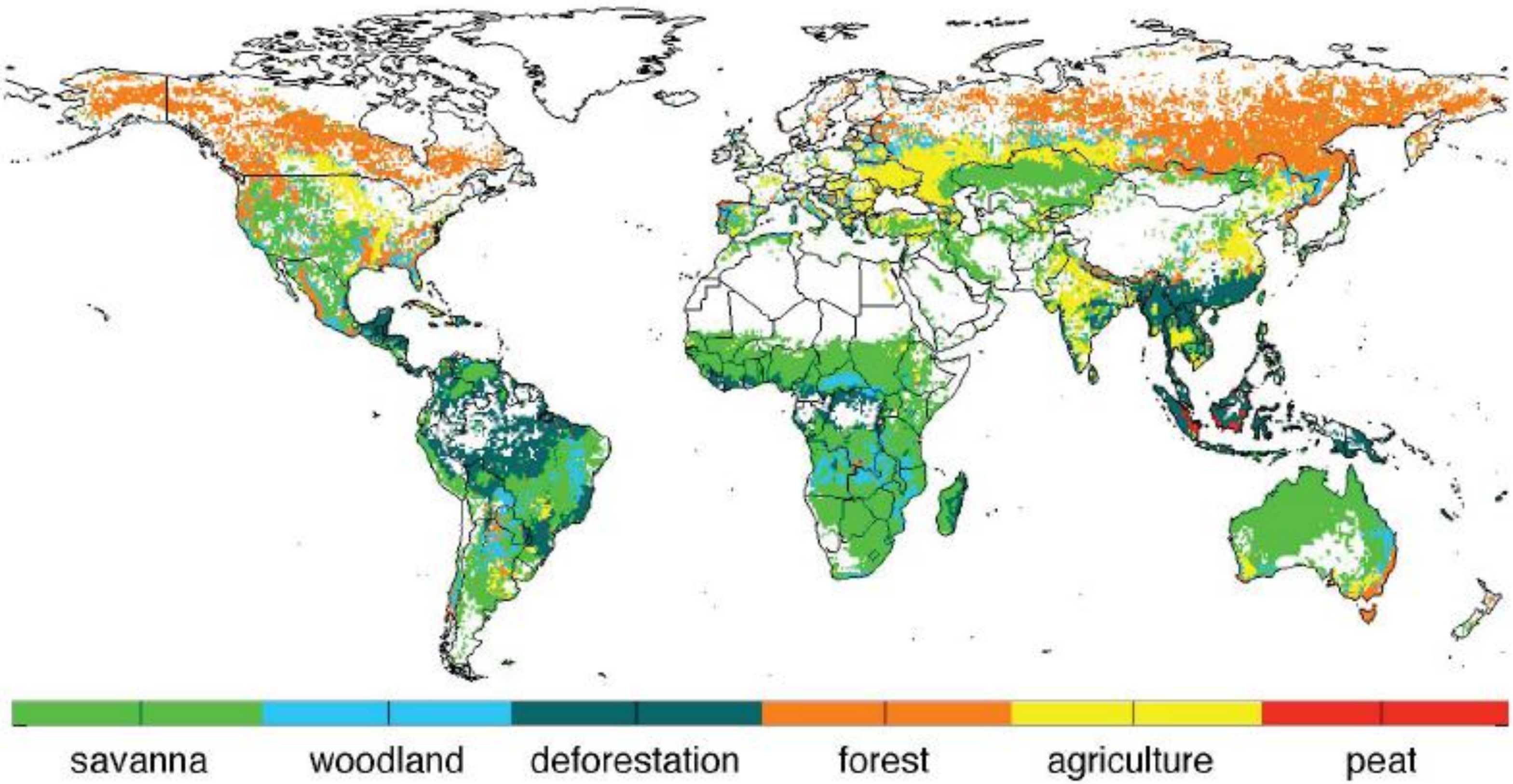


# Annual mean fire emissions 1997-2008

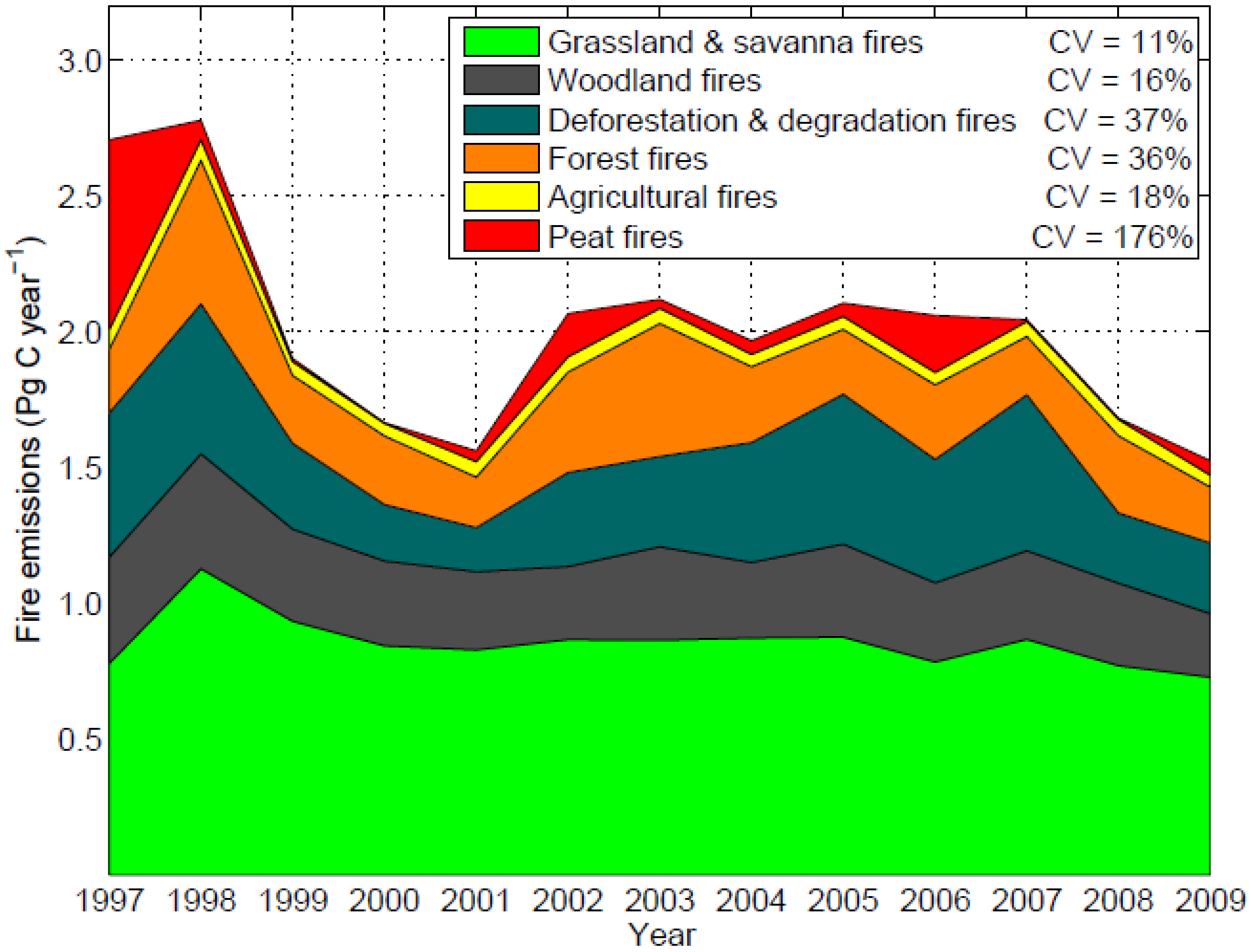



- Global fire emissions -> ~2.1 Pg C/yr
- ~ 1/4 of total occurs at the deforestation frontier
- ~ 1/2 of the net deforestation flux is emitted as fire

# Concurrent land cover information from MODIS and other sources at 500m allows for a spatial partitioning of fire types

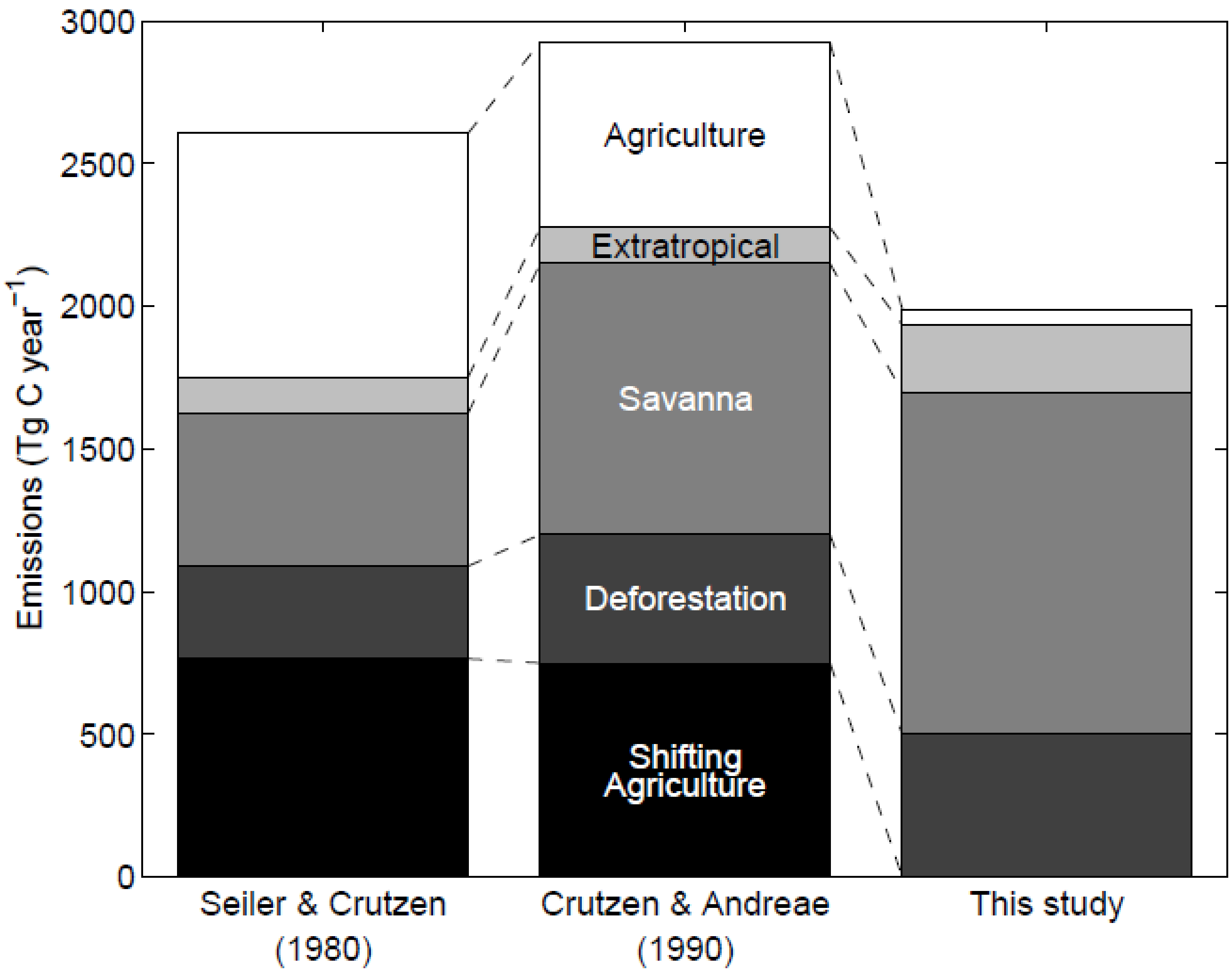


# Year-to-year variability of emissions varies with fire type



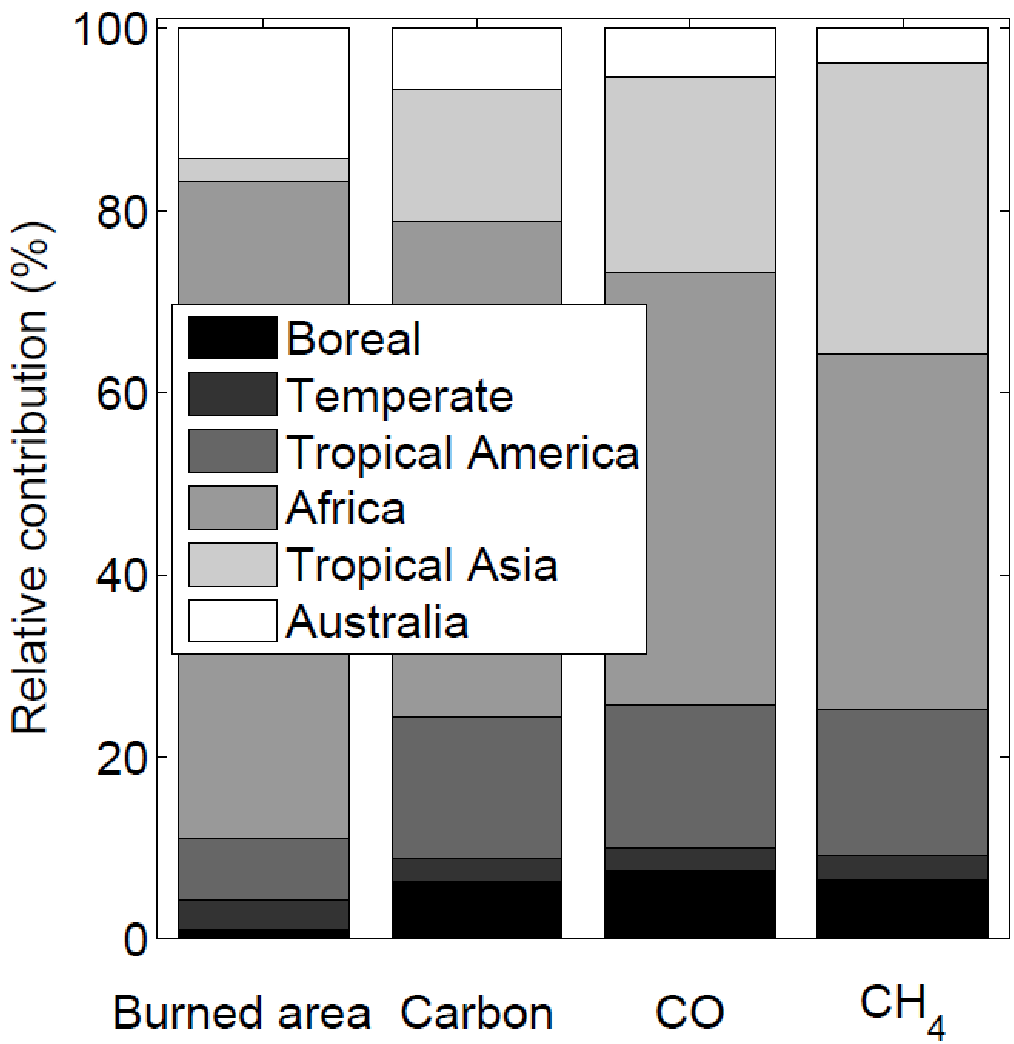

Van der Werf et al. (2010) ACPD

# Estimates of fire types and contributions to global emissions have changed over time



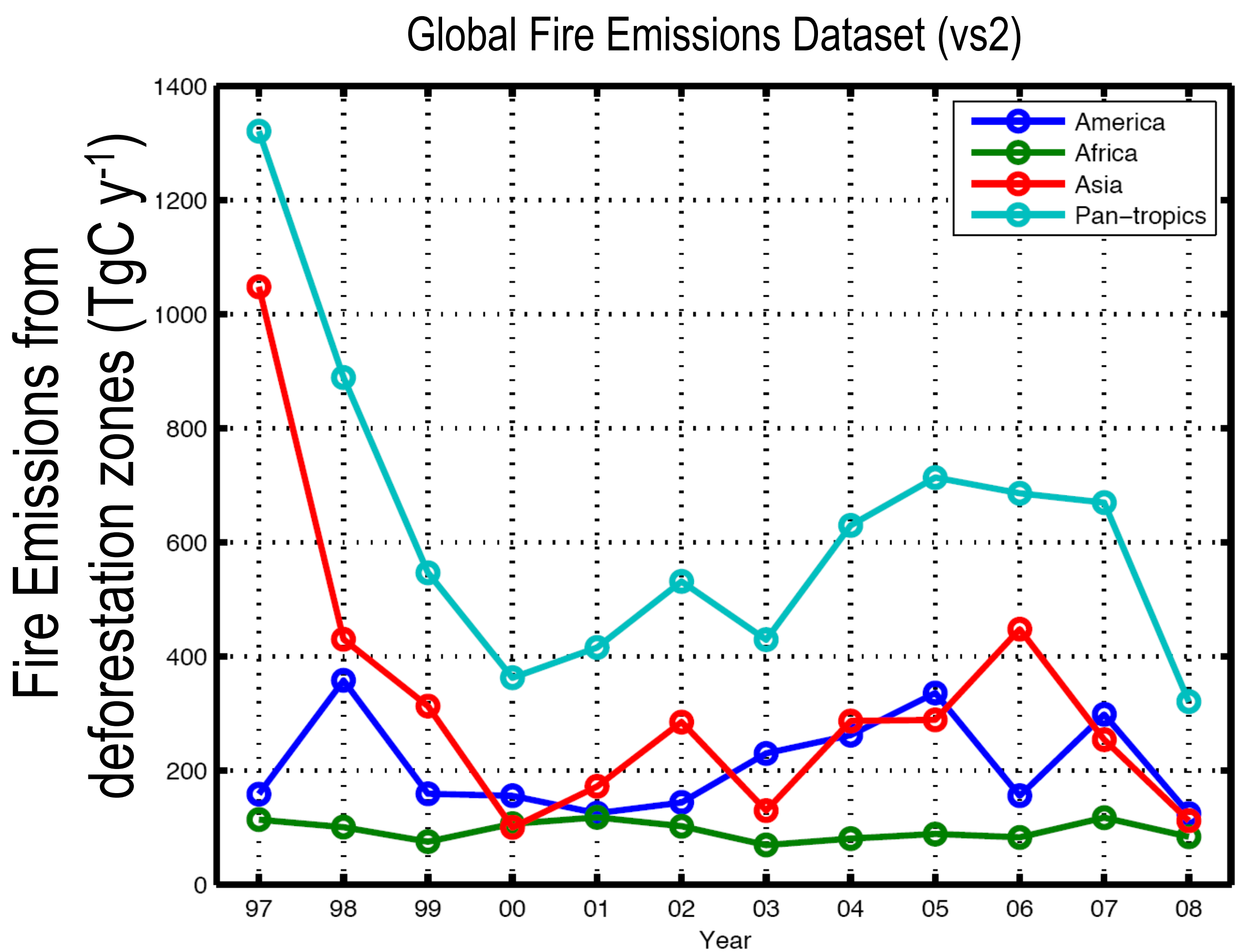

Van der Werf et al. (2010) ACPD

# Forest and peat fires contribute disproportionately to reduced trace gas emissions



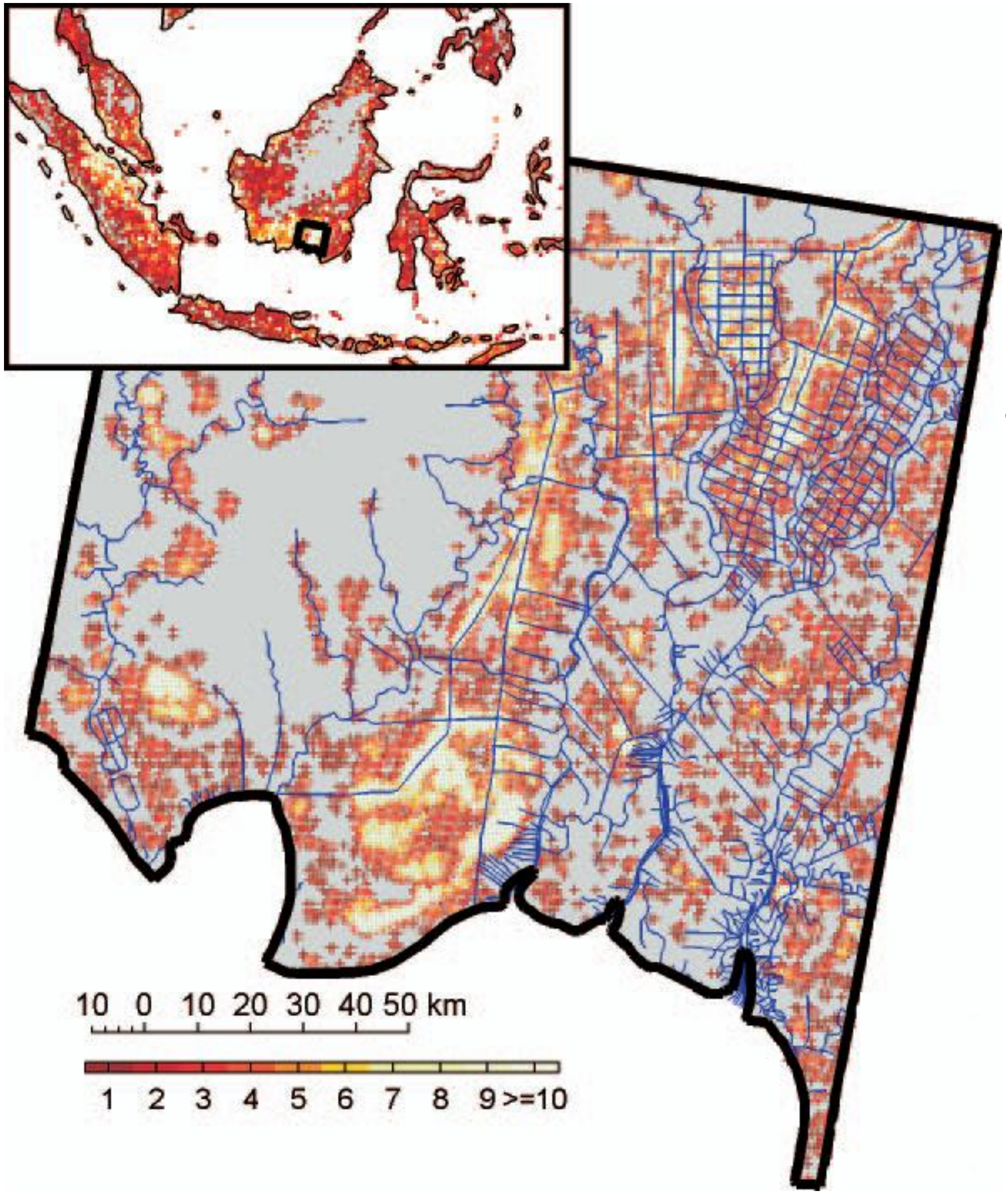

Van der Werf et al. (2010) ACPD

# Fire Emissions from Deforestation Zones




GFED carbon emissions sampled in deforestation regions measured independently by Hansen et al. (2008)

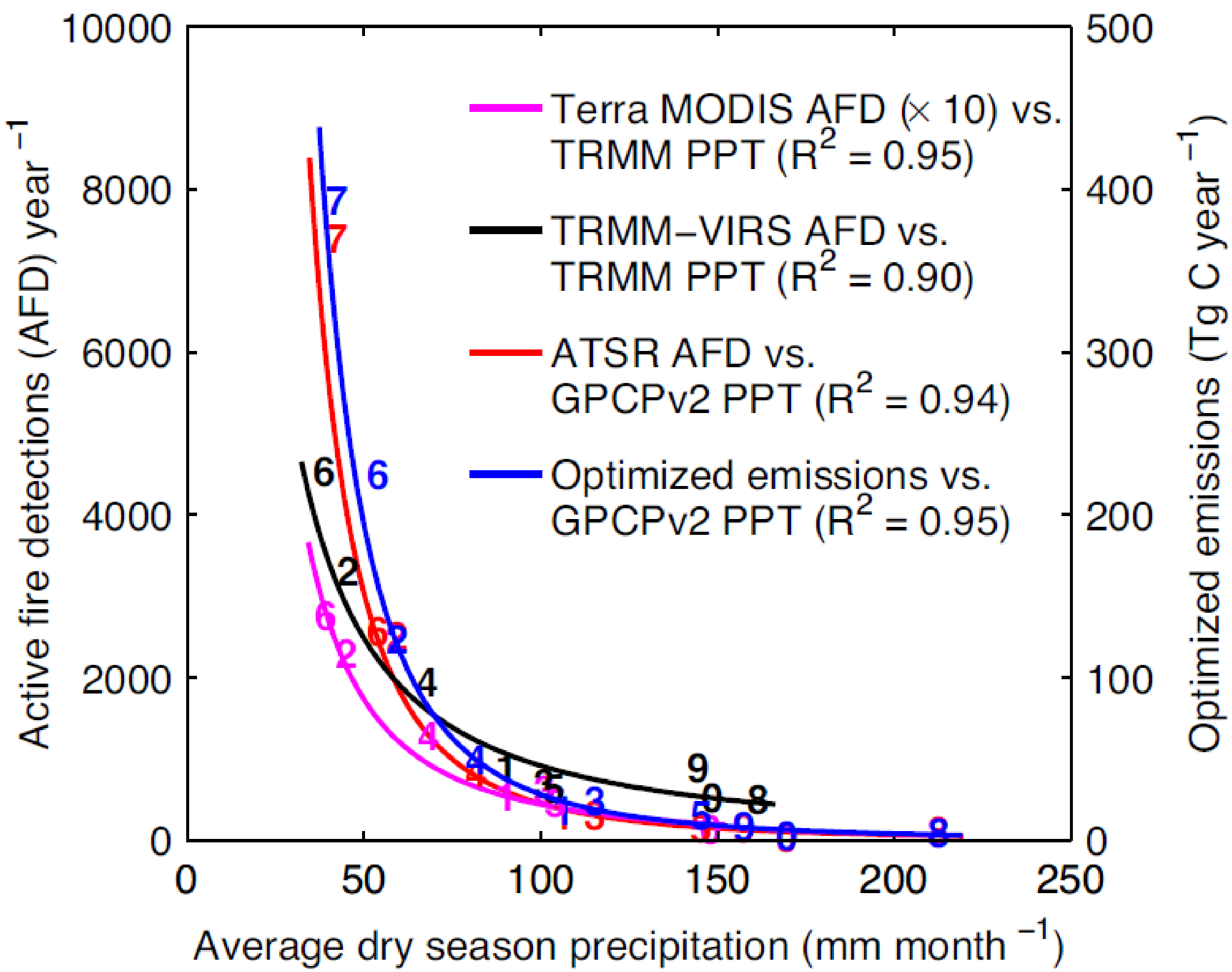
van der Werf et al. 2006, Atmospheric Chemistry and Physics, updated




# Do fires in equatorial Asia influence regional climate?

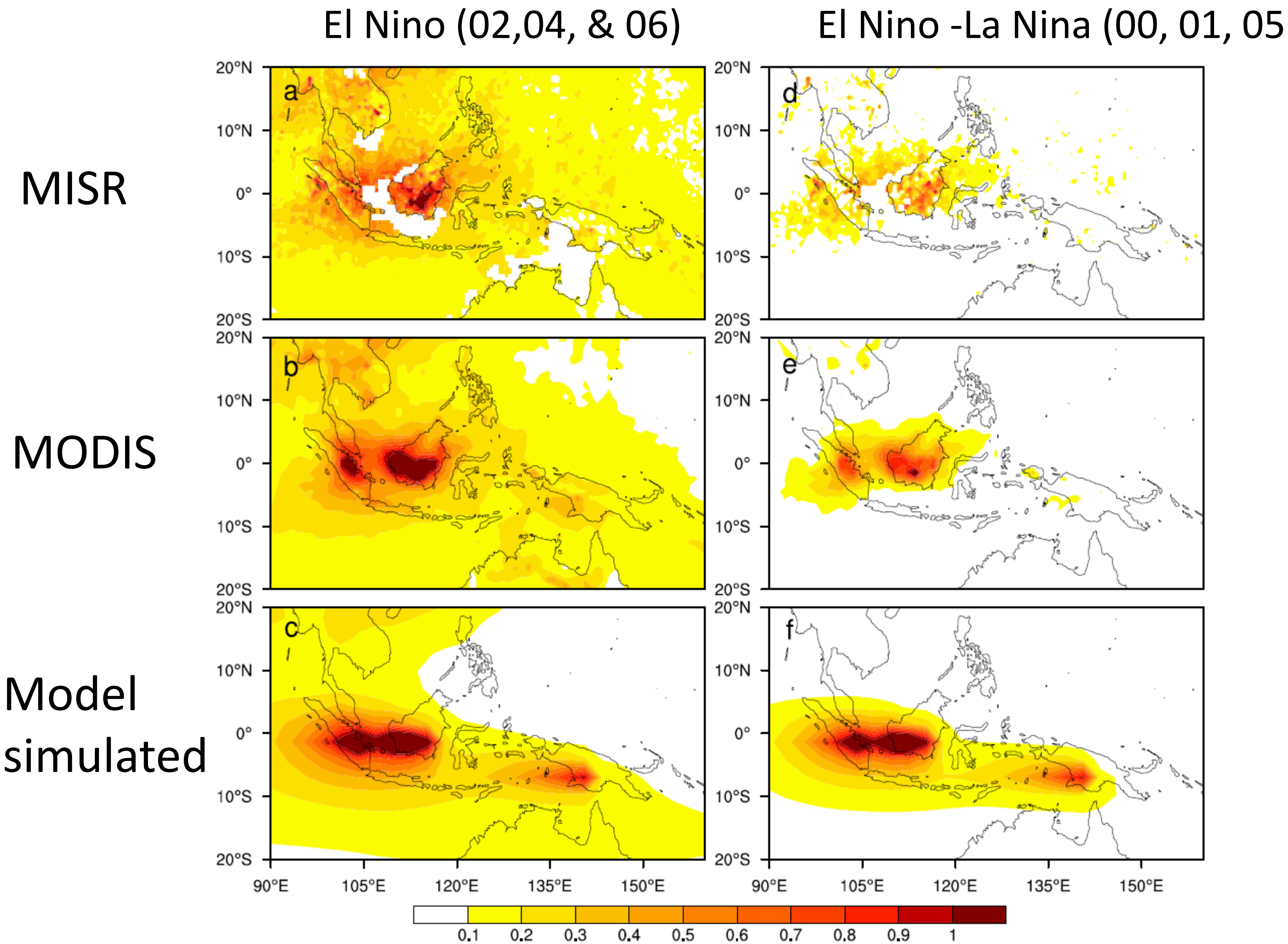
- Possible Feedback Components:
  - Fires and deforestation rates increase during drought (El Nino) years in Indonesia (van der Werf et al. 2008 *PNAS*)
  - Smoke clouds from the fires are large and optically thick, reducing shortwave radiation at the surface

# Fire activity and emissions are sensitive to drought stress in southern Borneo




Van der Werf et al. 2008 *PNAS*

# Observed and simulated smoke clouds



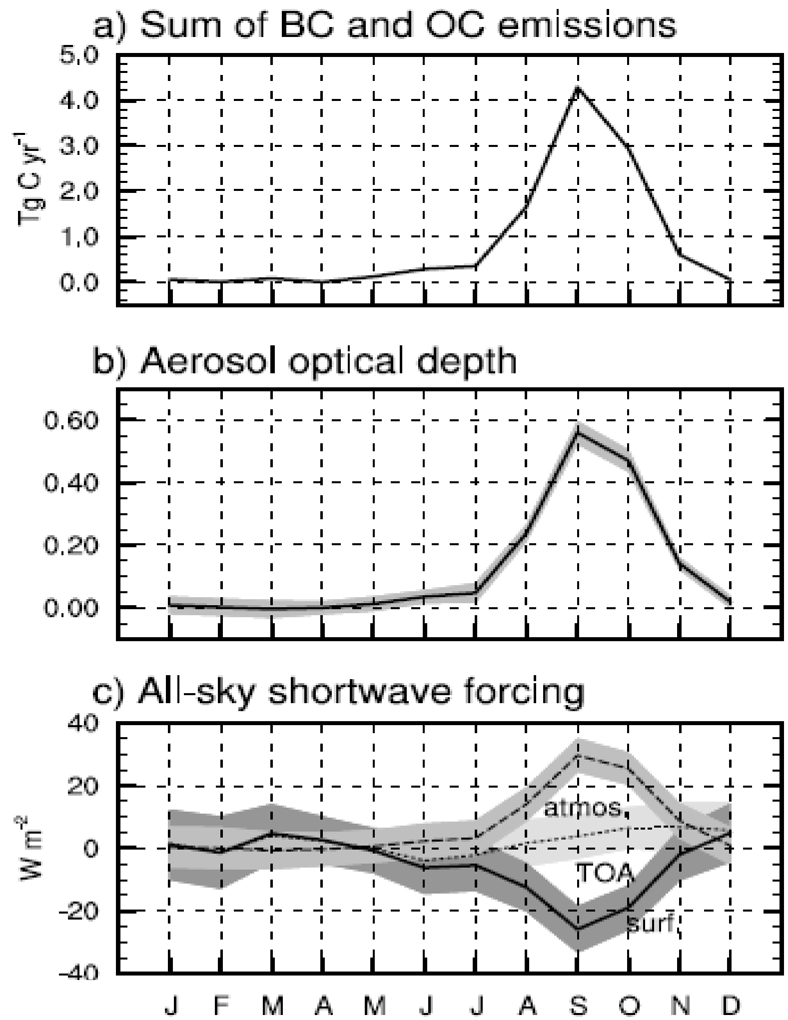

August – October means

Tosca et al. 2010 ACP

# Model Description and Forcing

- Community Atmosphere Model version 3.1
- Slab ocean
- Two 40-year simulations
- Fire emissions prescribed for a high (1997) or low (2000) fire year
- Direct and semi-direct aerosol effects

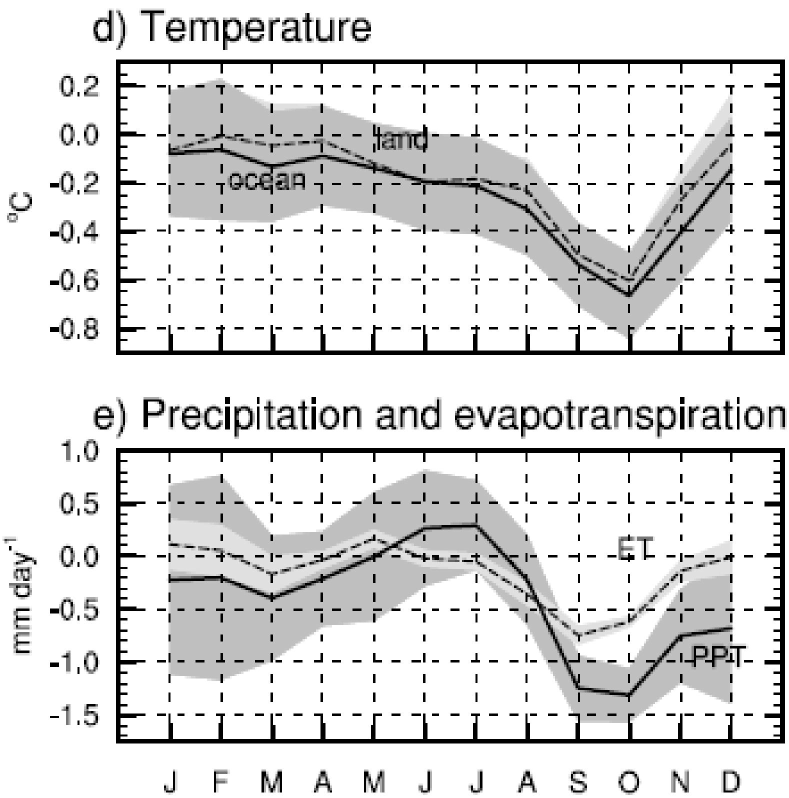
High – low fire model simulation differences




Region spanned by 5 N-5 S and 90 E-120 E

Tosca et al. 2010 ACP

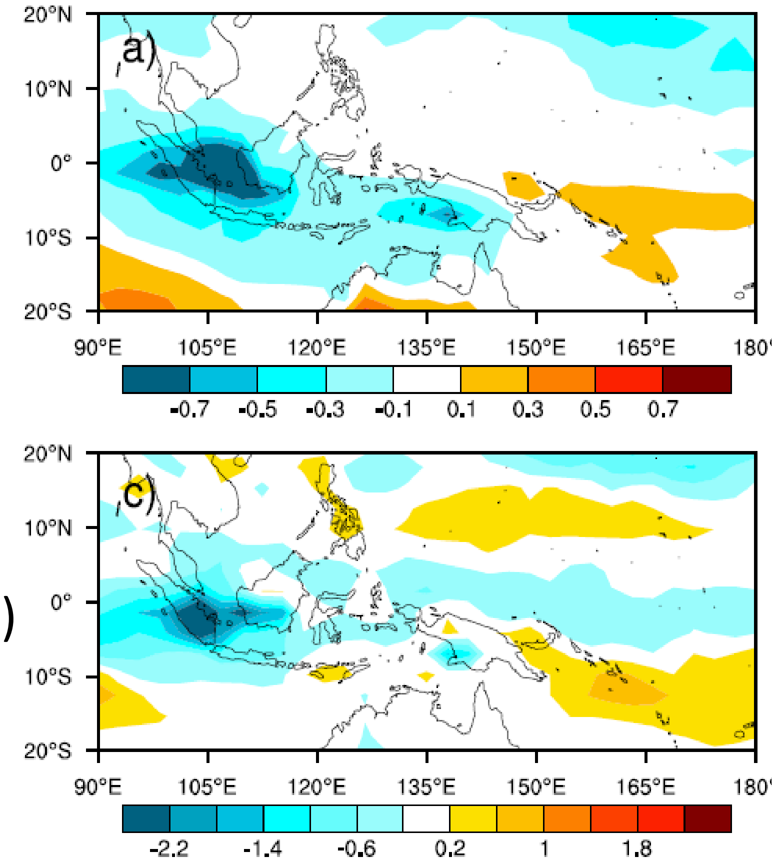
# Climate Response




Aug-Oct mean

Temp
( C)

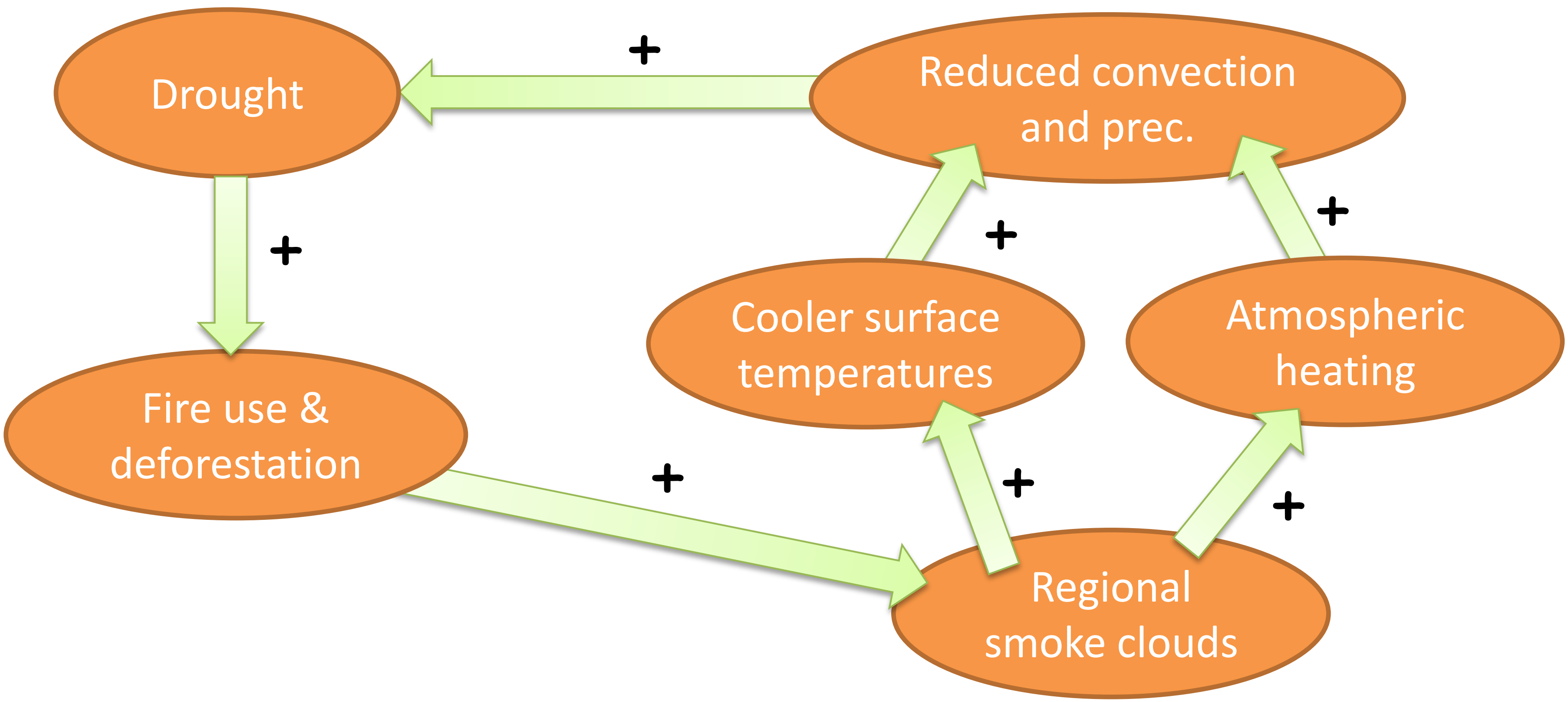
prec.
(mm day$^{-1}$)




Tosca et al. 2010 ACP

# Findings: Fire - climate interactions

- A plausible positive feedback loop exists during El Nino:




- a ~10% reduction in precipitation-> ~40% increase in emissions during El Nino

# What will exciting future research look like in our field?

- How will future changes boreal and temperate fires influence sea-level by changing the albedo of glaciers and ice sheets?
- How does biomass burning impact human health?
- Have ENSO dynamics been altered by tropical peat fires?
- Is the intensity of fire use changing on the deforestation frontier?
- How will the next generation of prognostic fire models in Earth System Models influence our understanding of the strength of climate-ecosystem feedbacks?

# What are the research needs of the community to realize this science program?

- Commitment to developing long-term fire records that span multiple decades and satellite platforms
- Systematic approaches for long-term monitoring of emission factors and relating them to environmental drivers
- Improved understanding and ability to simulate aerosol distributions and their direct, semi-direct, and indirect effects on atmospheric radiation and clouds
- A new satellite that simultaneously measures CO, $CH_4$, $CO_2$, and aerosol amounts
  - Technology exists
  - Would transform our understanding of source/sink processes associated with fires, deforestation, and emissions from agriculture and cities

# Acknowledgements

- Global Fire Emissions Team:
  - Guido van der Werf, Louis Giglio, Jim Collatz, Doug Morton, Prasad Kasibhatla, Ruth DeFries, Mingquan Mu
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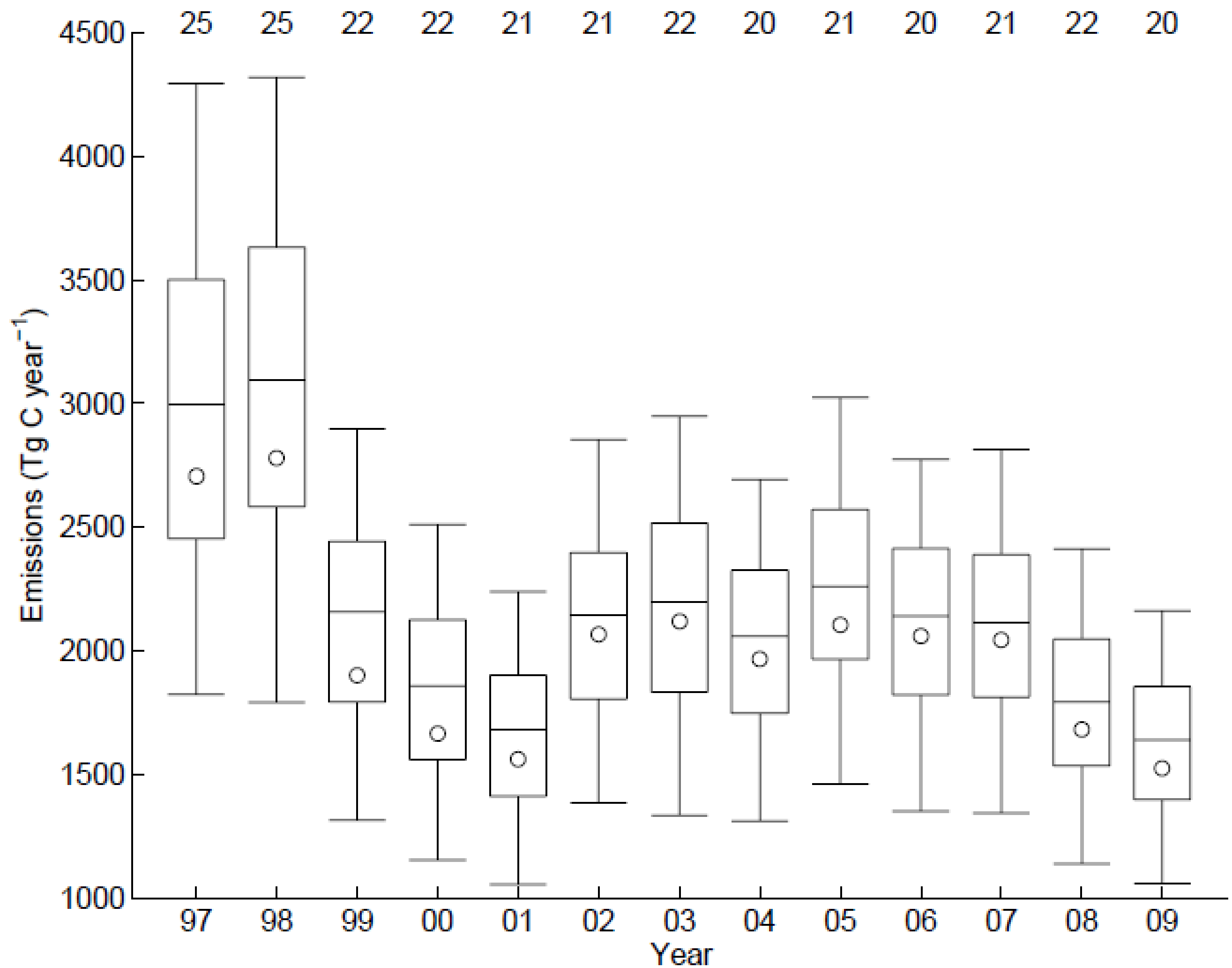
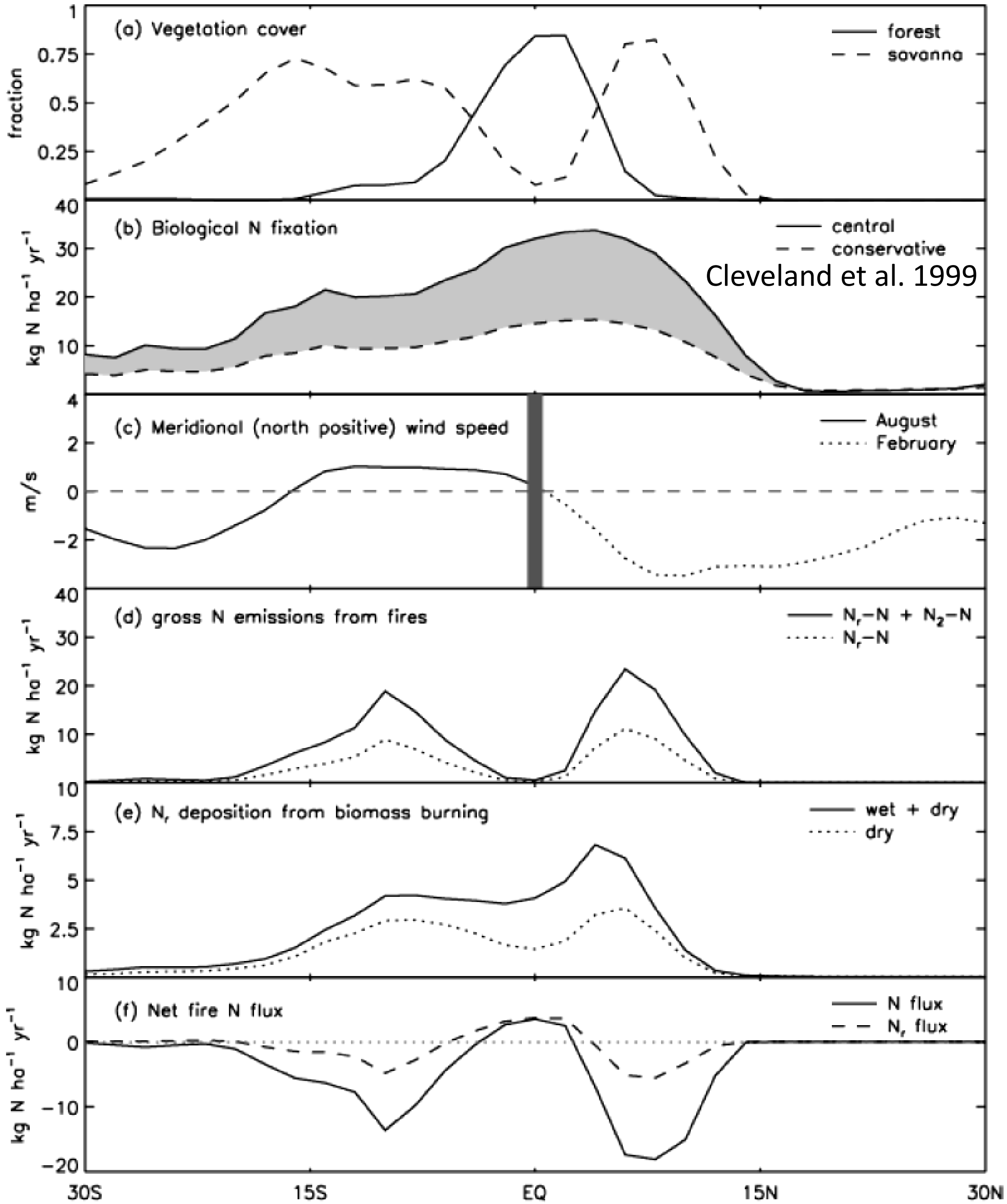
- CESM Biogeochemistry Working Group
- Funding support from NSF and NASA

Comments or questions: please email me: *jranders@uci.edu*

# Uncertainties remain substantial although much smaller than a decade ago




Van der Werf et al. (2010) ACPD




# Africa North-South Transect

Mean over

10 E-30 E

Chen et al. submitted to GCB

# Findings – Atmospheric N transport

- More than 25% of annual BNF in global savannas is lost to fire
- Equatorward transport of reactive nitrogen from savanna and deforestation fires may increase NPP and carbon storage in intact tropical forests
  - Long term carbon storage increasing in both Amazonian (Phillips et al., 2009) and African (Lewis et al., 2009) forests
  - P deposition in interior Amazon also enhanced by fires (Mahowald et al., 2005)
  - Nutrient loading from fires & land use change at the perimeter provides an alternate mechanism for fueling tropical C sinks
- Provides a basis for speculating that the Hadley Circulation may be sustained by coupled biogeochemical cycles

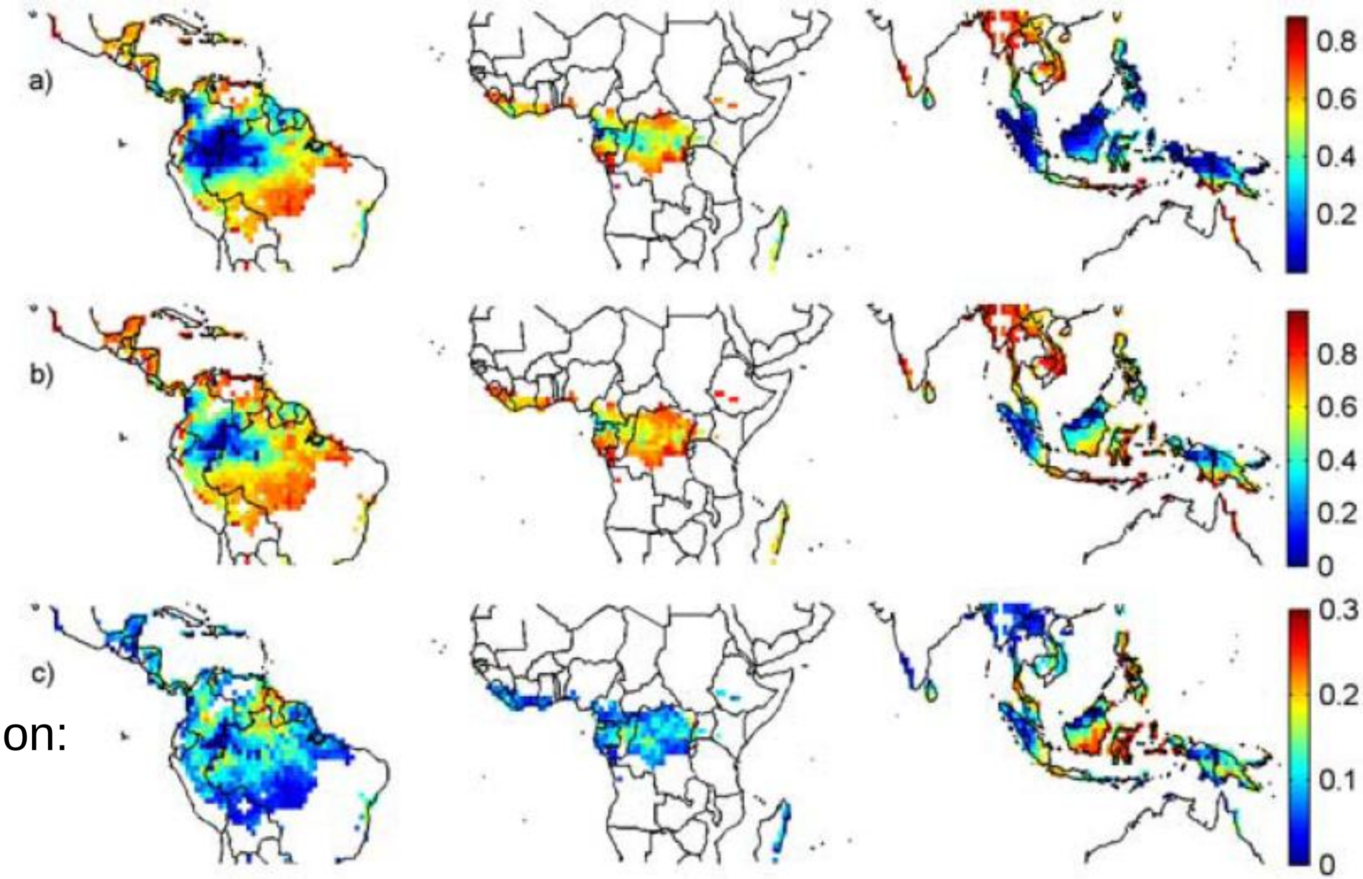
# Vulnerability of tropical forests to fire use varies considerably by continent

Fire-driven Deforestation Potential (FDP) scalar combines information about the length and intensity of the dry season

Mean (98-06):

Minimum:

Standard deviation:




Van der Werf et al. (2008) GBC