Emissions from savanna wildfires

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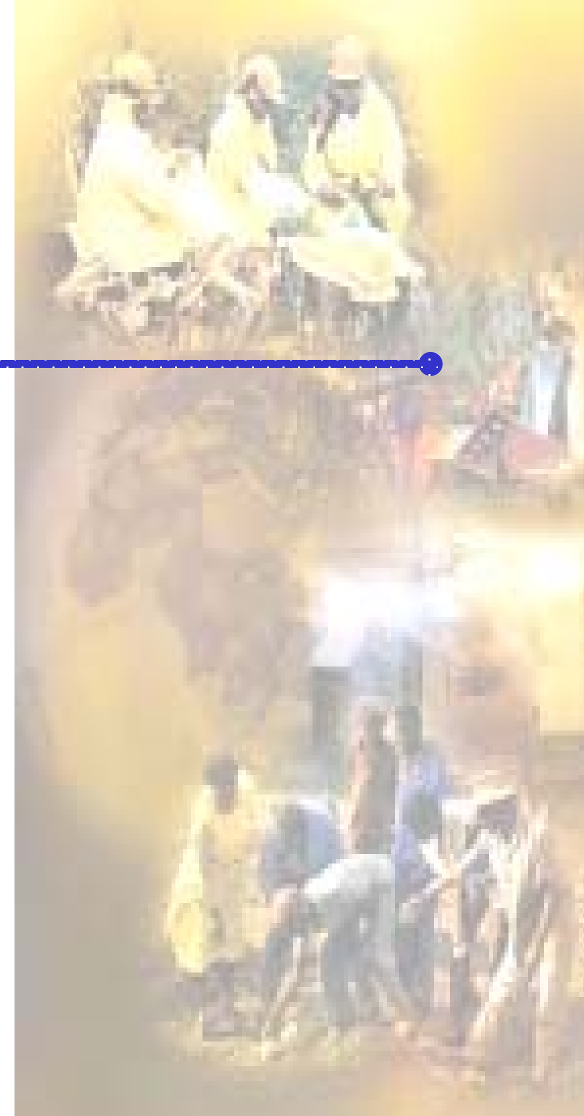
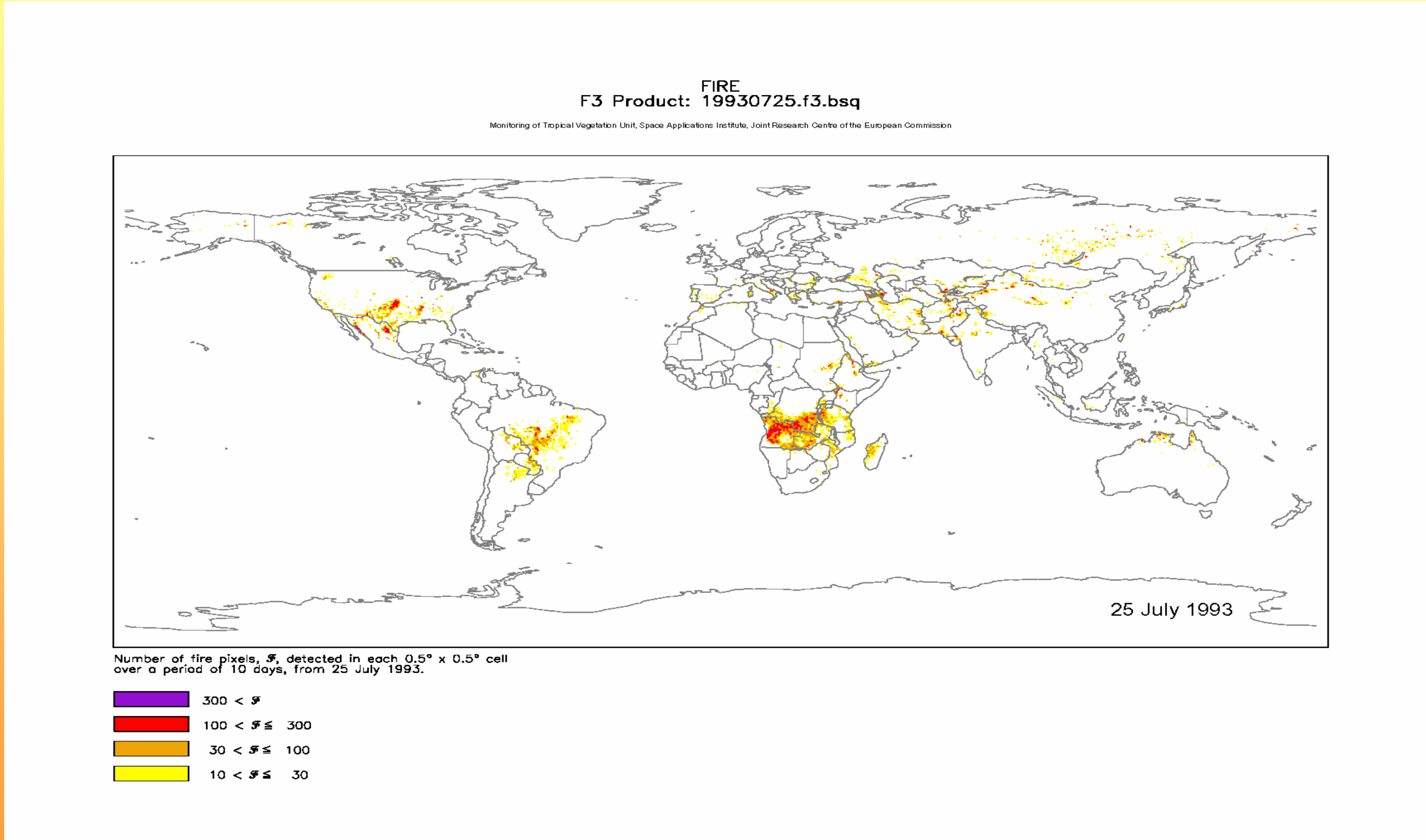


The major extent of wildfire is in savannas

Africa has 60% of the global savanna area



Active fire products: Global Fire Atlas, Modis, AVHRR, DMSP, etc

Key sources

Special edition of JGR 101(D19) for results of SAFARI 92 (1996)

Special edition of JGR 108 (D13) for results of SAFARI 2000 (2004)

How much trace gas is emitted by fires in Africa? An unresolved controversy

Example: carbon monoxide, savannas in Africa south of the equator

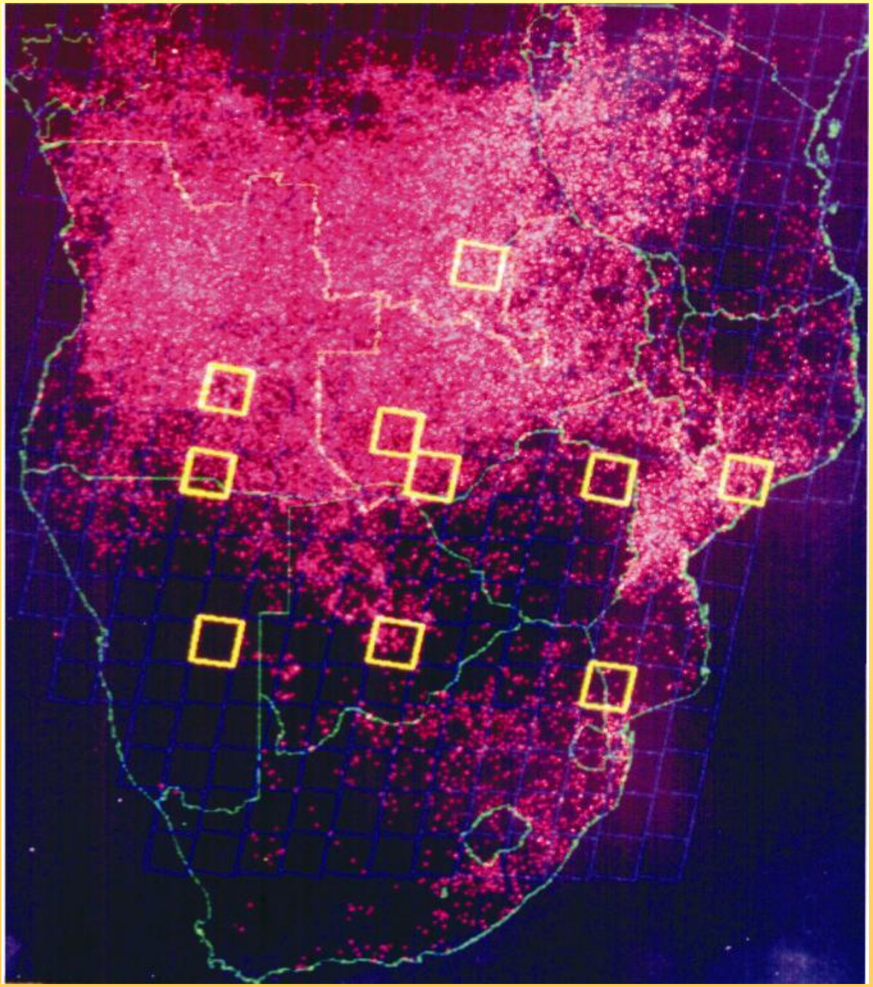
Variable	**Hao *et al* 1990**	**Scholes *et al* 1996**
Area burned (M km^2)	3.05	1.33
Fuel burned (Tg)	576	129
Emission factor (g/kg)	105	58-127
Emission (Tg)	60.5	8.7

Hao, WM et al 1990 Ecological Studies 84,440-462
Scholes, RJ et al 1996 JGR 101, 23667–76, 23677-82

Outline

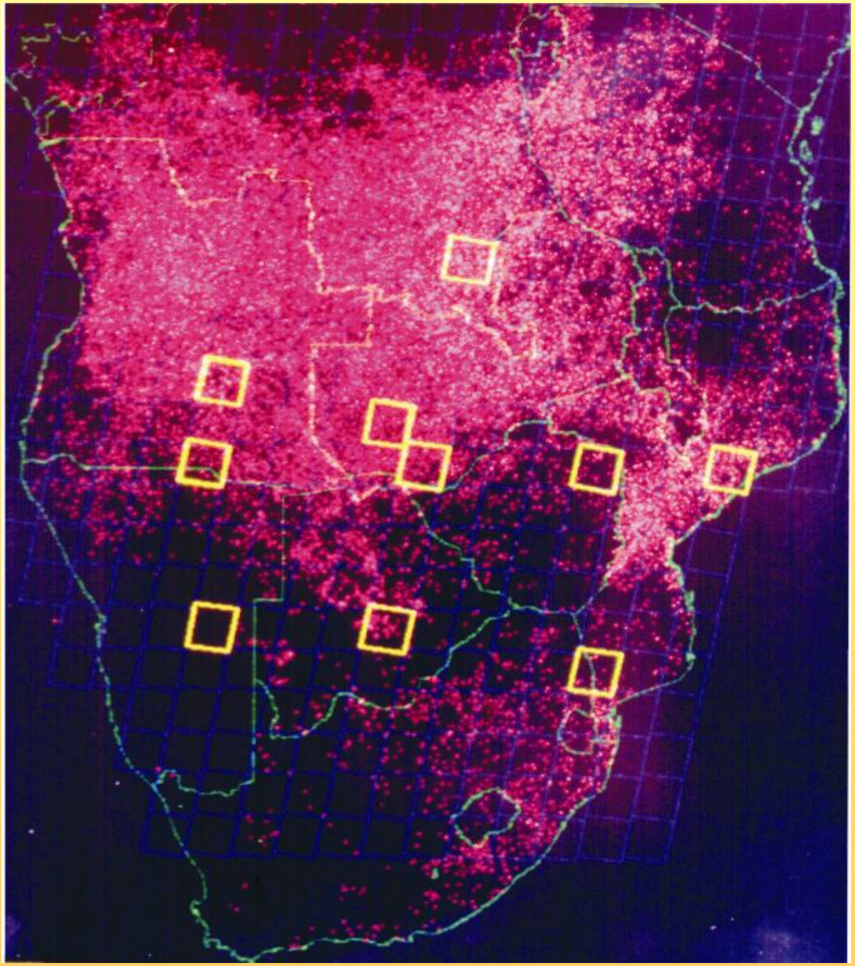
- **Why do savannas burn?**
- **What area of savannas burn?**
- **How much fuel is consumed?**
- **What gases and particles are emitted?**
- **What are the consequences?**

Why does Africa burn?

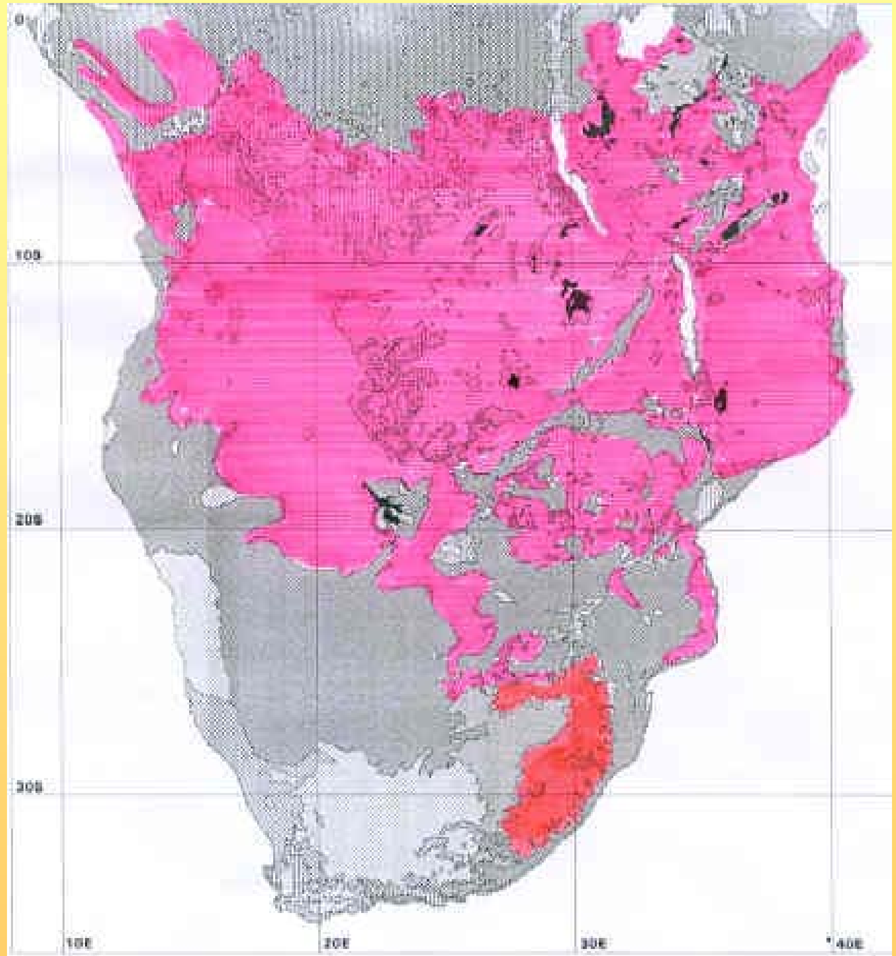


Active fires
May-Oct 1989
NOAA_AVHRR
J Kendall, NASA

The infertile savannas and grasslands burn

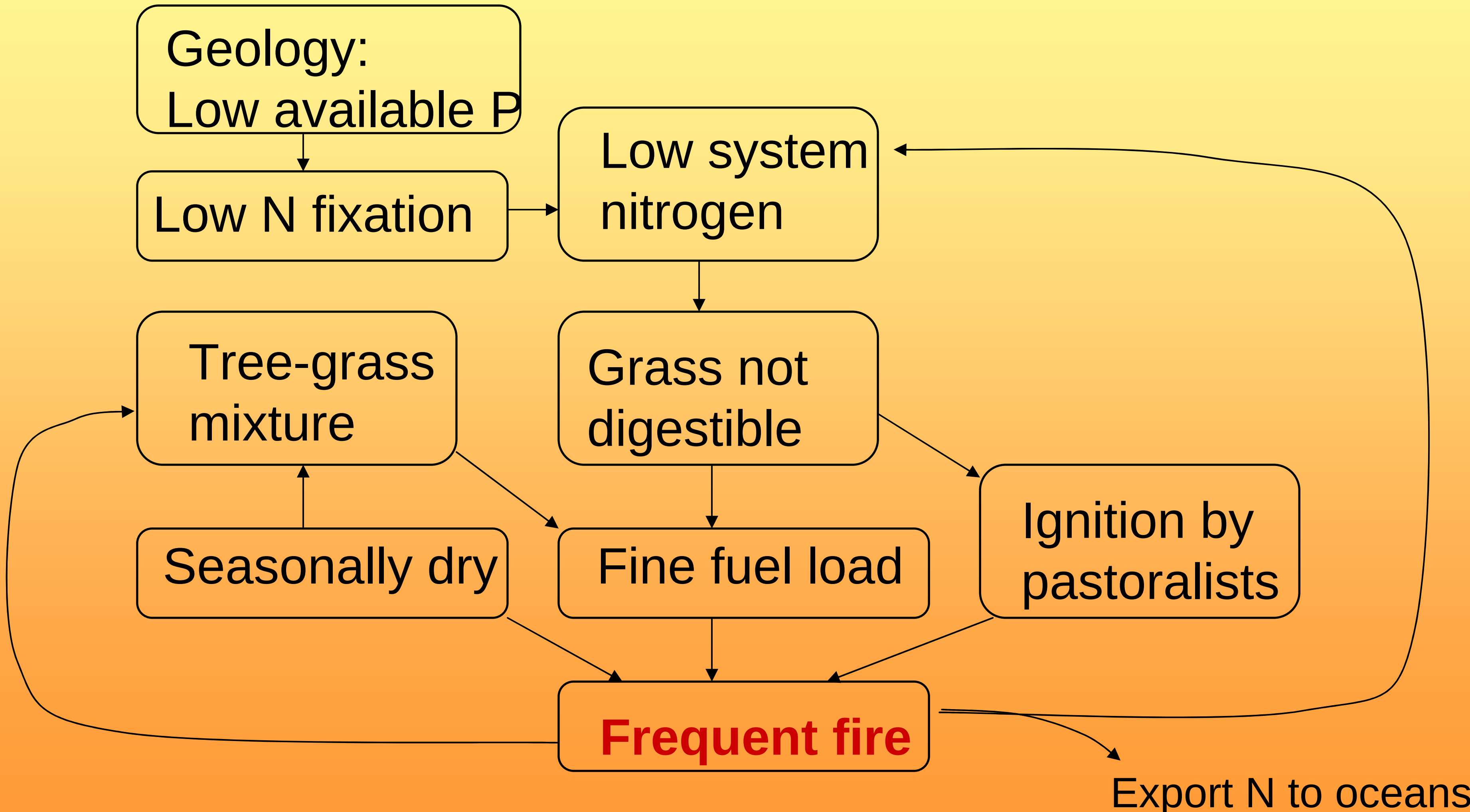


Fires in Africa, May-Oct 1989
Scholes et al JGR 101, 23677



Infertile savannas and grasslands
Van Wilgen & Scholes 1997 In 'Fires in African savannas' Witwatersrand UP ch 3.

Continental-scale biogeochemistry



Africa has burned for millennia

Environmental evidence of frequent fires in Africa for

~ 5 million years

- Seasonal wet/dry in place since current continental configuration established
- Coevolution of life history strategies
- Nutrient poor savannas are indirect evidence of a long-term nitrogen leak

In Africa, *people* are the ‘natural’ source of fire

- For the past million years, hominids have been the main igniters of ‘wild’ fire
- Lightning adds ~10% of current ignitions
- *Hypothesis*
  - Fewer ignitions in pre-colonial landscape, but greater extent of individual fires
  - Therefore the area burned was roughly similar

Homo habilis

The basic wildfire emissions model

Emission = Area * Fuel * Completeness * Emission Factor

Emission	Area	Fuel	Completeness	Emission Factor
kg	km^2	$g\ m^{-2}$	$g\ g^{-1}$	$g\ kg^{-1}$

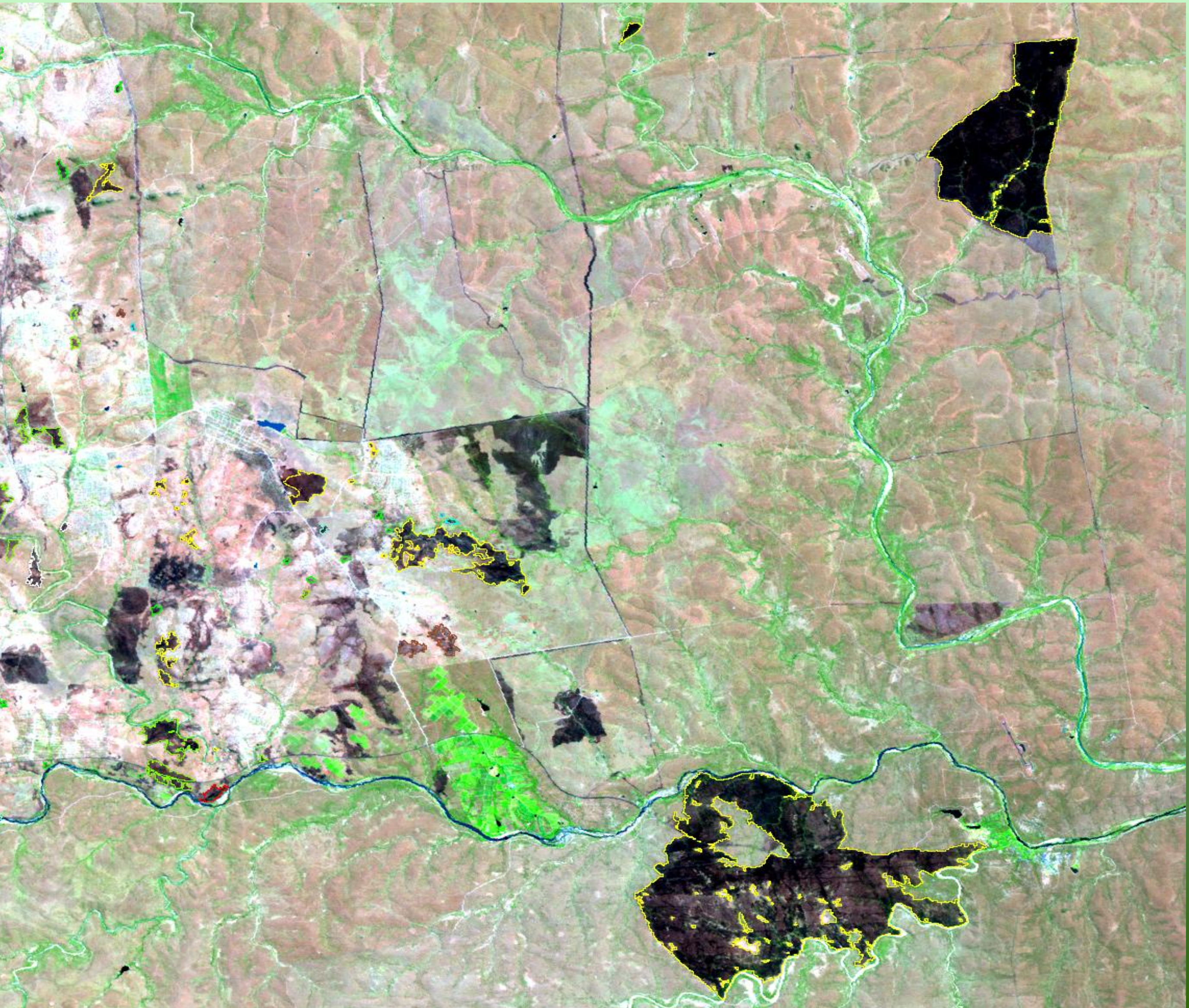
Can be applied to whole ecoregions, or on a pixel-by-pixel basis

Seiler and Crutzen (1980) *Science*

Approaches to burned area estimation

- Calibrated active fire product
  - Uses AVHRR, Modis or Envisat thermal data
  - Area burned per hot pixel varies greatly
- Automatic fire scar measurement
  - Uses time series of moderate resolution Vis and NIR data to detect drop in albedo
- In situ or high-resolution image manual mapping
  - Most accurate, but time-consuming

Overestimation of burned area



High-resolution post-fire imagery shows that a smaller fraction of the landscape burns than is indicated by low-resolution or active fire products

Skukuza
3 Sep 2001

What fraction of southern Africa burns?

Data from large conservation areas

Location	Area Mha	Mean Annual Rainfall	Fraction burned
Hluhluwe 1960-2000	0.09	700	0.26
Pilanesberg 1989-96	0.06	650	0.33
Hwange 1967-91	1.5	620	0.2
Kruger 1946-96	1.9	500	0.22
Etosha 1970-79	2.22	450	0.12

- **Larger fractions burn in the years after good rains**
- **Lightning ignites 10-20% of fires**
- **Burned fraction is not highly dependent on fire management policy**

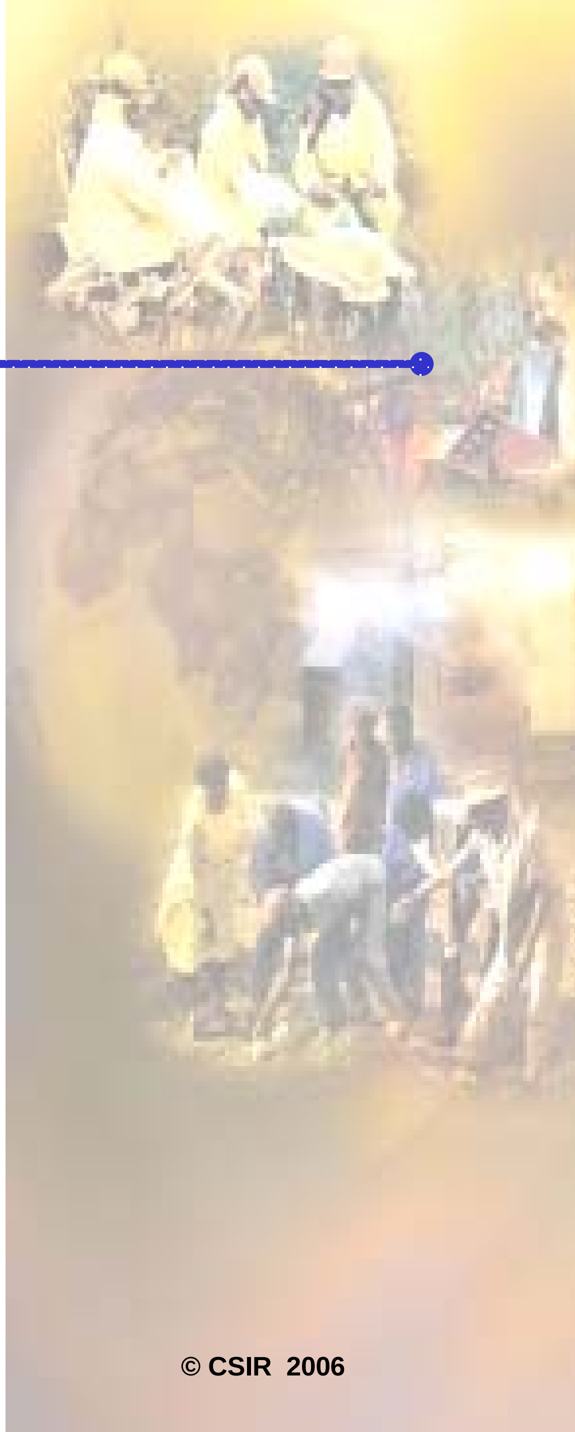
Balfour, D (pers com) Kwazulu-Natal Nature Conservation
Brockett, BH et al 2001 Intl J Wildland Fire 10, 169-183
Van Wilgen BW et al 2000 SA Jnl Science 96, 167-178
Rogers, CML 1993 Woody veg survey of Hwange NP
Siegfried, WR1981 Madoqua 12, 225-30

Fuel loads in savannas

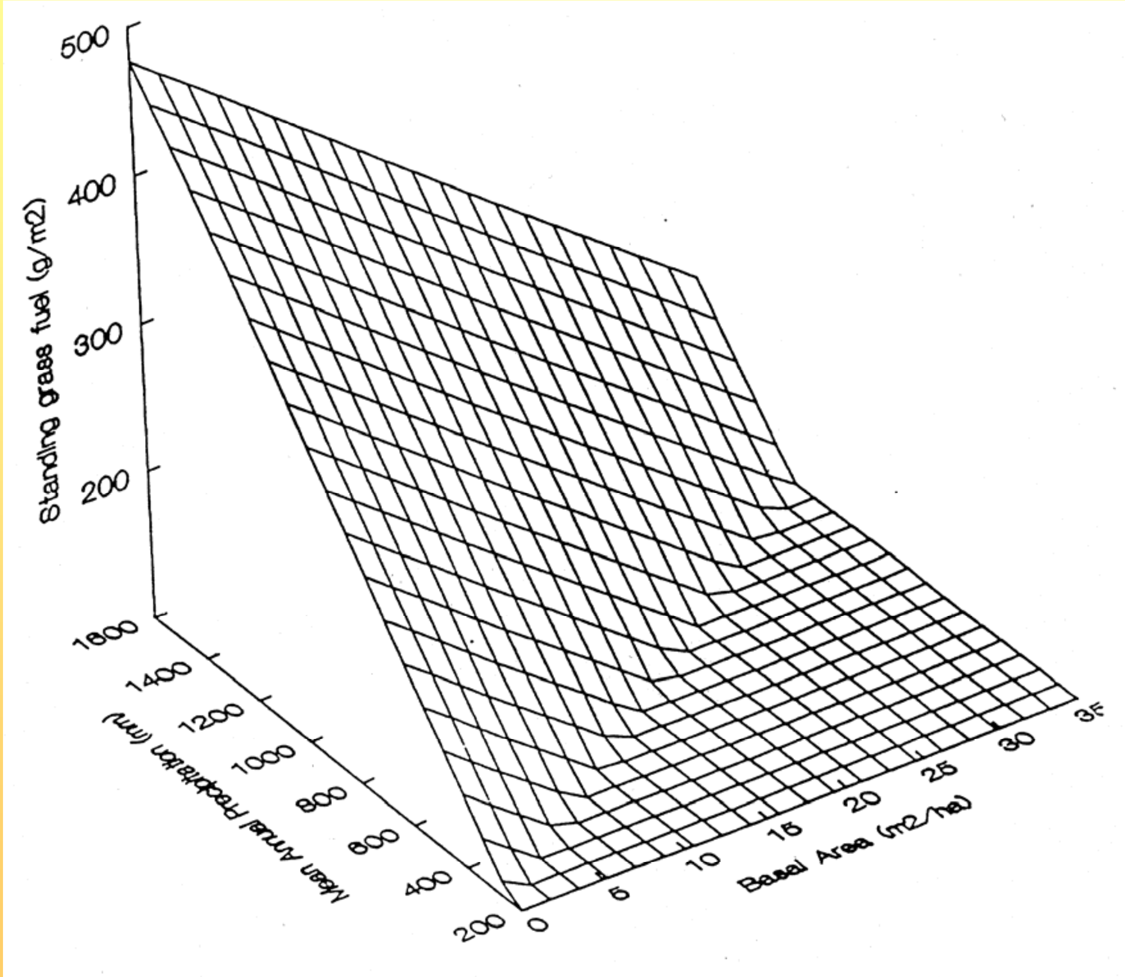
(Amount exposed to fire, not amount burned or total organic matter present)

Fuel component (g/m^2)	Mean	Max
Dry grass	150	1000
Tree leaf litter	100	500
Twigs (< 2 cm ϕ)	50	200
Large woody debris	50	5000
Shrub green leaf, dung etc	10	100

Eg Shea *et al* JGR 101 23558-61 (1996)



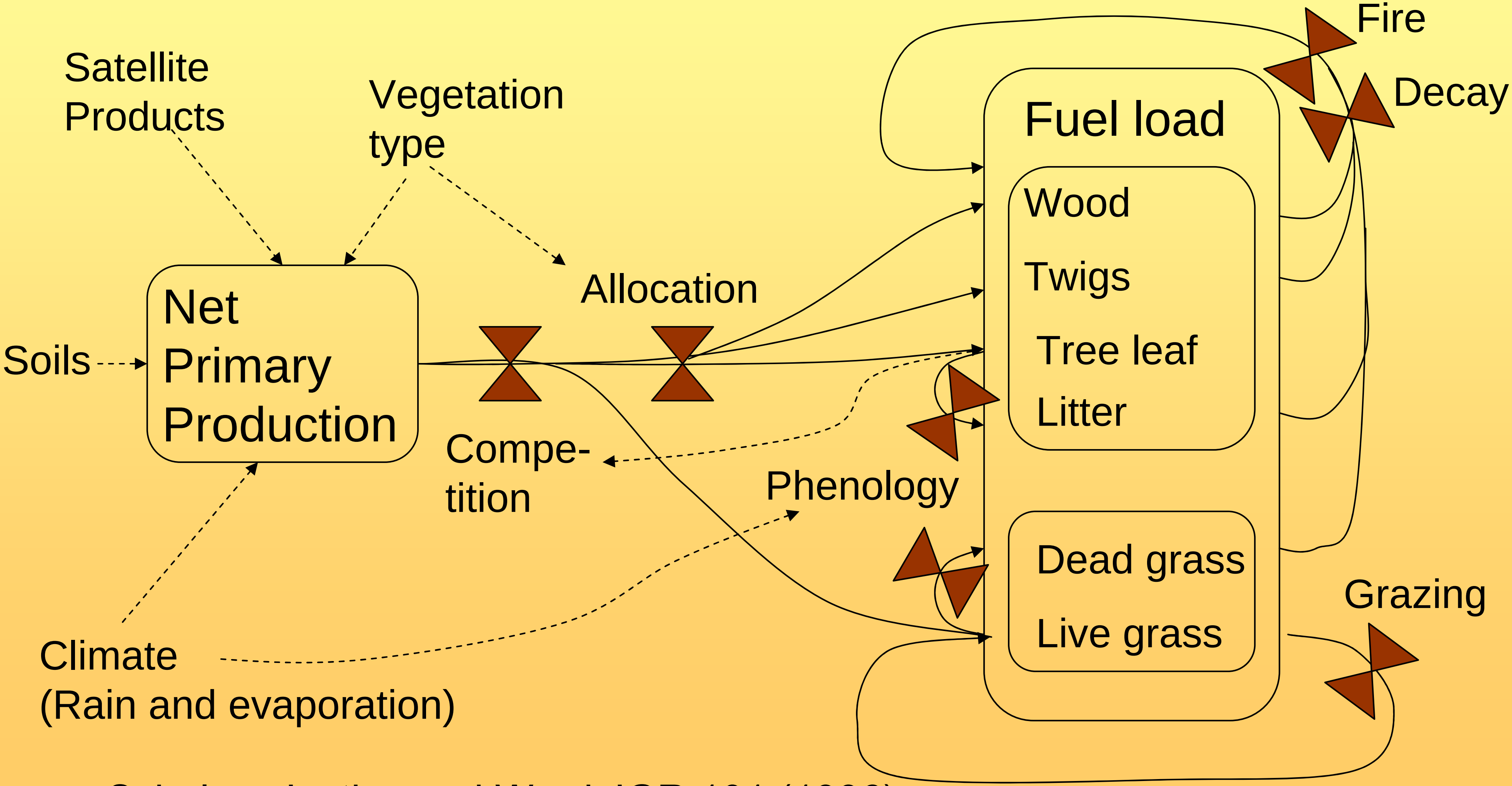
Measured fuel loads in savannas



Mangue, P 1997 Fuel loads in southern Africa. MSc, University of the Witwatersrand

Calculating fuel load dynamically

Iterate monthly, for duration of the inter-fire period +1

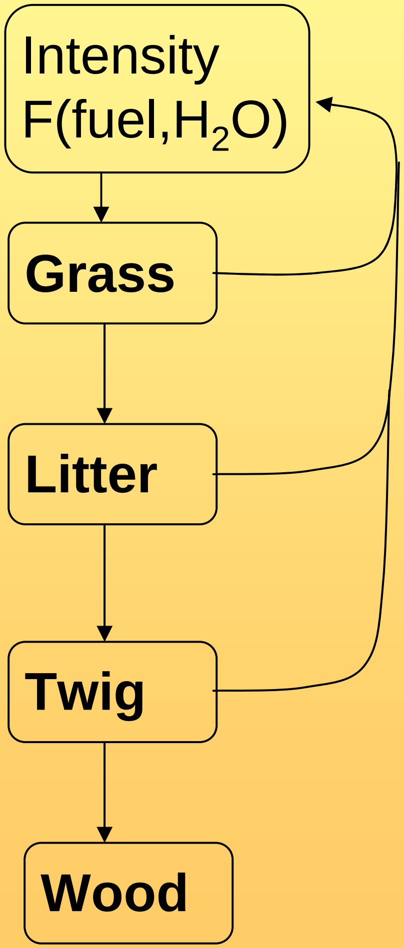


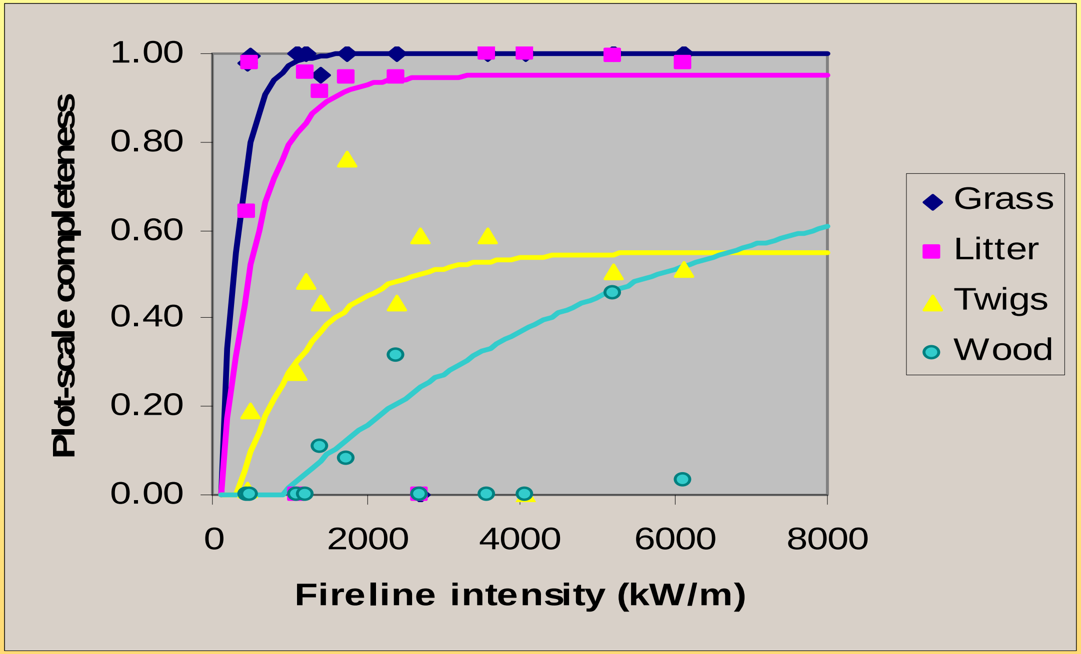
See eg Scholes, Justice and Ward JGR 101 (1996)

Combustion completeness

Fraction of exposed fuel that actually burns

$$C_{plot} = a(1-\exp(-b(I-I_0)))$$



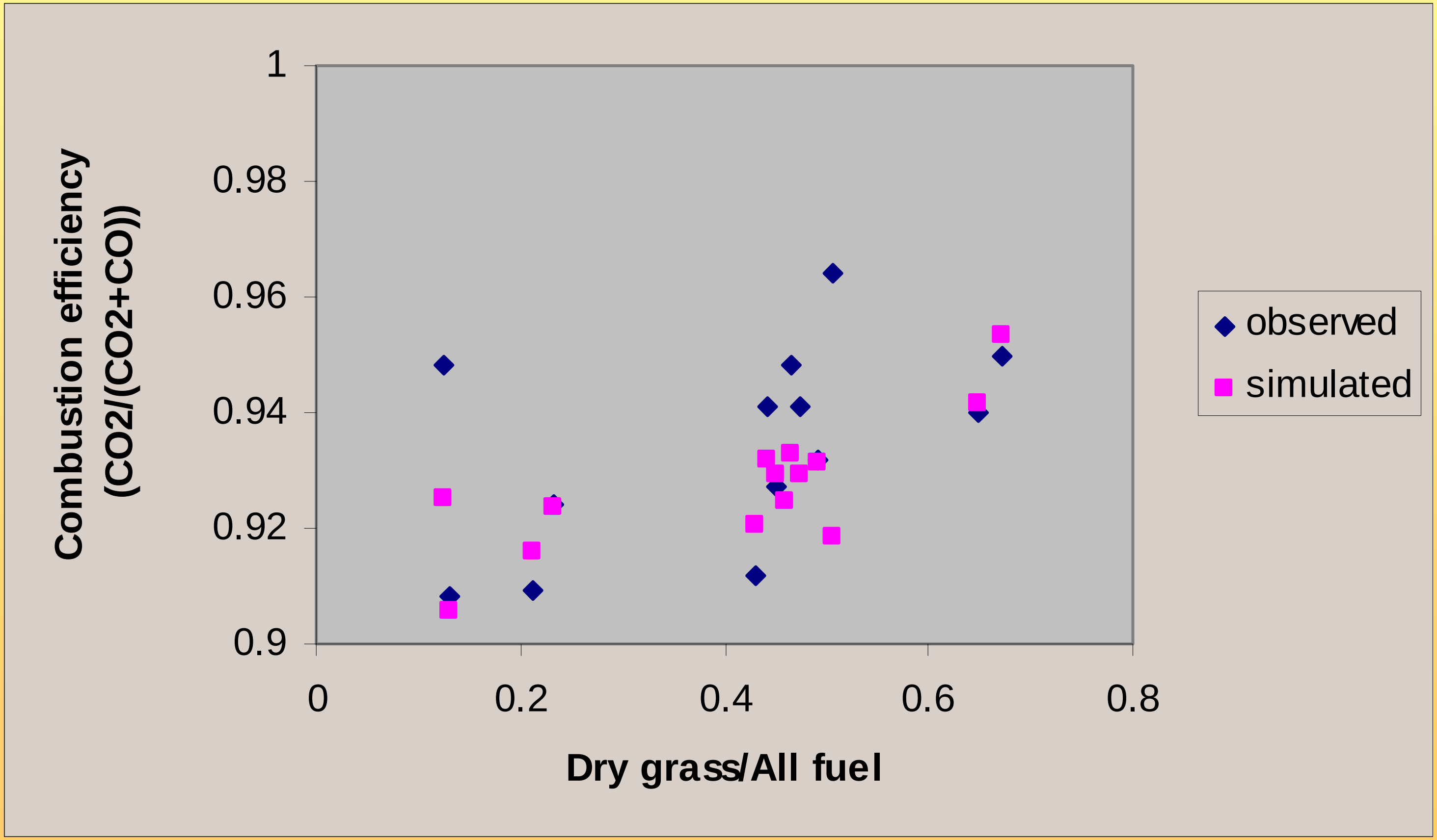


	a	b	Io
Grass	1	.004	100
Litter	.95	.002	100
Twig	.55	.001	300
Wood	.8	.0002	900

Combustion efficiency

A measure of the the oxidation conditions in the fire

CE = (0.96*dry grass+0.94*live grass+0.91*twigs+0.85*wood+0.94*leaf)/all fuel



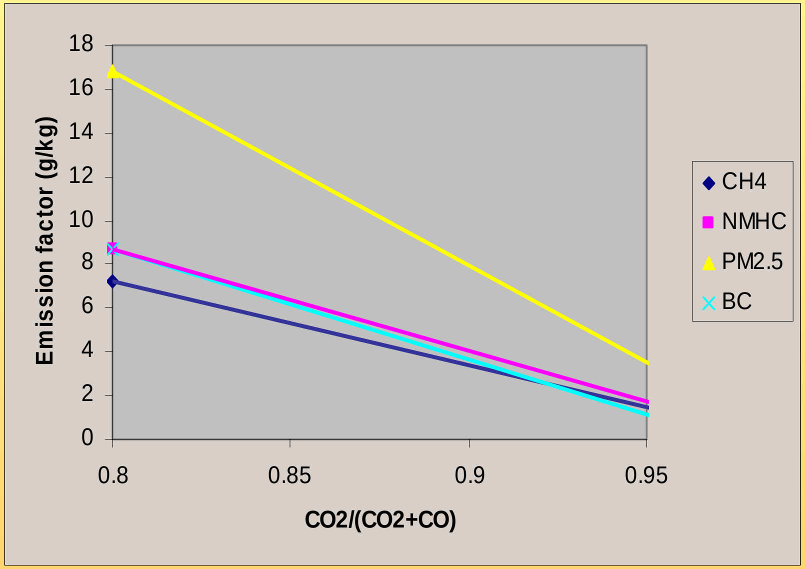
n=11
$r^2 = 0.63$
f=17.04
$p<0.002$

Data: Shea et al JGR 101, 23551-68

Emissions of gases and aerosols

$$EF(g/kg) = a*CO_2/(CO+CO_2) + b$$

Gas	a	b	Source
Carbon dioxide	1701	0	1
Carbon monoxide	-1081	1081	1
Methane	-38.1	37.7	2
NMHC	-46	45.46	1
PM2.5	-88.51	87.65	1
Black carbon	0.65	0	3

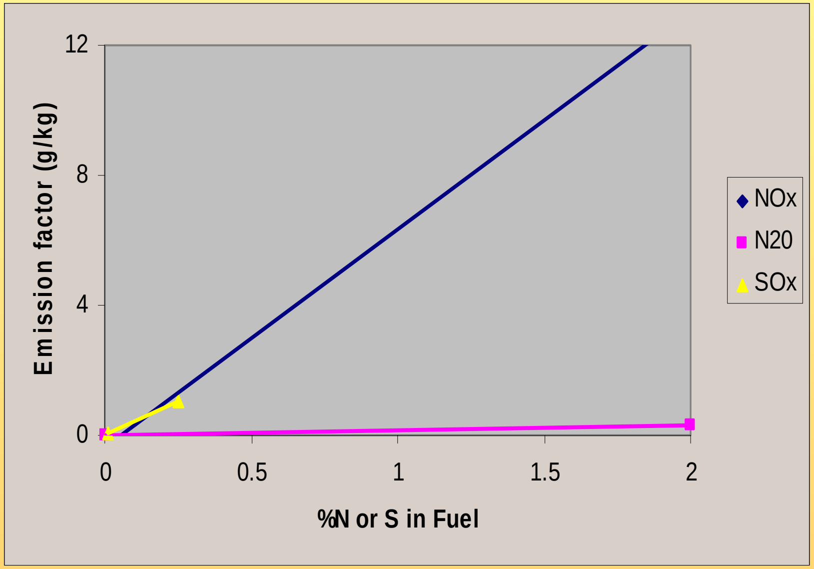


1	Ward et al JGR 101, 23569-76
2	Hao et al JGR 101 23577-84
3	Kuhlbusch JGR 101, 23651-55

Nitrogen and sulphur-containing gases

EF (g/kg) = a* %N + b; EF (g/kg) = a* %S + b

Gas	a	b	Source
NOx	6.69	-0.35	4
N2O	0.163	0	5
SOx	4.3	0	3



3	Kuhlbusch JGR 101, 23651-55
4	Lacaux JGR 101, 23585-96
5	Lobert and Warnatz 1993 in Biom

Sources of pyrogenic products

Africa south of the equator, Tg/y ~1990

	Source	CO	Aerosol	CH_4	NO_x
Biomass	Wildfire	14.9	2.2	0.50	1.04
	Home fires	14.2	1.5	0.31	0.25
	Land clearing	4.7	0.5	0.11	0.14
Fossil	Industry	0.4		0.02	1.83
	Transport	2.7		0.04	0.48
	Total	**40.0**		**0.98**	**3.74**
	Non-fire sources	0.5		>0.32	0.29

Scholes & Scholes SAJS 94, 422-5, Hao et al 1990, Marufu et al, Fleming et al

Impact on global warming

- **There is no evidence for an overall increase or decrease in wildfire extent in Africa**
  - **Less in dry years, more in wet years**
- **Therefore assume a zero *net* impact on additional post-1750 radiative forcing**
- **CO_2 approximately balanced, but**
  - **Net radiative forcing due to non-CO_2 gases and aerosols**
  - **Small export of long-lived carbon to the oceans**

Potential for management

- Fire management in Africa could lead to a greenhouse gas ‘sink’ lasting several decades
  - Net uptake of CO_2 due to woody plant growth
  - Less emission of CO, CH_4 and NO_x and aerosols
- Co-benefits
  - less pollution, fewer deaths, loss of property
- Disbenefits
  - Possible loss of biodiversity
  - More catastrophe fires when they do occur
  - Reduced long-term biospheric sink

Conclusions

- Pyrogenic trace gases from savannas are a significant atmospheric perturbation, with high interannual variability
- Can be estimated using a combination of remote sensing, models and measurementsuel load
- Burned area estimation is much improved as a result of new algorithms
- Fuel load is now the biggest error term