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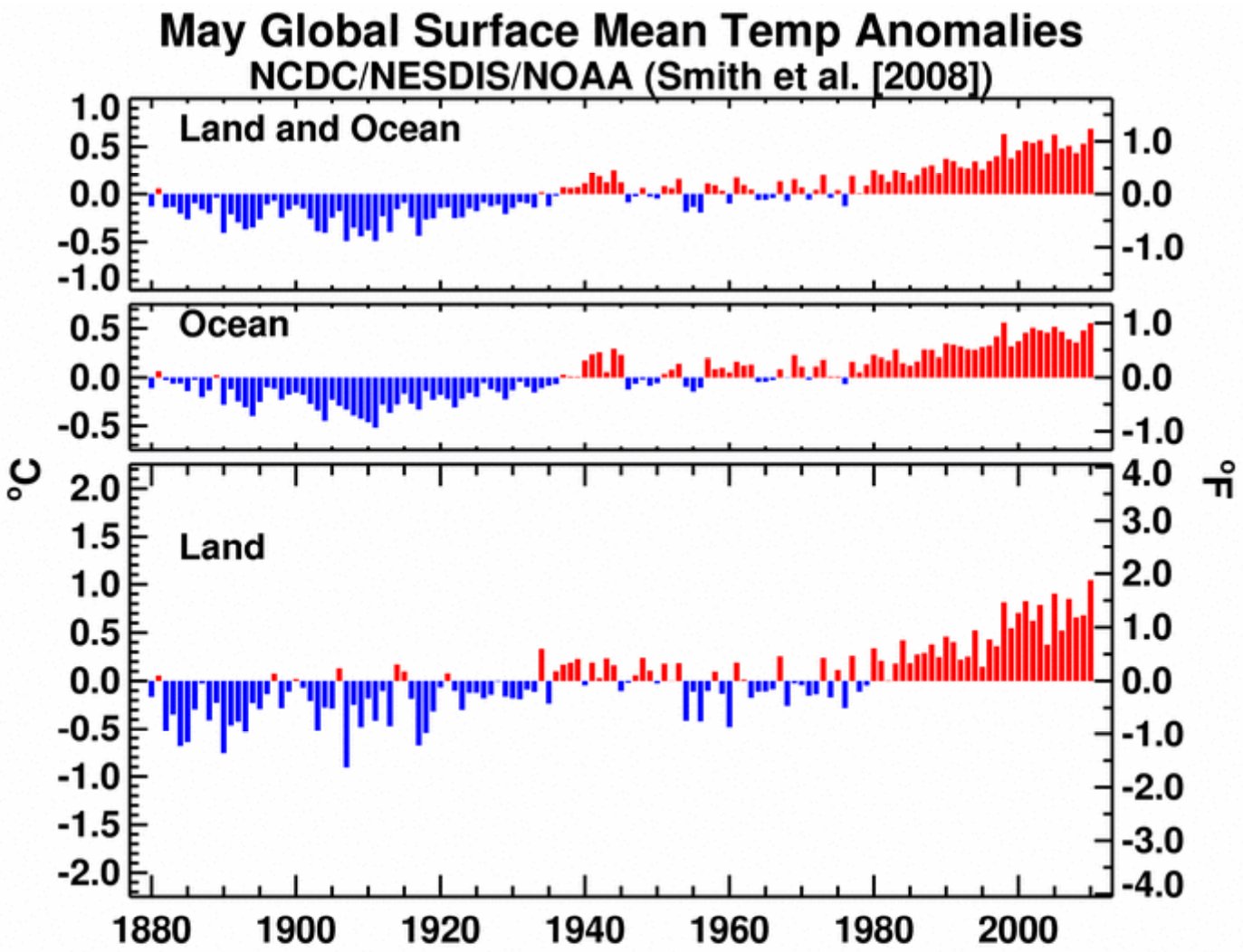
Overview of Carbon Dioxide and Methane Cycle Research

Apr 18, 2013 at 南京信息工程大学

Discussion Topics

- Climate change and global warming
- Causes of climate change
- Large-scale research
  - Global observation network
- Ecosystem-scale methods
  - chamber-based flux measurement
  - ecosystem flux
- Methane flux

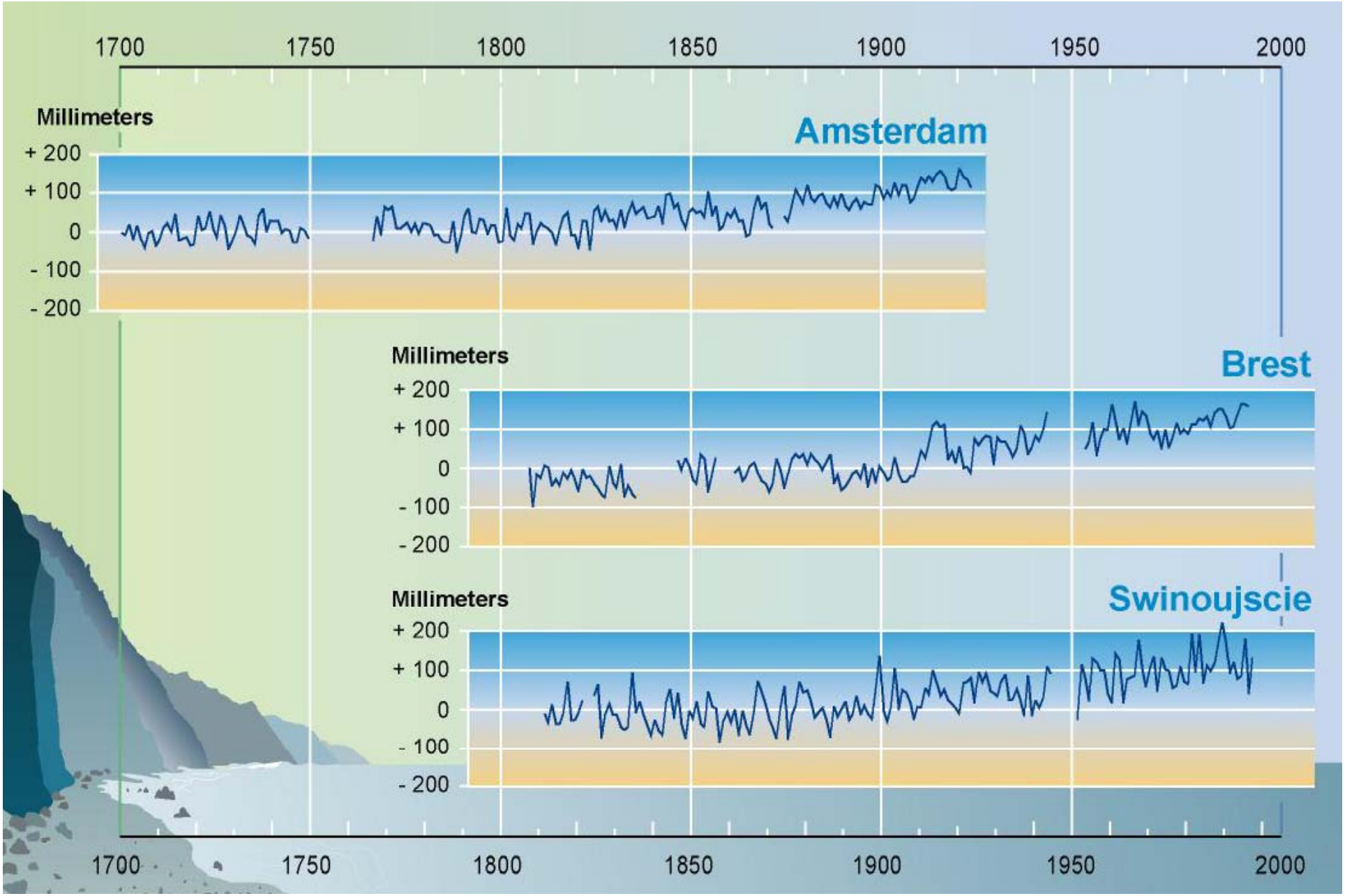


Courtesy of IPCC

Glacier retreat !

New Denver Glacier
British Columbia, Canada

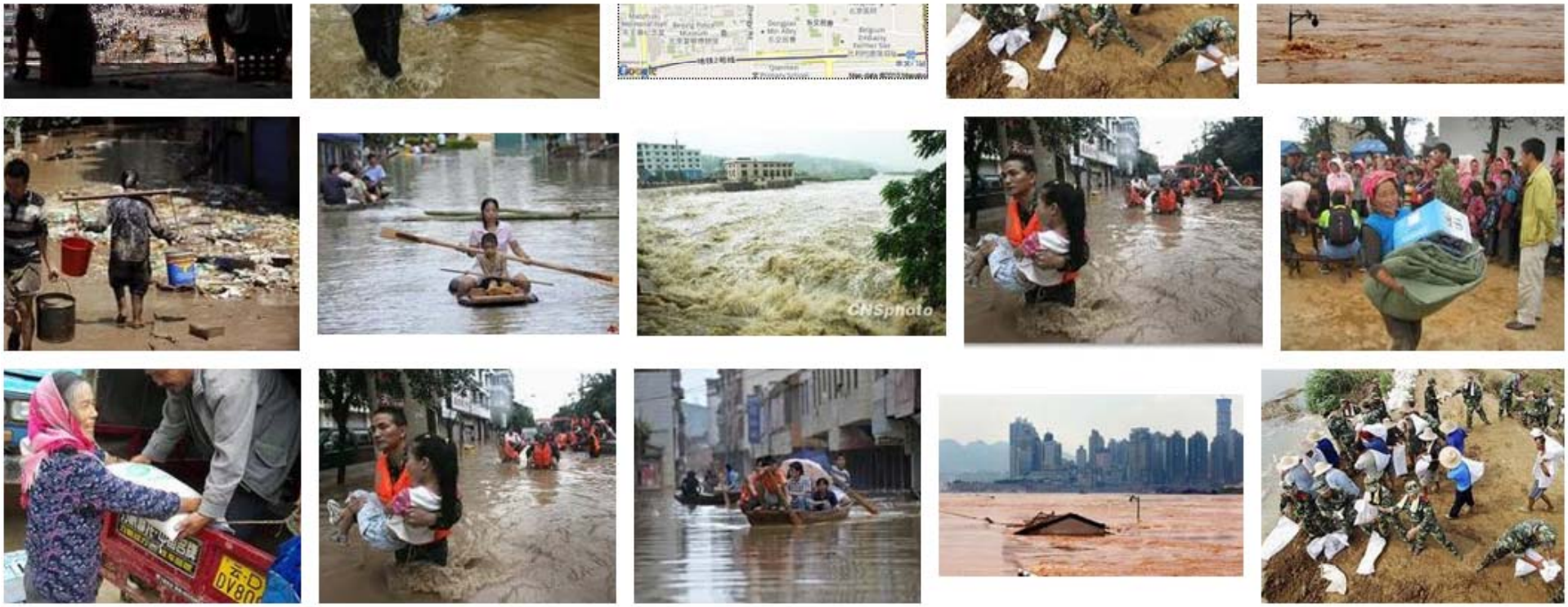
Sea Level Rise



Hydrological Cycle Disrupted

Spring of 2010 that affected Yunnan, Guizhou, Guangxi, Sichuan, Shanxi, Henan, Shaanxi, Chongqing, Hebei and Gansu.

Hydrological Cycle Disrupted



Page 2

Flooding in China 2010 Summer

Damage by 2010 flood

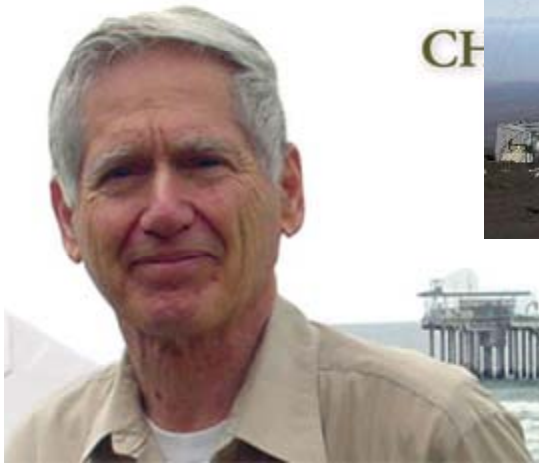
Duration	May to Sept 2010
Fatalities	3189+ dead, 1056+ missing
Damages:	$ 51.4 billion
Areas affected:	28 provinces, autonomous regions and municipalities

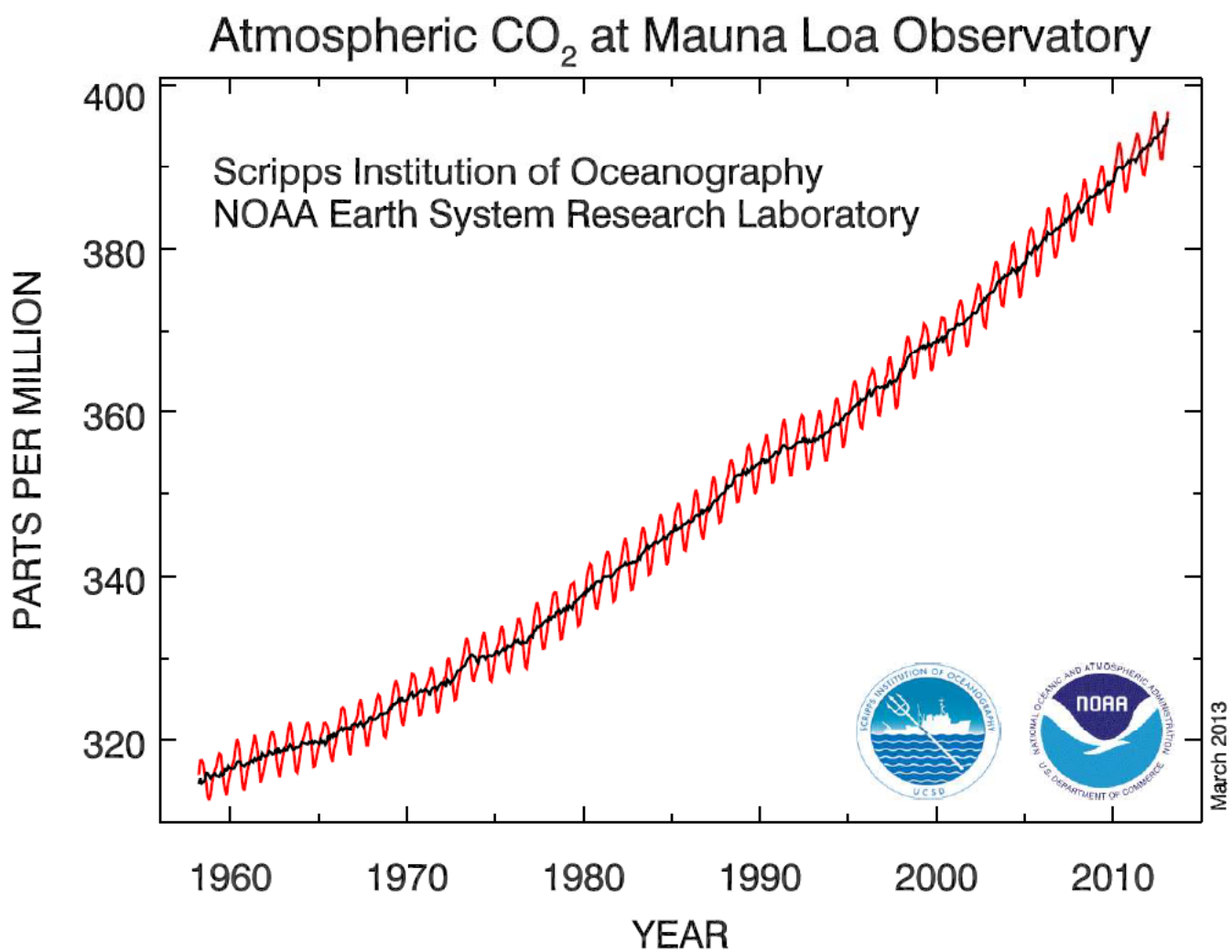
Flooding in China 2010 Summer

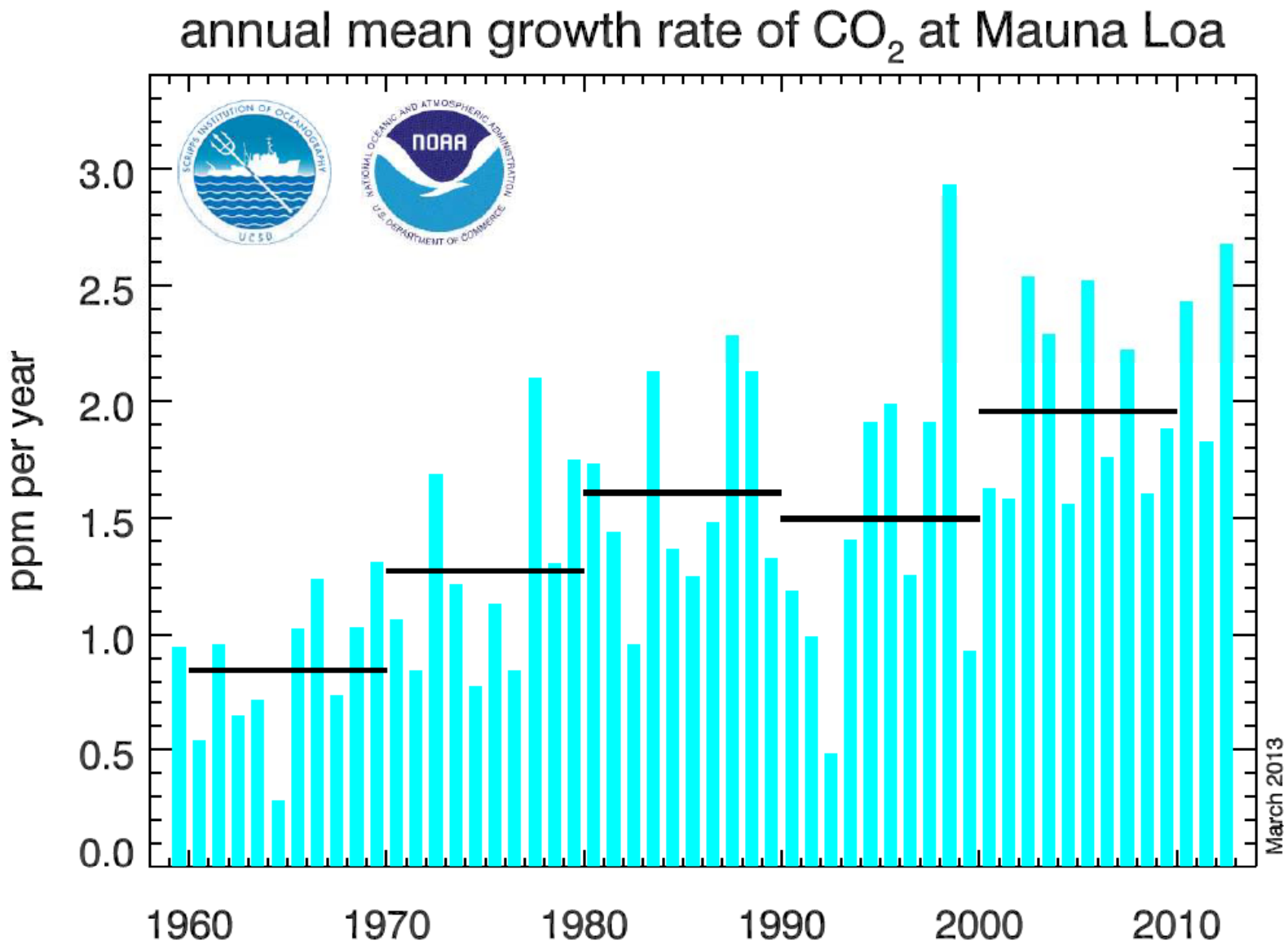
2012 Arizona dust storm


Mauna
Loa

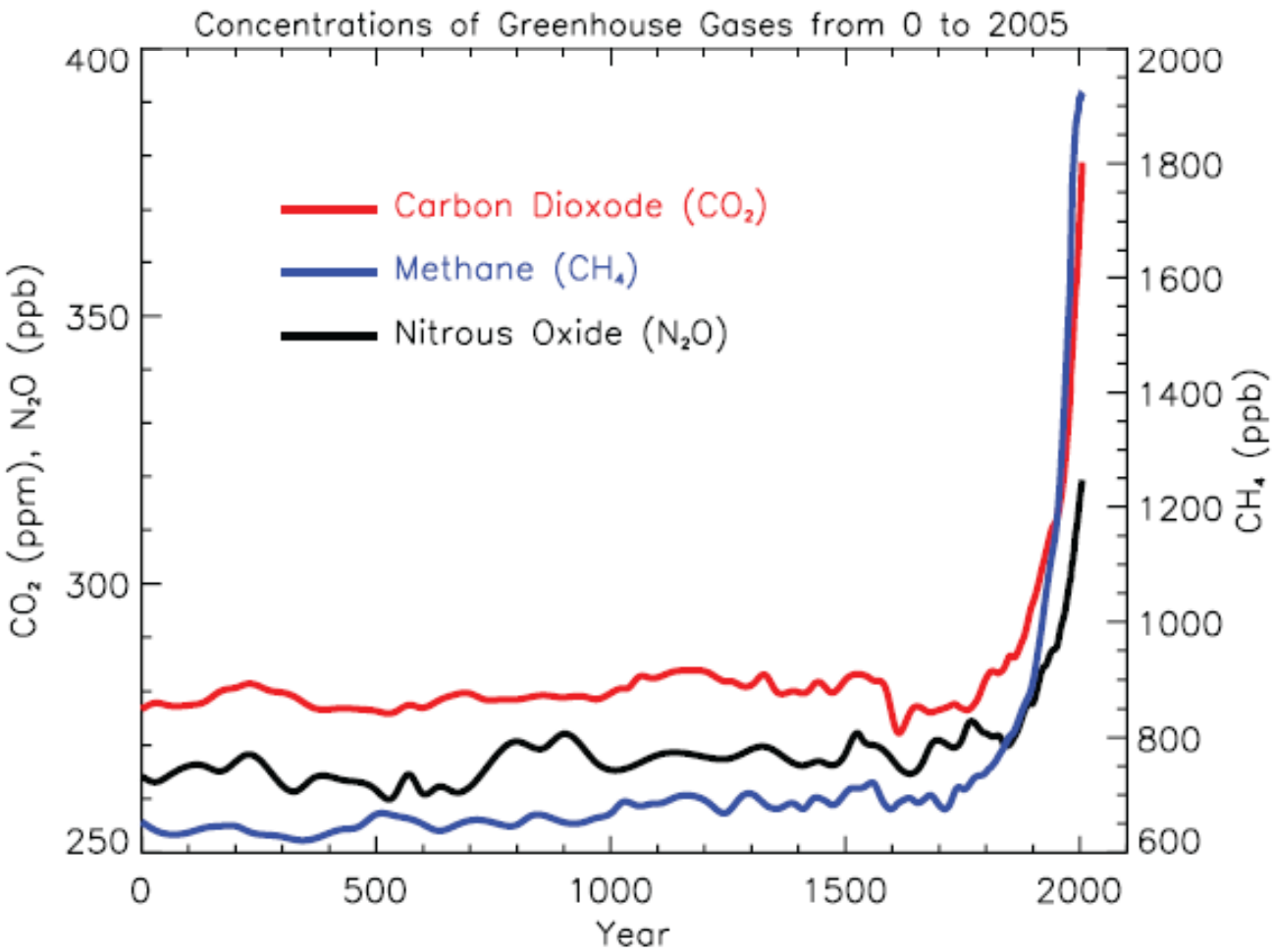

Dedication June 28, 1956




Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
March 2013


annual mean growth rate of CO_2 at Mauna Loa
ppm per year
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1960
1970
1980
1990
2000
2010
March 2013

Atmospheric CH_4 Growth Trend



Greenhouse Effect

	Concentrations[b] and their changes[c]		Radiative Forcing[d]	
Species[a]	2005	Change since 1998	2005 (W m^{-2})	Change since 1998 (%)
CO_2	379 ± 0.65 ppm	+13 ppm	1.66	+13
CH_4	1,774 ± 1.8 ppb	+11 ppb	0.48	-
N_2O	319 ± 0.12 ppb	+5 ppb	0.16	+11

Radiative forcing is usually quantified as the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere due to the presence of the gas species.' When radiative forcing is evaluated as positive, the energy of the Earth-atmosphere system will ultimately increase, leading to a warming of the system.

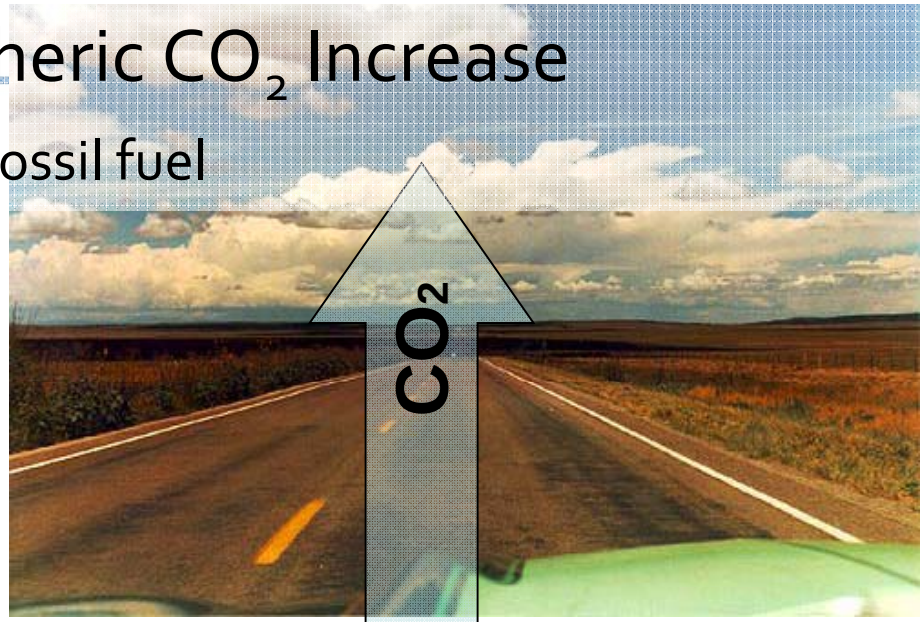
IPCC 2007, Changes in Atmospheric Constituents and in Radiative Forcing

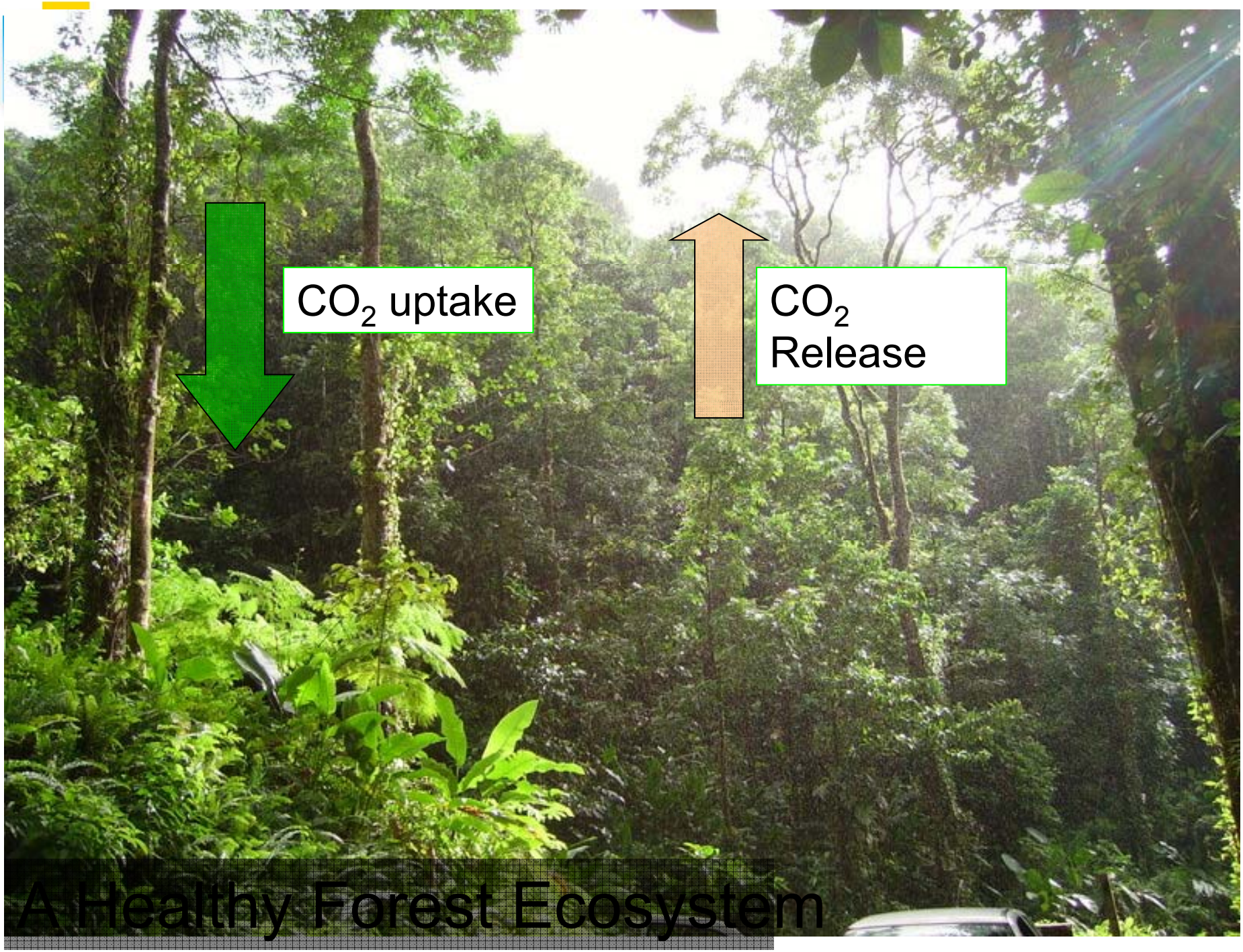
Causes of Atmospheric CO_2 Increase

Burning fossil fuel

Causes of Atmospheric CO_2 Increase

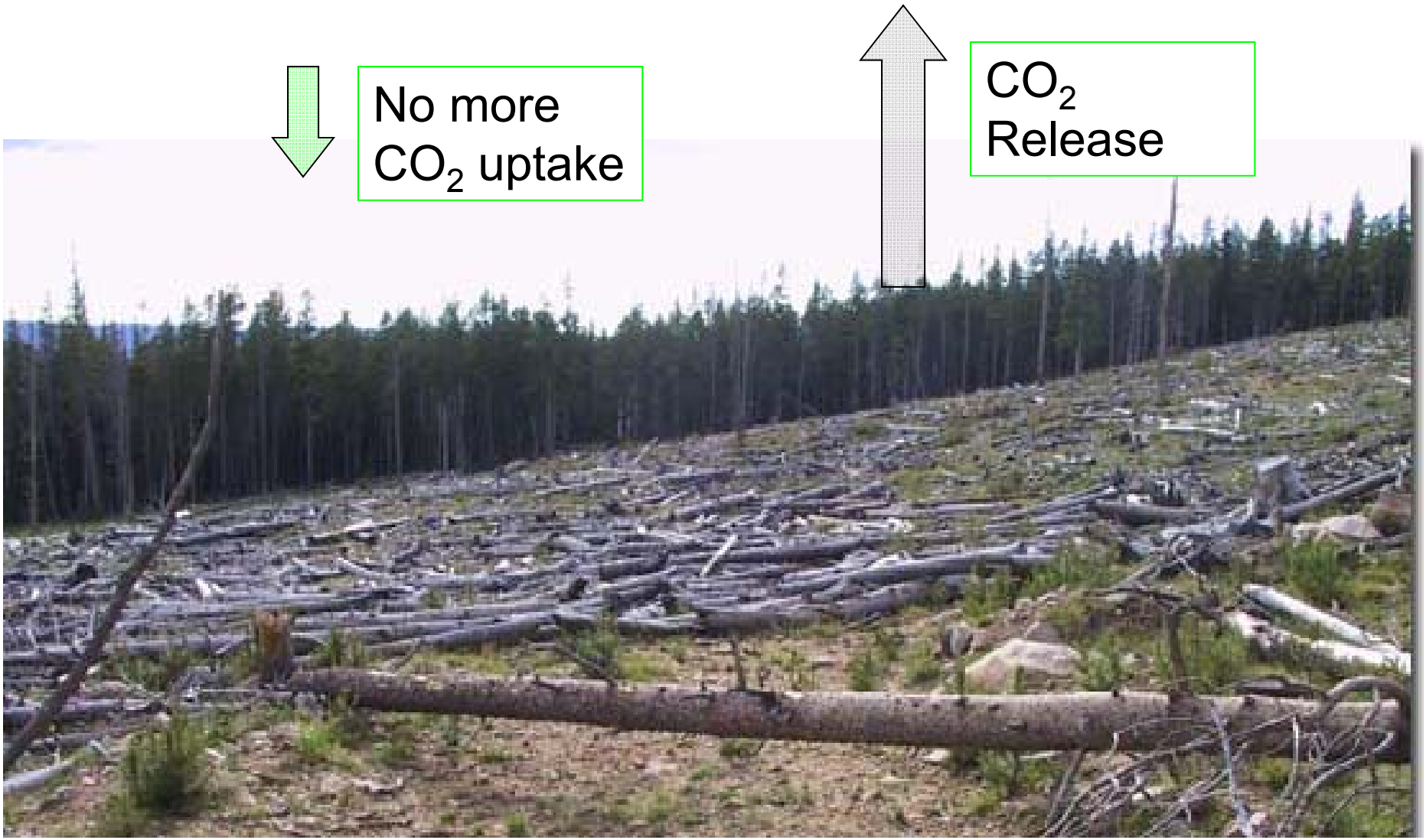
Burning fossil fuel





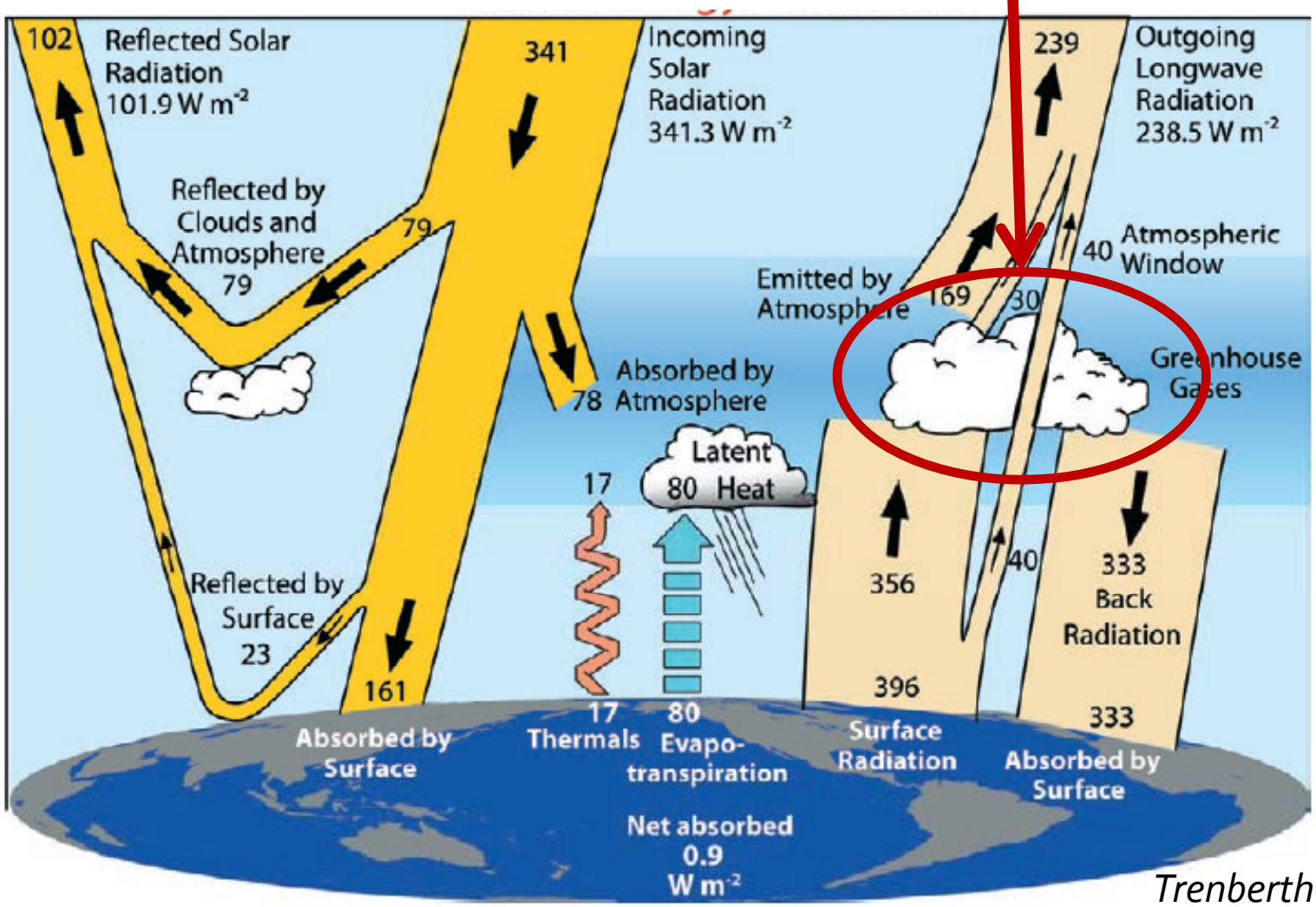
A Healthy Forest Ecosystem

Causes of Atmospheric CO_2 Increase; Deforestation

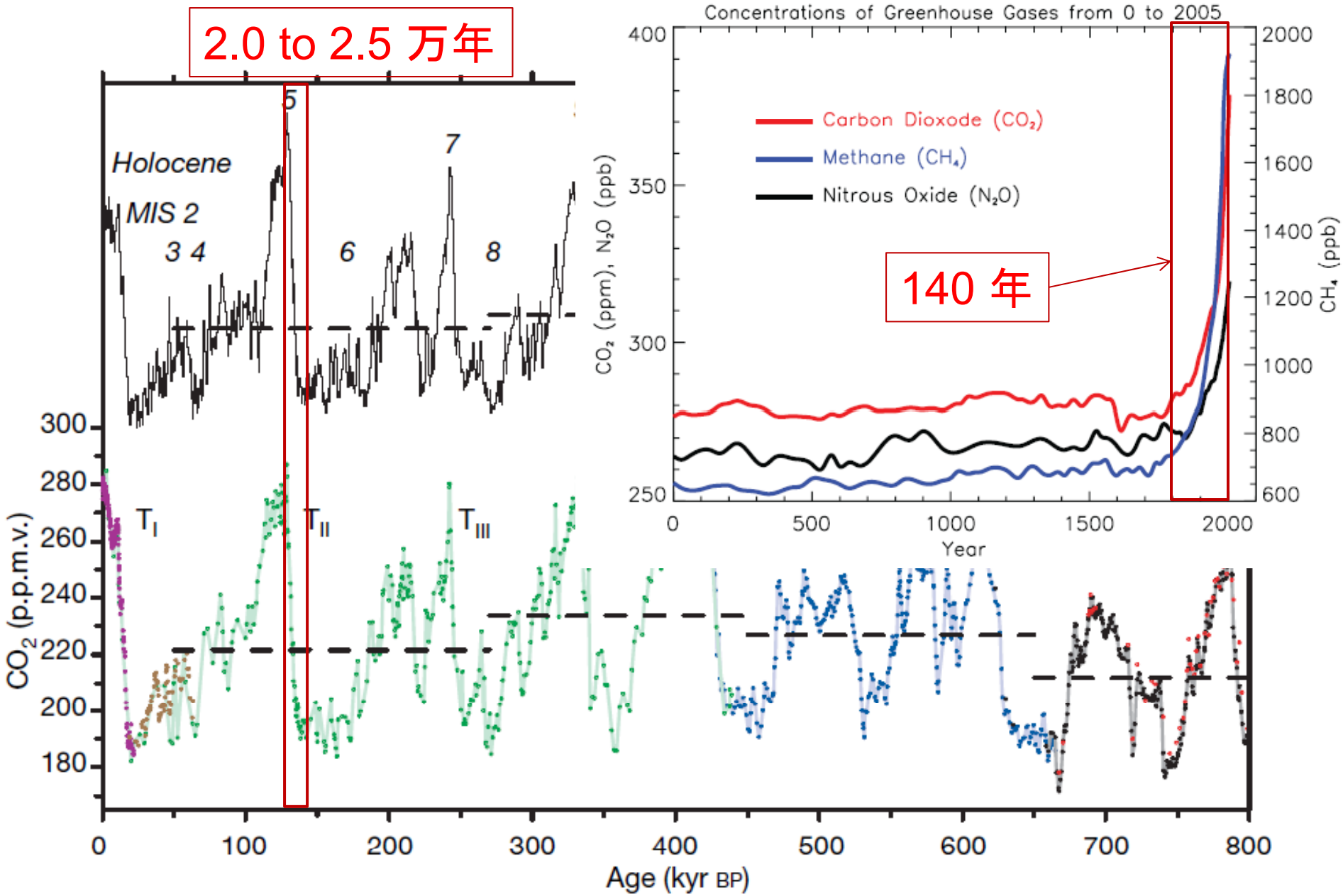


Global Energy Flow (W m^{-2})

This component is affected



Trenberth et al., 2009



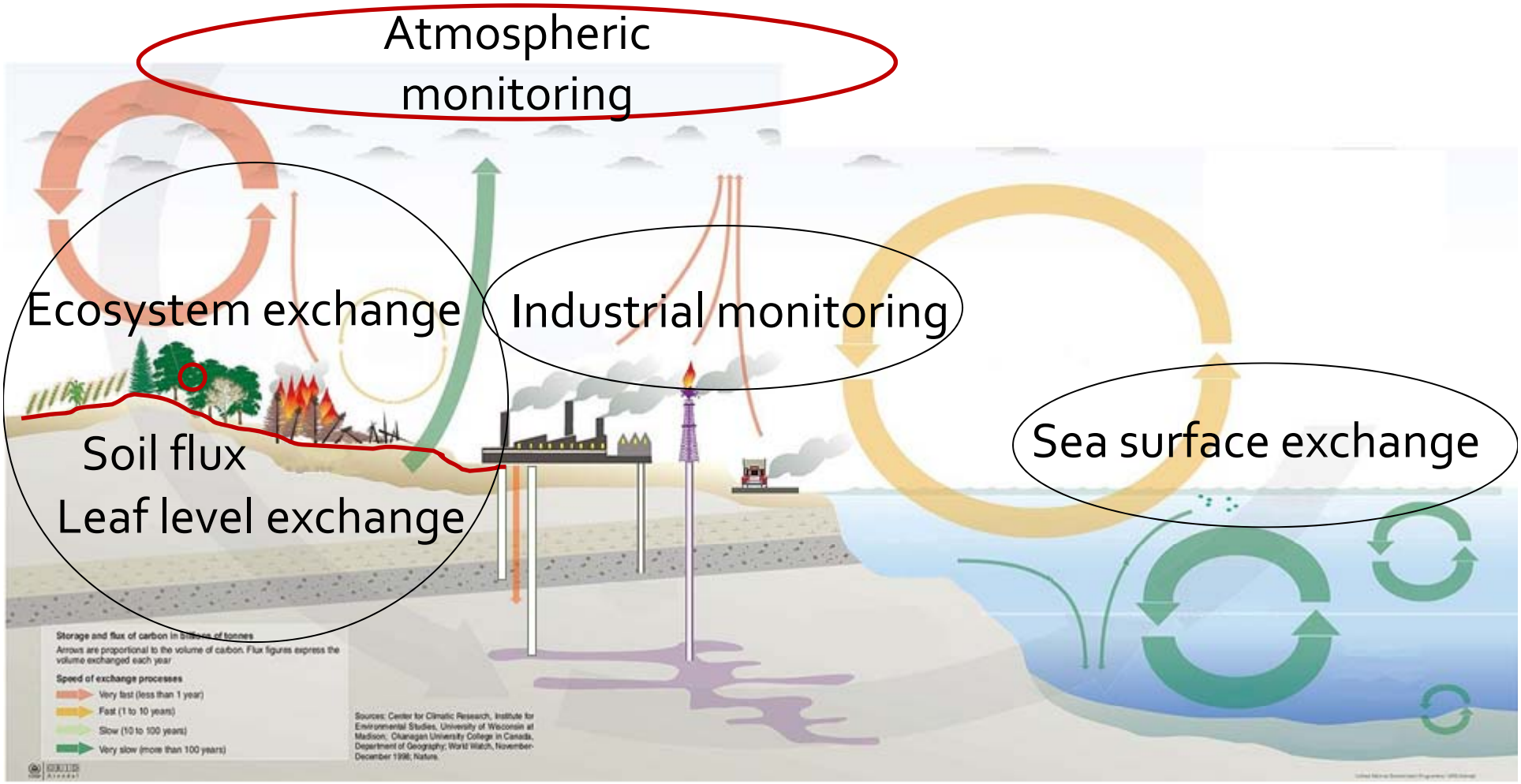
Lüthi et al., 2008. Nature. 453:379-382.

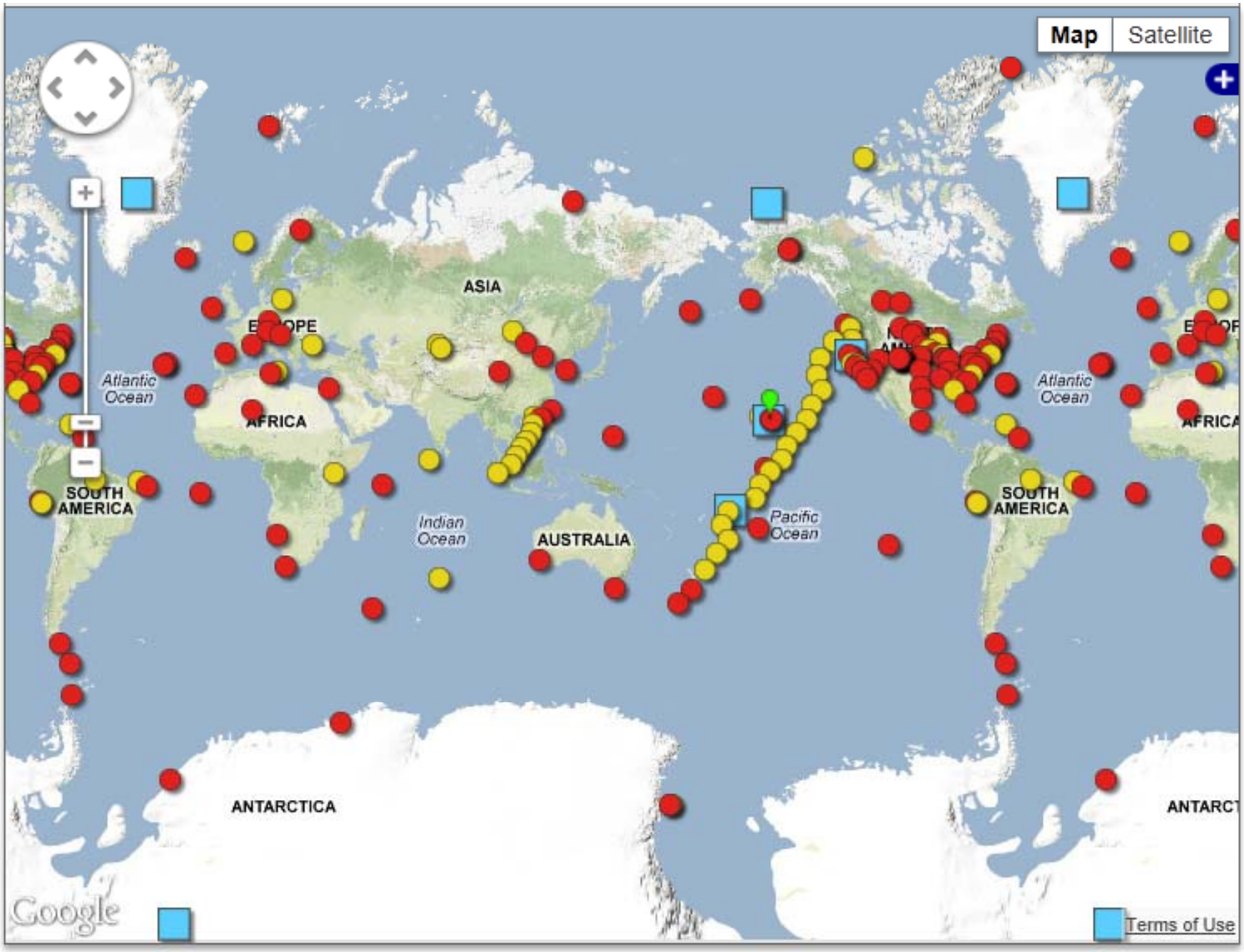

地球的命运在我们人类的手中
THE EARTH IS IN OUR HANDS

Questions scientists are trying to answer are:

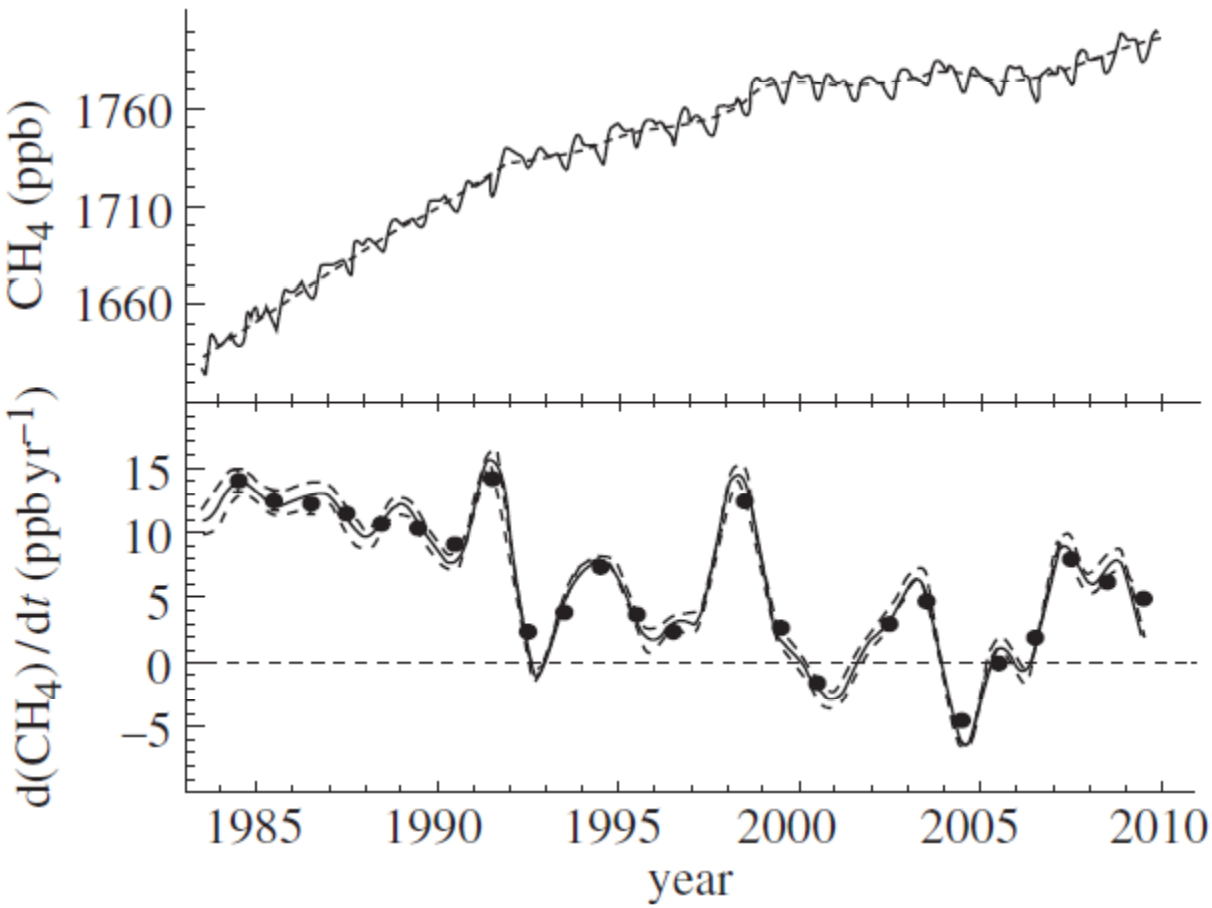
- What are the sources, sinks of CO_2, CH_4, N_2O?
- What are the factors that regulate these source and sink strength?
- Atmospheric CO_2, CH_4, N_2O trend?
- What kind of impact on climate from the changes in atmospheric CO_2, CH_4, N_2O concentrations?

Global Carbon cycle




Map
Satellite
ASIA
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
Pacific Ocean
Atlantic Ocean
SOUTH AMERICA
ANTARCTICA
Google
Terms of Use

Atmospheric CH_4 Growth Trend

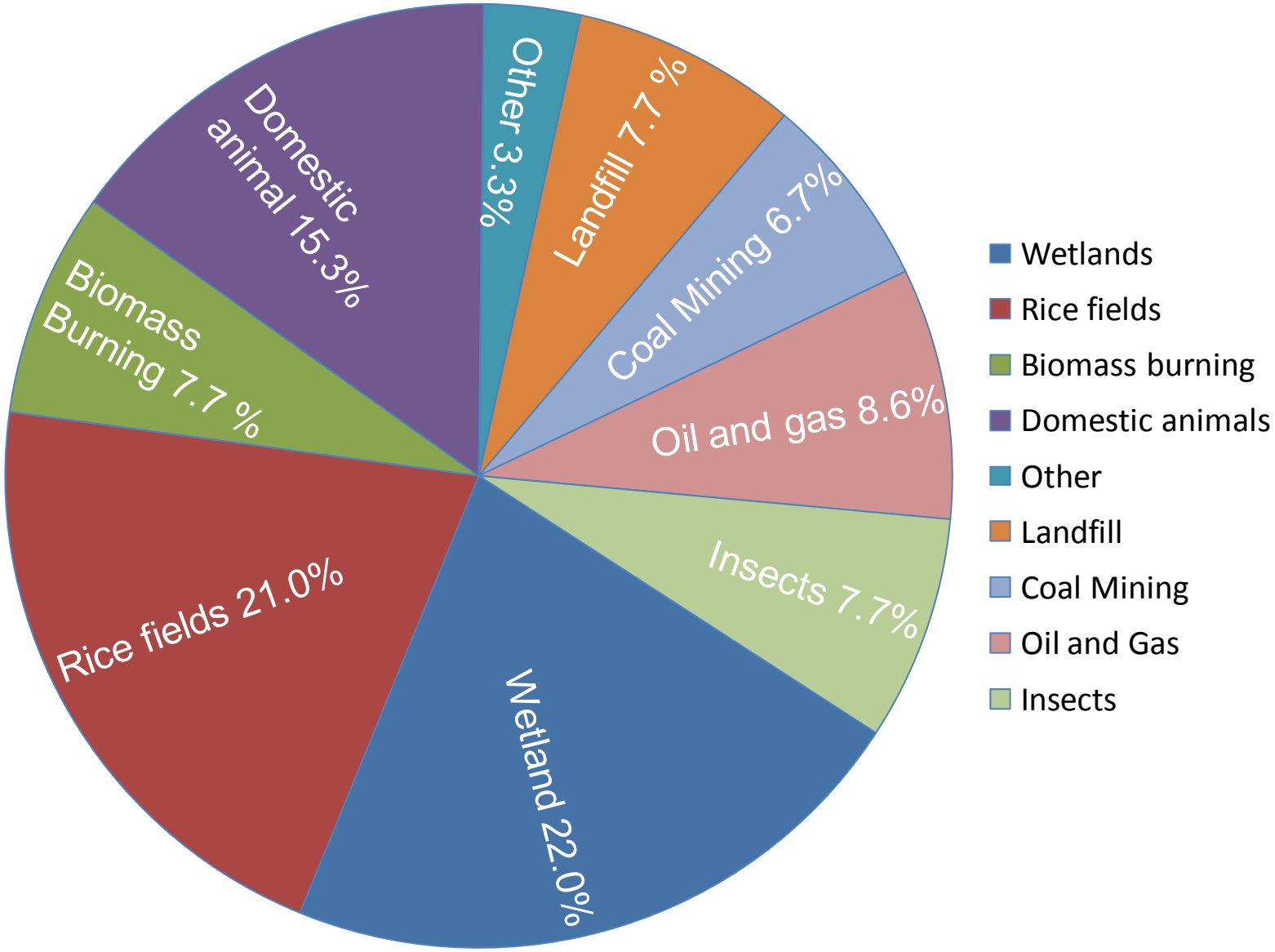


Dlugokencky et al., 2011. Phil. Trans. R. Soc. A 369: 2058-2072.

Methanogenesis

- Produced in anaerobic environments
- $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$
- Formed at low *Eh* (Redox potential)< -200 mV

Methane Sources



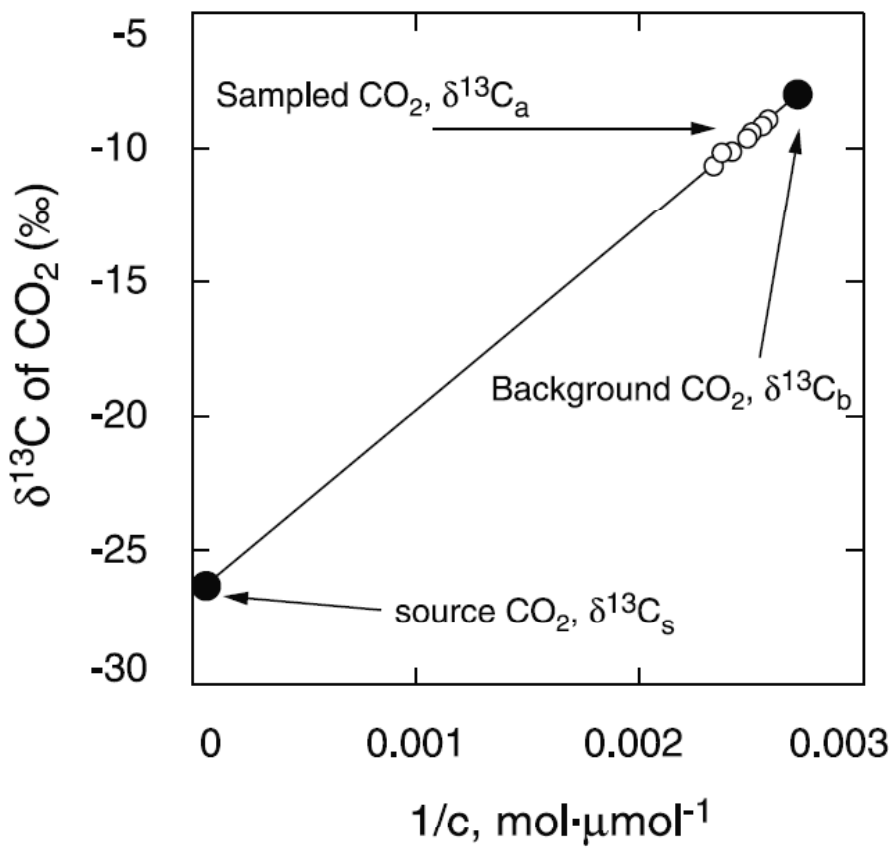
Isotopic monitoring (CH_4)

Source	$\delta^{13}C$ (‰)
Ambient background air	-47
Wetland	-70 to -60
Savanna grassland burning	-20 to -15
Boreal forest burning	-30 to -25
Ruminants digesting C_4 species	-55 to -50
Ruminants digesting C_3 species	-65 to -60
Coal and natural gas	-34 to -35
Rice field	-62

$$\delta^{13}C = \left(\frac{R_{sam}}{R_{std}} - 1\right) * 1000$$

$R = {}^{13}C/{}^{12}C$

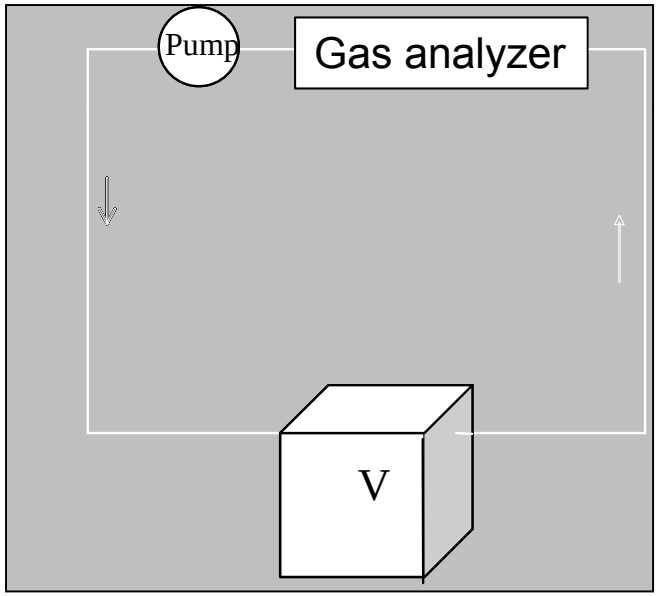
Keeling plot to identify the source

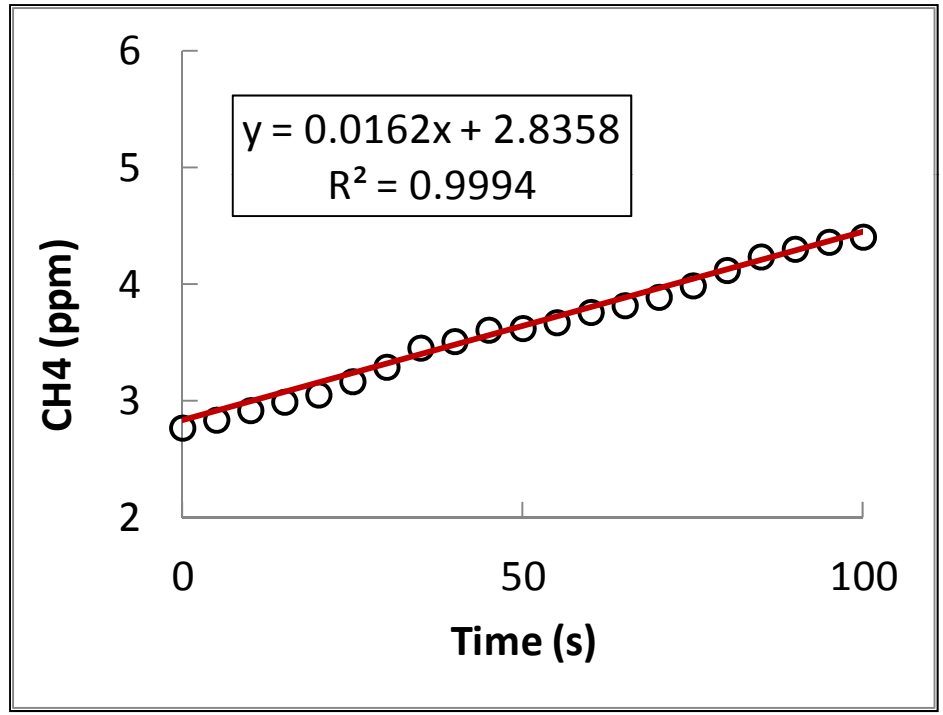


Pataki et al., 2003. The application and interpretation of Keeling plots in terrestrial carbon cycle research. *Global Biogeochemical Cycle*. 17:1022.

Research method for ecosystem:

Chamber-based flux measurement





$$F_{CH\,4} = \frac{V}{A}\frac{\partial C}{\partial t}$$

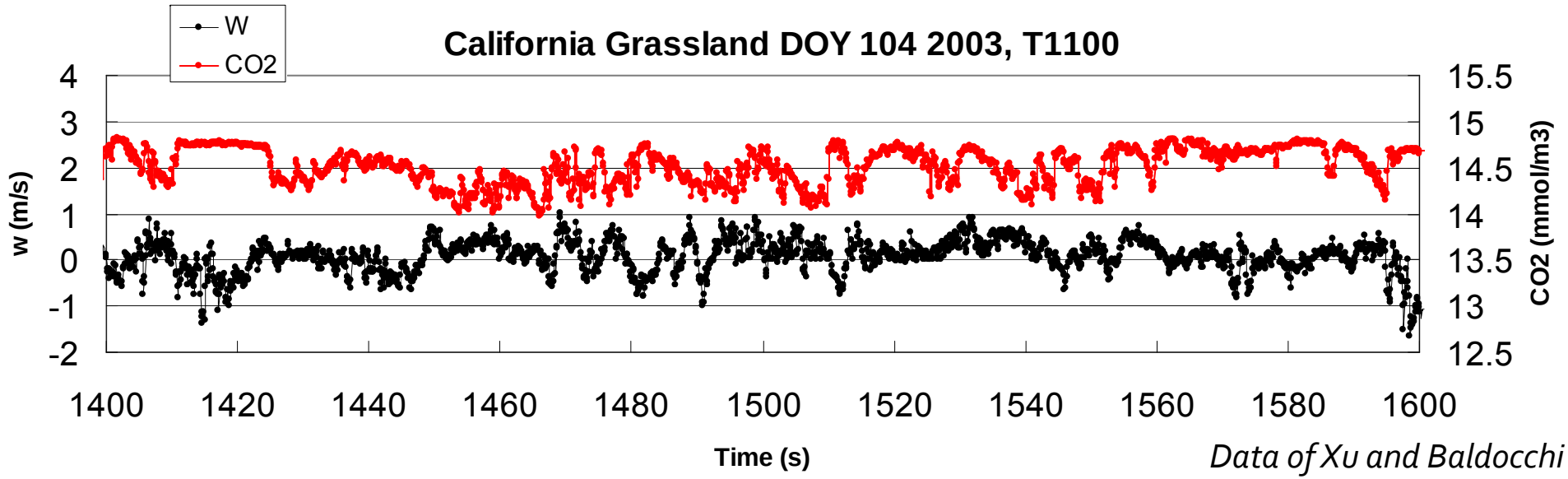
Requirements for chamber-based flux measurement

$$F_{CO_2} = g \times (CO_2^{soil} - CO_2^{chamber})$$

1. **$CO_2^{chamber} = CO_2^{air}$**
2. CO_2^{soil} not disturbed
3. **$P_{Chamber} = P_{ambient}$**
4. Good mixing inside chamber
5. No disturbance to soil moisture, temperature or radiation balance

Research method for ecosystem:

Eddy covariance flux measurement for F_{CO_2}, F_{CH_4}, LE, H



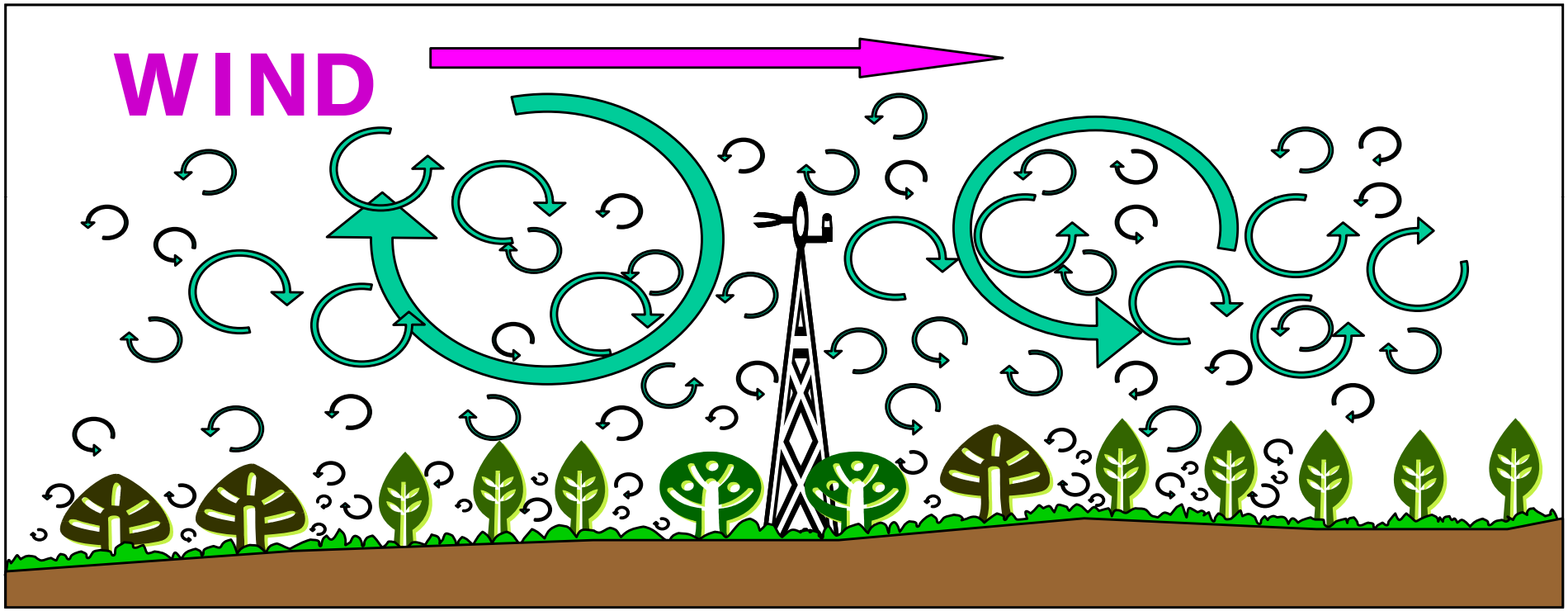
Data of Xu and Baldocchi

Example of 10-Hz real data!

Picture courtesy of Dr. Youngryel Ryu

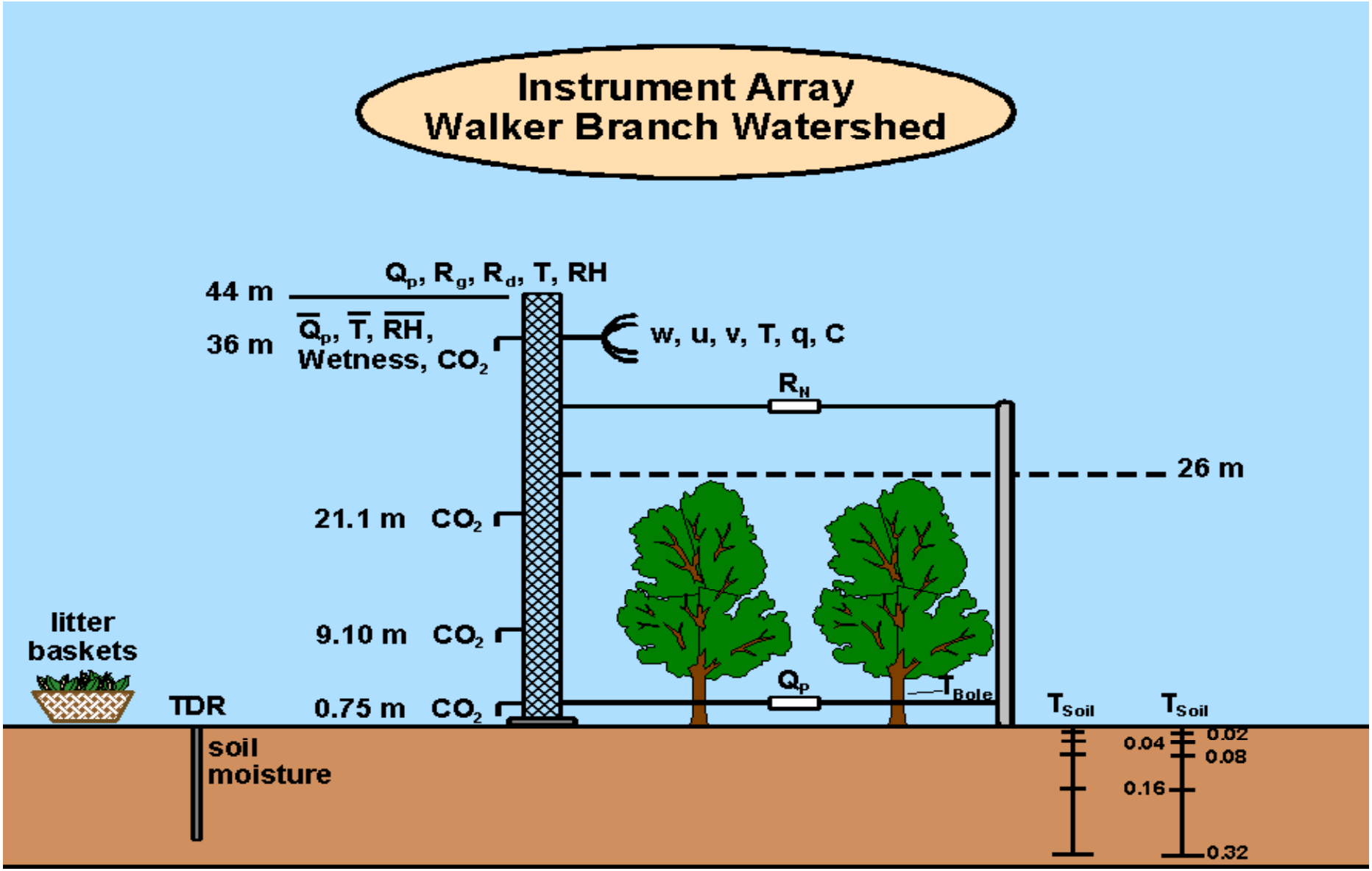
Research method for ecosystem:

Eddy covariance flux measurement for F_{CO_2}, F_{CH_4}, LE, H



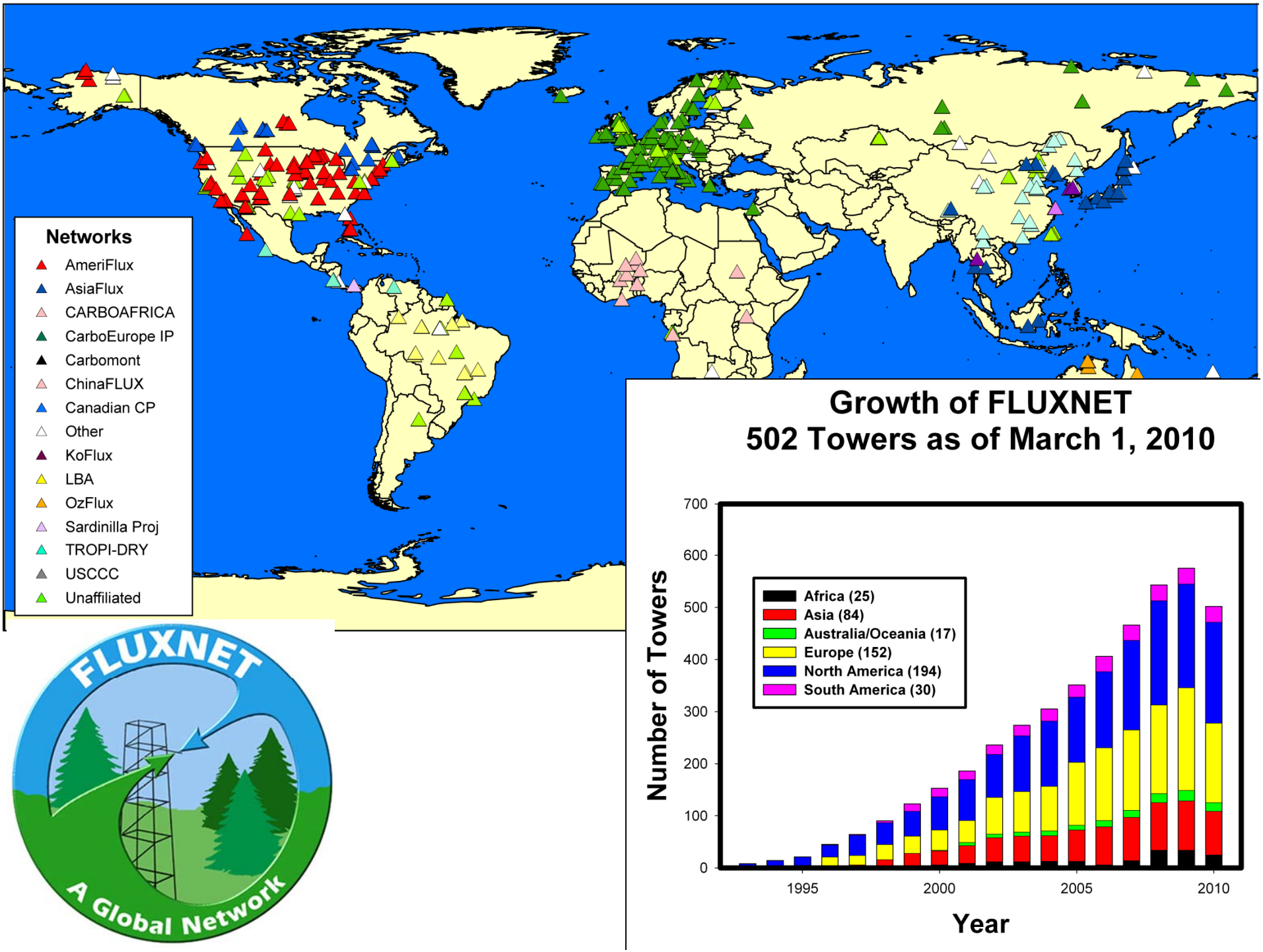
$$F = \overline{\rho_a}\,\overline{w's'}$$

Example of instrumentation at a flux station



Advantages of the EC Method over other methods

It is a direct measure of the flux density,
it is *in situ*,
it introduces no disturbance on the system
it is quasi-continuous,
and represents a large upwind area.


Networks
AmeriFlux
AsiaFlux
CARBOAFRICA
CarboEurope IP
Carbomont
ChinaFLUX
Canadian CP
Other
KoFlux
LBA
OzFlux
Sardinilla Proj
TROPI-DRY
USCCC
Unaffiliated
Growth of FLUXNET
502 Towers as of March 1, 2010
Africa (25)
Asia (84)
Australia/Oceania (17)
Europe (152)
North America (194)
South America (30)
Number of Towers
0
100
200
300
400
500
600
700
1995
2000
2005
2010
Year

Transport of methane to atmosphere

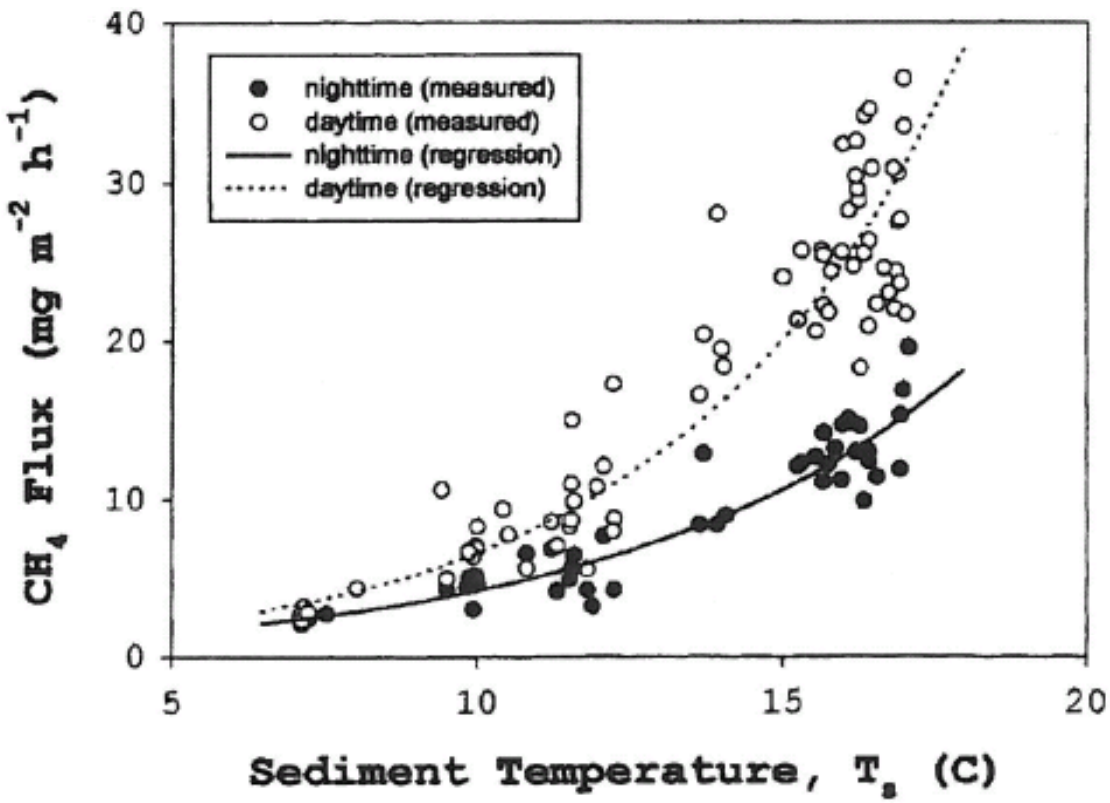
1. Convective flow through plant conduits
2. Diffusion across the air-water boundary layer
3. Water convection
4. Direct injection into the air via bubble transport

Convective flow through plant conduits

Phragmites Australis

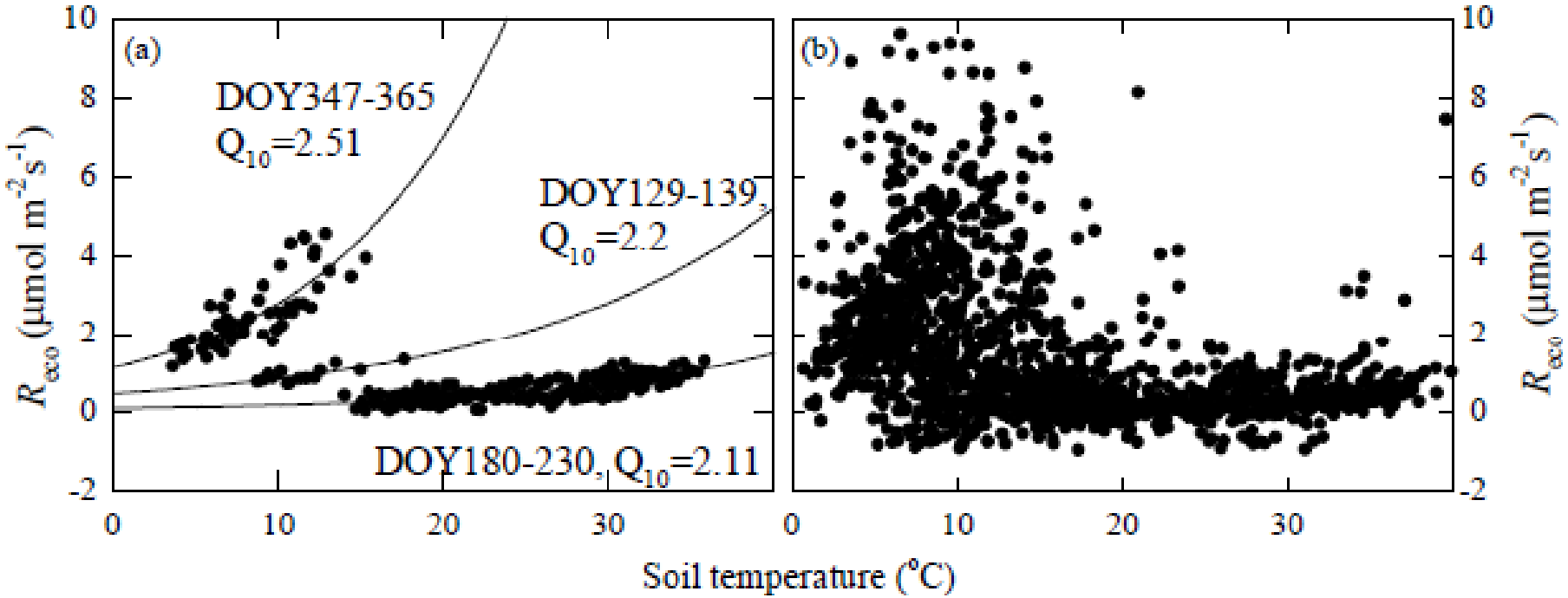
Convective flow through plant conduits

Temperature Response ??



Kim et al., Global Change Biology, 1998

L. Xu, D.D. Baldocchi / Agricultural and Forest Meteorology 1232 (2004) 79–96



Diffusive CH_4 flux

$$F = K_L(C_W - C_O) \quad (1)$$

where F is flux in mass/area/time, K_L is the exchange coefficient across the liquid boundary layer in length/time, and C_W is the concentration of methane dissolved in the surface water. The calculated concentration of dissolved methane (C_O) in equilibrium with atmospheric methane can be expressed as

$$C_O = \alpha p \quad (2)$$

Barker et al., Global Biogeochemical Cycle, 1988.

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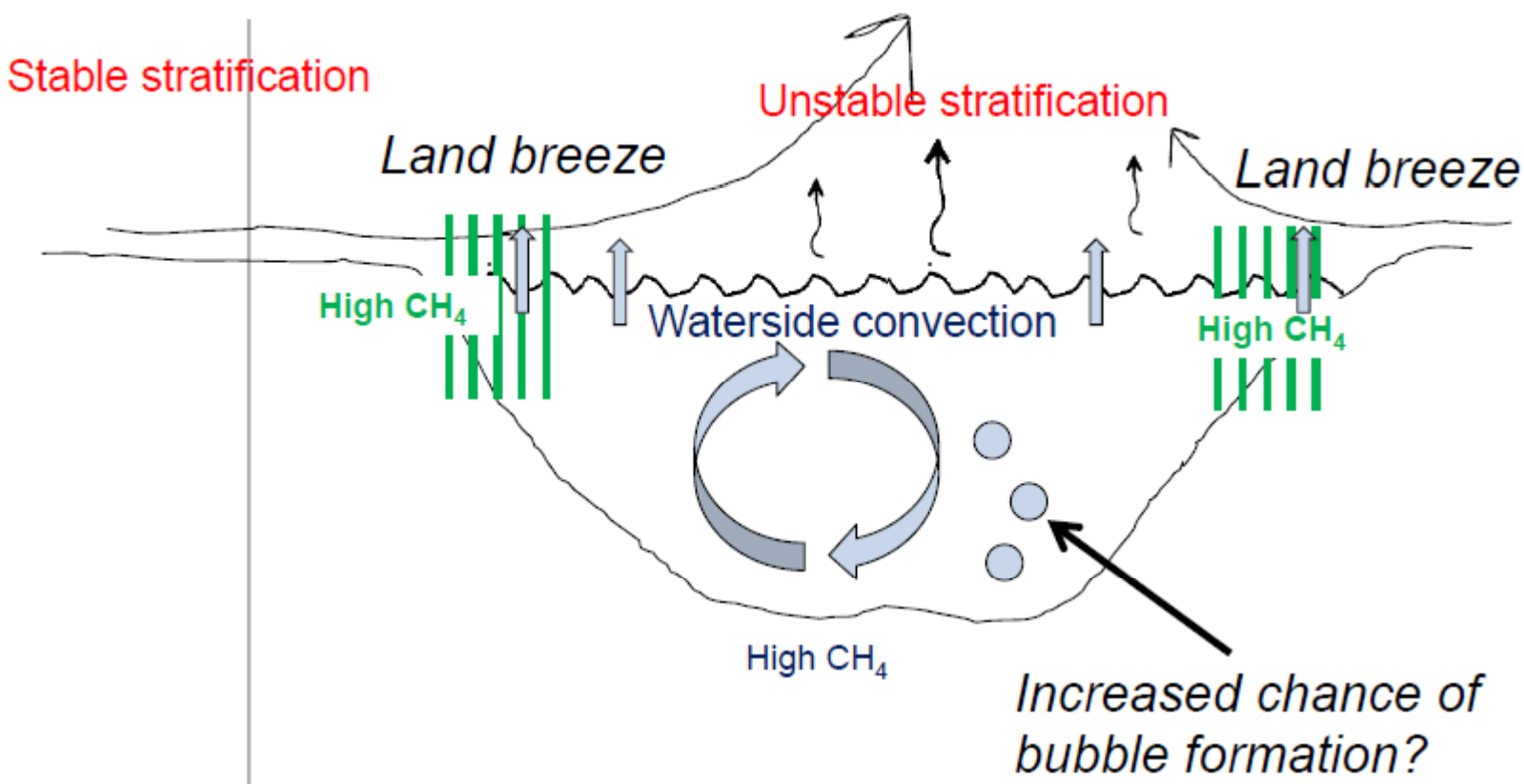
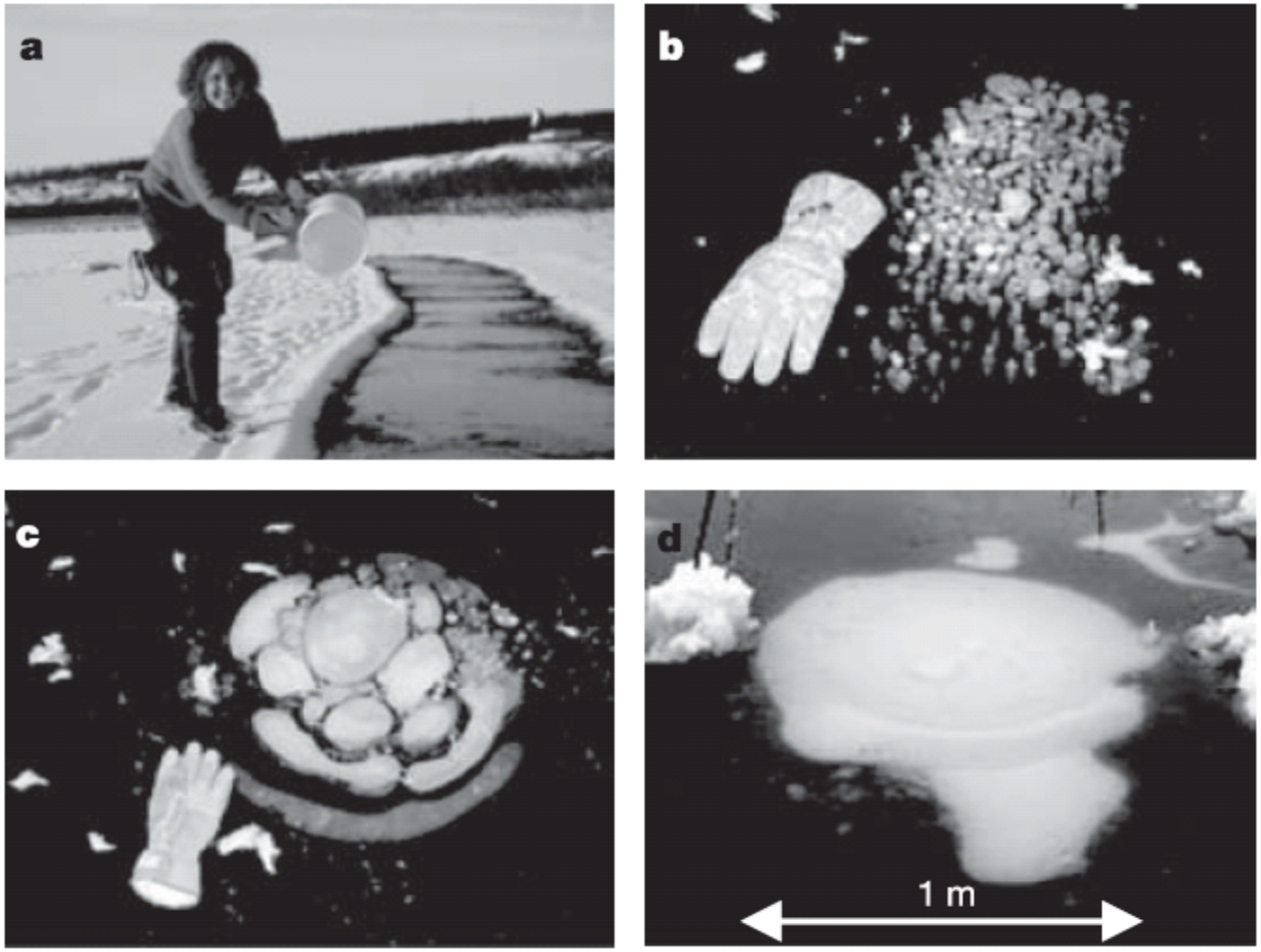
Via. Water convection



Sahlee et al., 2011

Direct injection into the air via bubble transport



Walter et al., 2006.. Nature 2006

CH_4 flux vs. barometric pressure studies in the literature

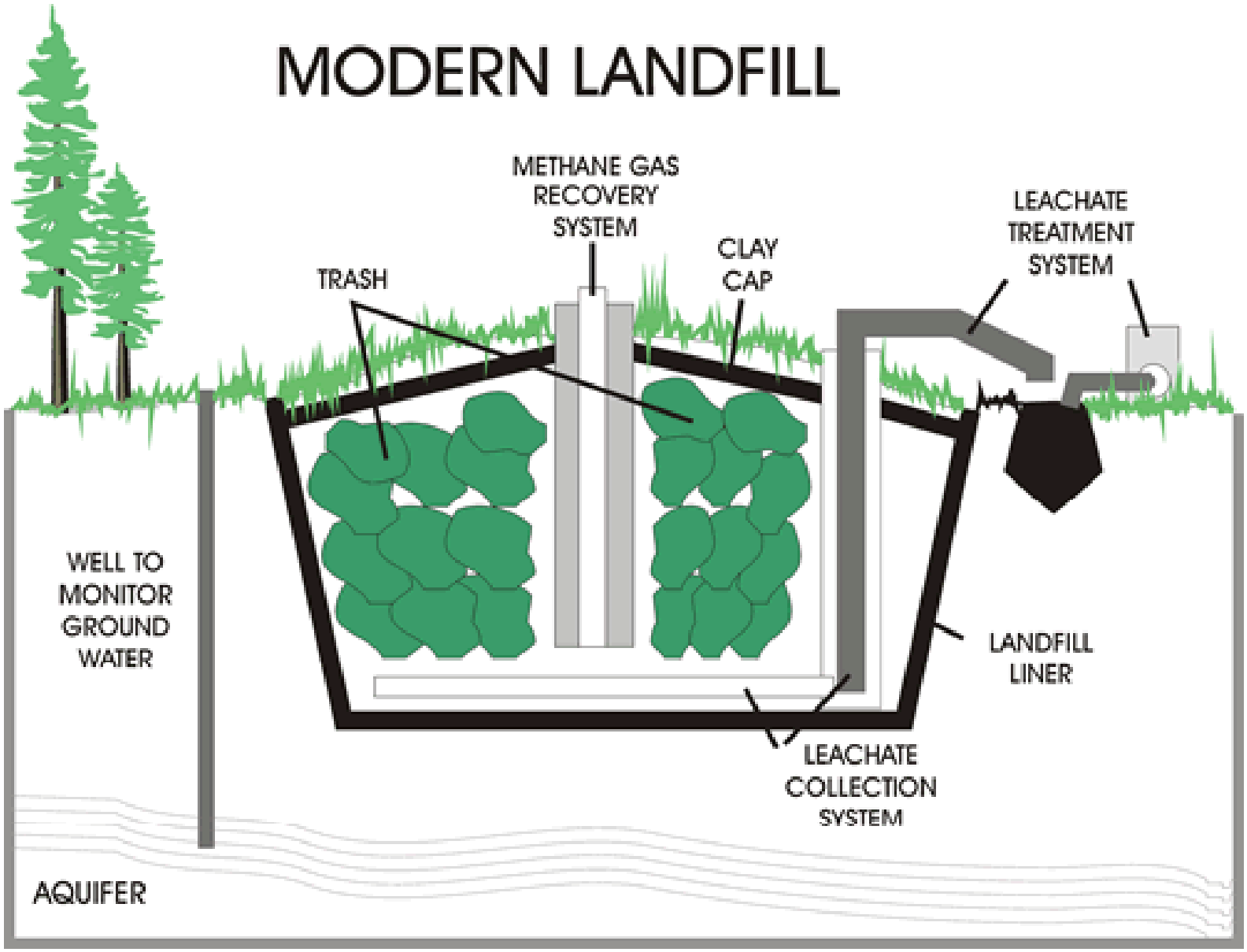
- Mattson, Likens 1990. Air pressure and methane fluxes, *Nature*, **347**

  "At Mirror Lake, New Hampshire, we observed that sporadic methane bubble releases (ebullition) from the sediments were correlated with changes in local air pressure."

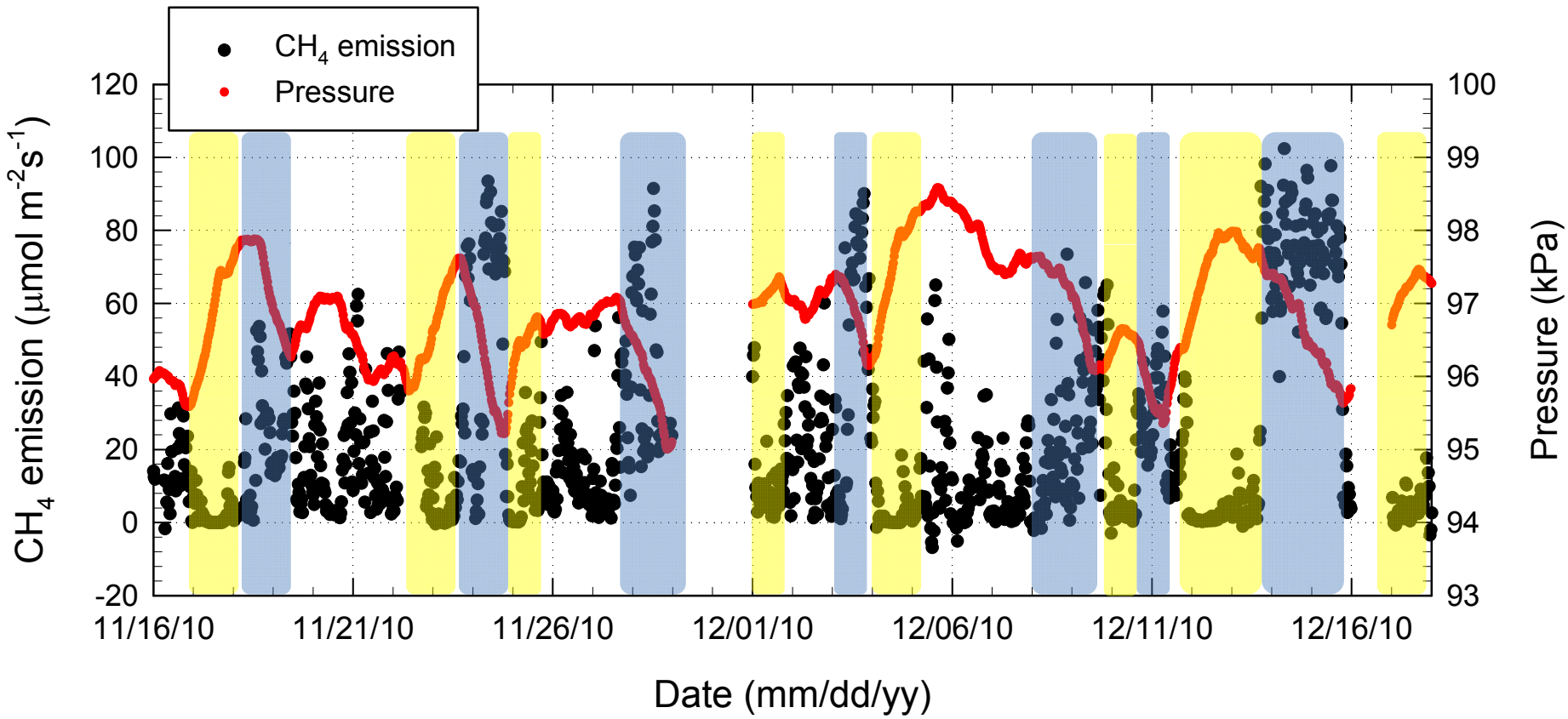
- McQuaid, Mercer 1991. Air pressure and methane fluxes, *Nature*, **351**

  "A similar phenomenon has been known to mining engineers in the UK for more than 250 years."

MODERN LANDFILL



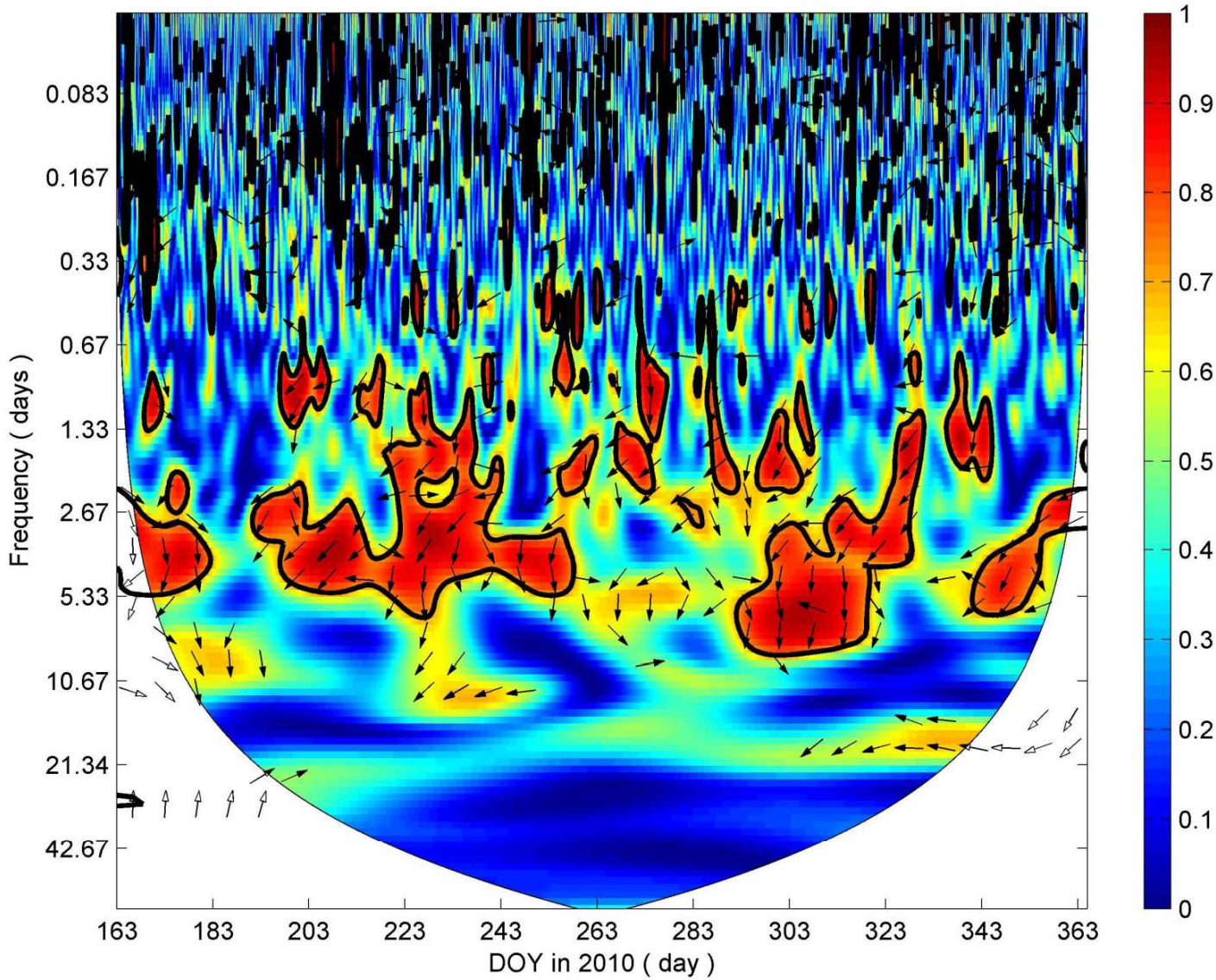
Changes in barometric pressure and landfill CH_4 emission

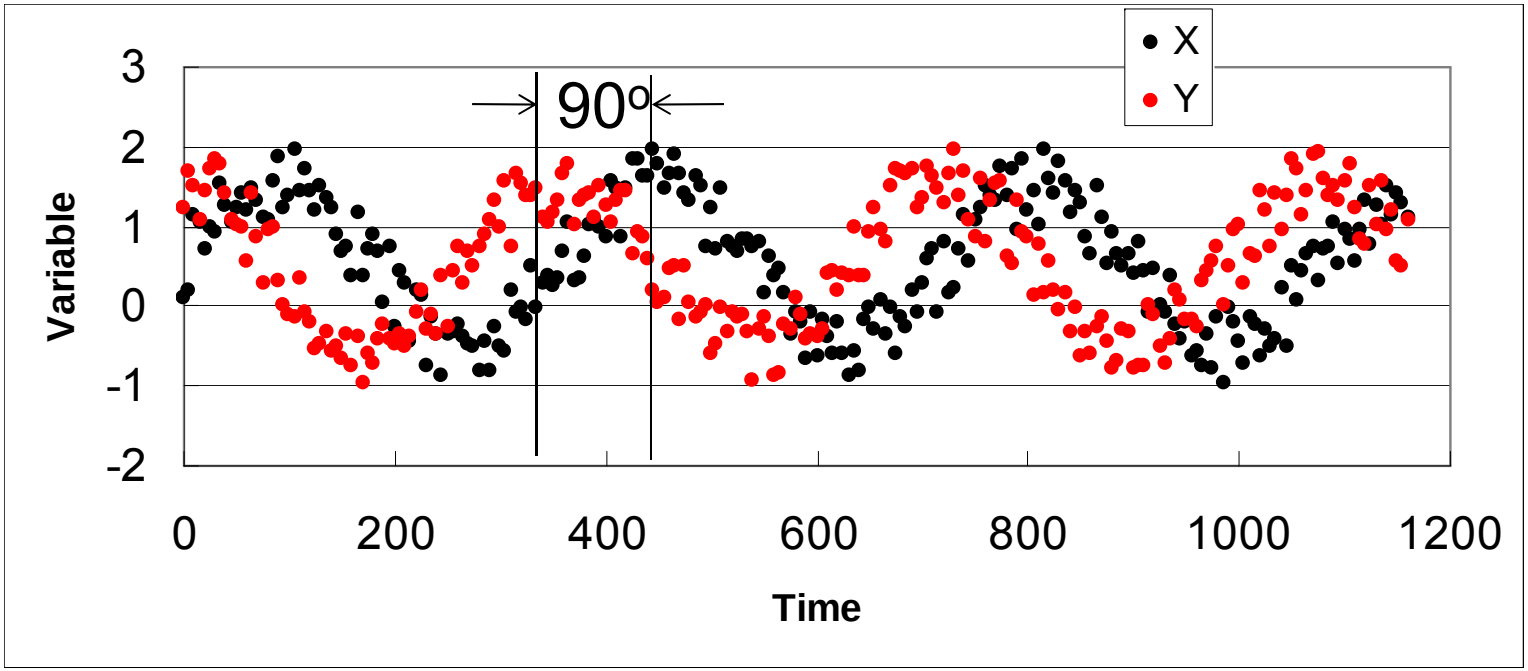


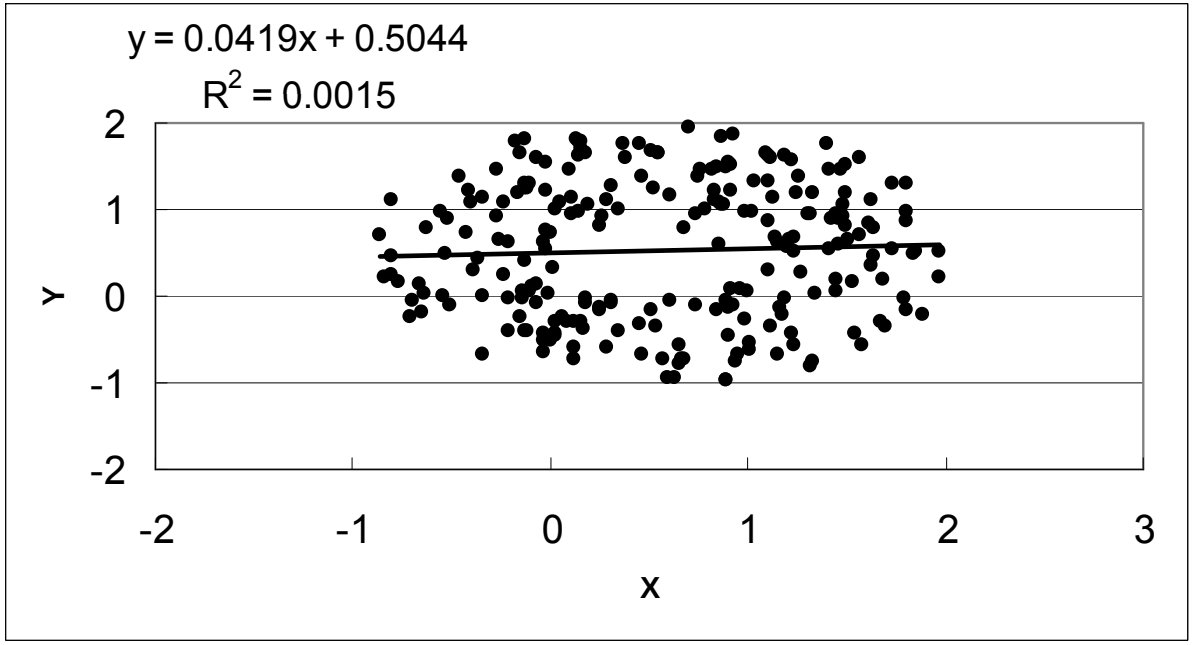
Xu et al., 2013. Impact of Changes in Barometric Pressure on Landfill Methane Emission. Submitted to *Global Biogeochemical Cycle*.

Coherence between barometric pressure and CH_4 emission

A wavelet coherence analysis



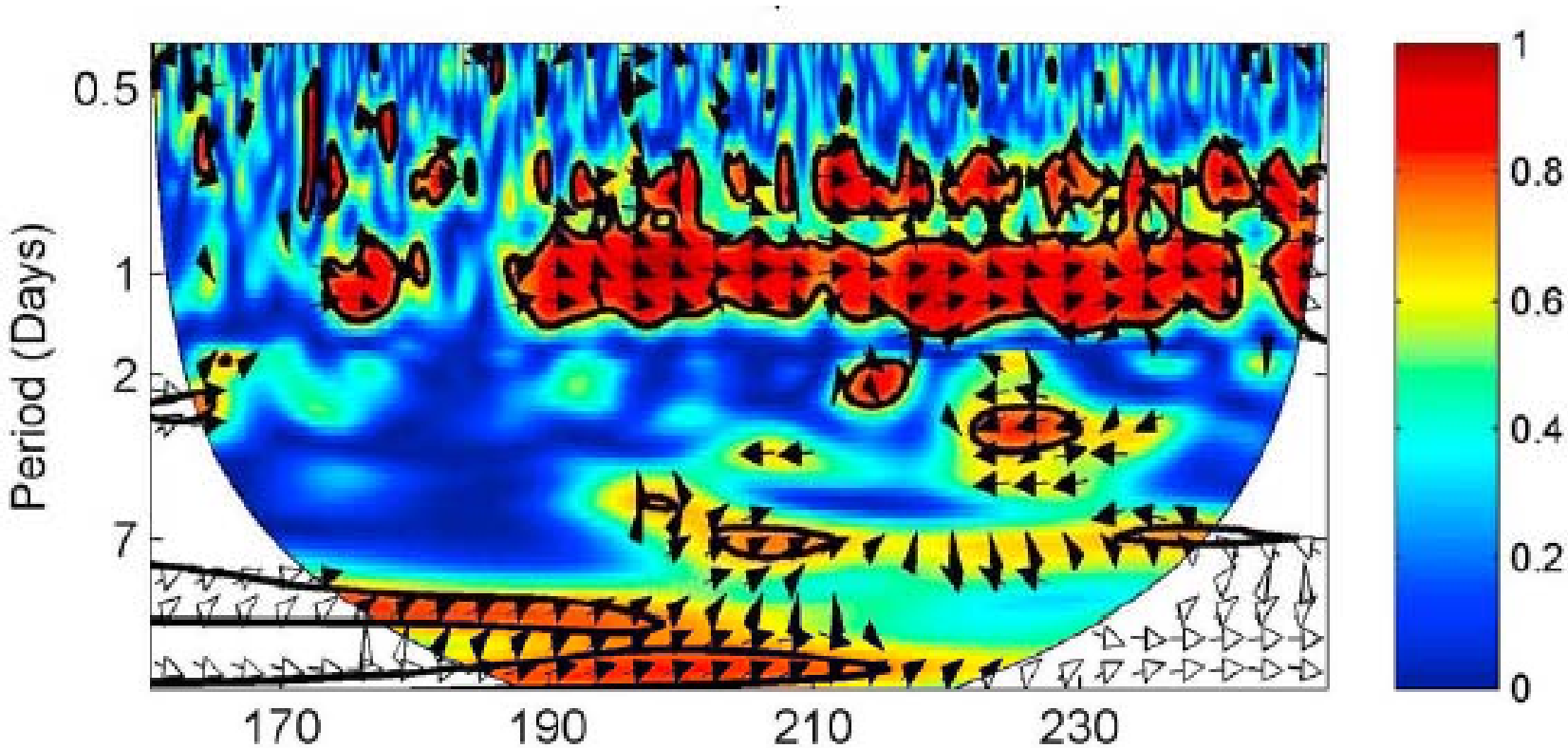

X
Y
90°
Variable
3
2
1
0
-1
-2
0
200
400
600
800
1000
1200
Time


y = 0.0419x + 0.5044
R2 = 0.0015
Y
2
1
0
-1
-2
-2
-1
0
1
2
3
x

Rice paddy CH_4 flux

- Very few long-term CH_4 flux study from rice paddy in the literature
- 90% of rice production is from Asia?

Photosynthesis and methane emission from rice field



Hatala et al., 2012.*Geophysical Research Letters*, 39:

Methane Sinks

1. Reaction with hydroxyl radical in troposphere and stratosphere (~95%)

   $CH_4 + OH \rightarrow CO_2 + H_2O$

2. Dry soil oxidation (~5%)

Summary

- Global warming, climate change
- Atmospheric CO_2 and CH_4 concentration increasing
- Increasing rate unprecedented
- More frequent extreme weather events, including drought, flood, hurricane etc.
- Research on CO_2, CH_4 sources and sinks
- Mitigation and adaptation

谢 谢

Thank You