Introduction to the Biosphere-Atmosphere system

Lecture Autumn 2025

Part VI

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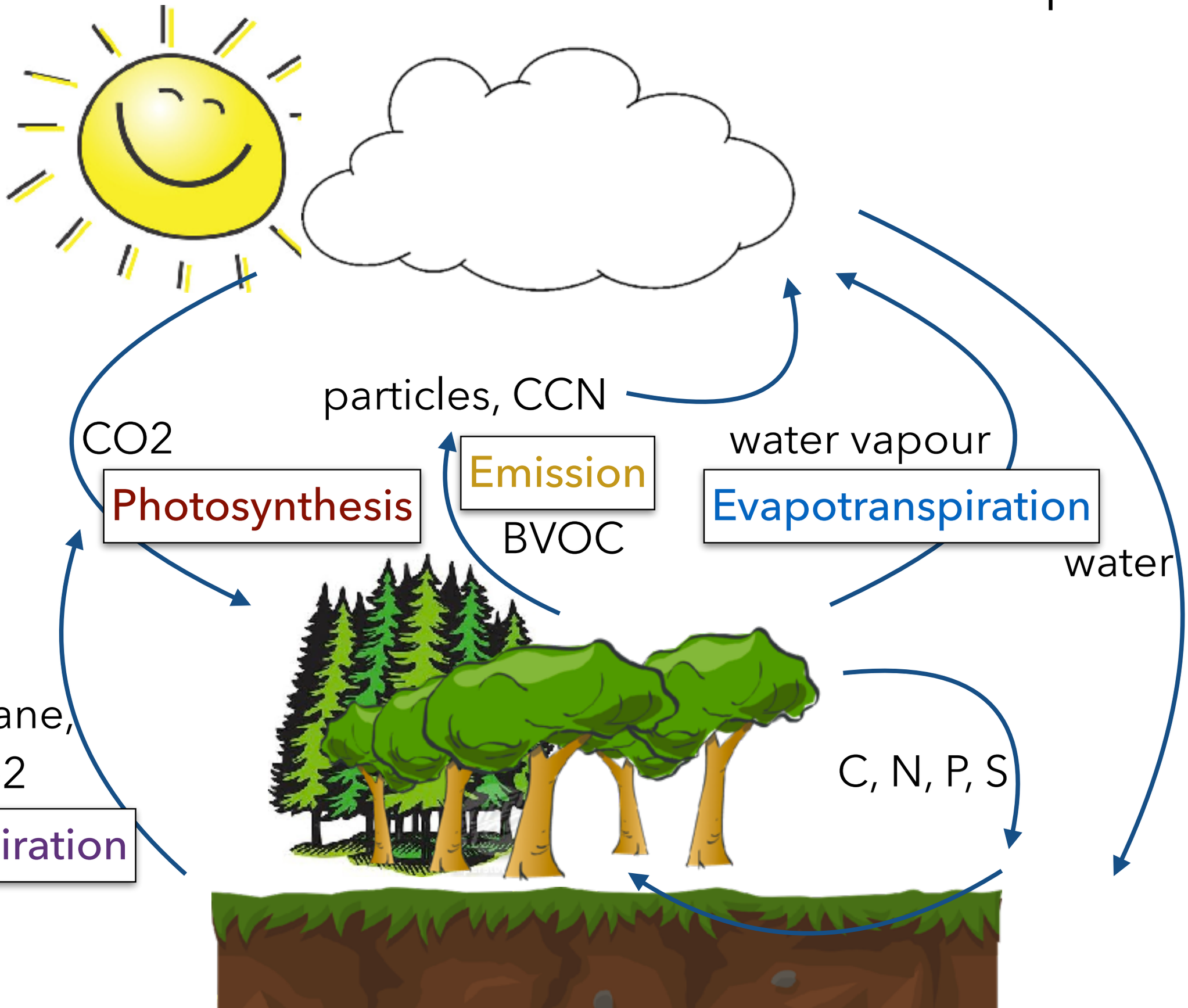
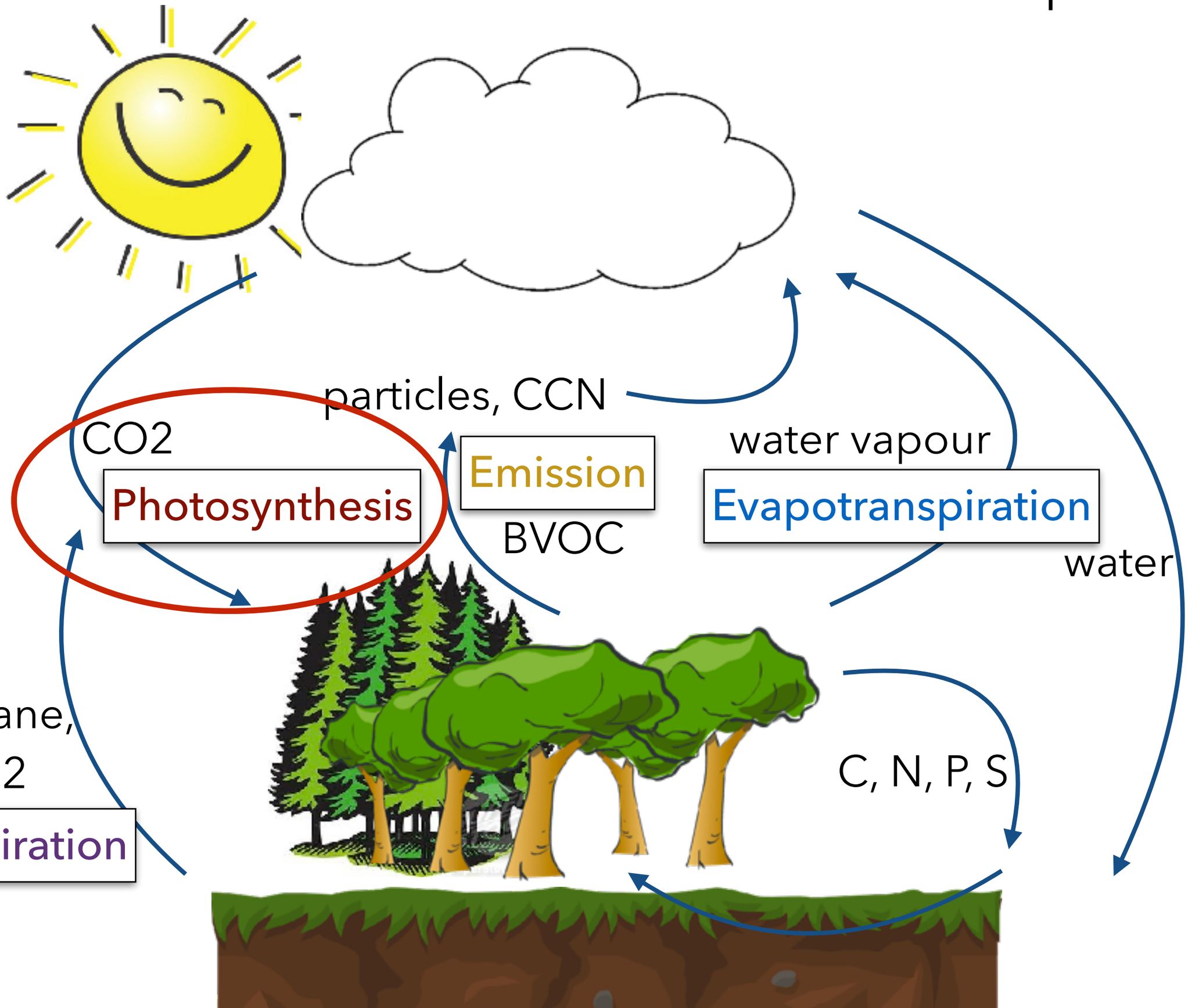
Processes between the forest and the atmosphere



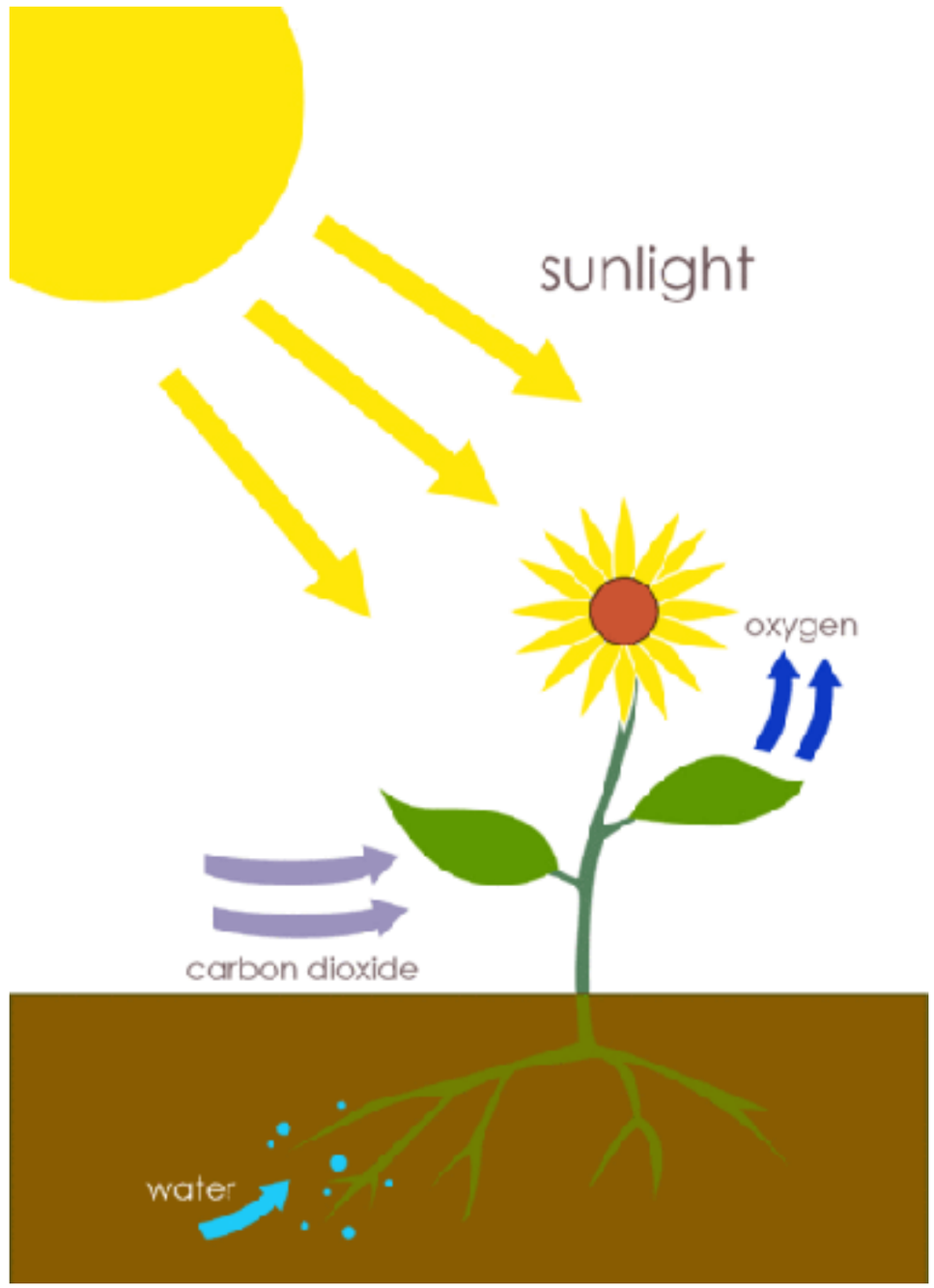
Processes between the forest and the atmosphere



Photosynthesis

General: Takes up carbon (CO_2) from the atmosphere and releases oxygen (O_2) to the atmosphere.

Basic needs:
Sunlight for energy.
Water for oxidation.



$6CO_2$ Carbon dioxide + $6H_2O$ Water $\xrightarrow{\text{Light}}$ $C_6H_{12}O_6$ Sugar + $6O_2$ Oxygen

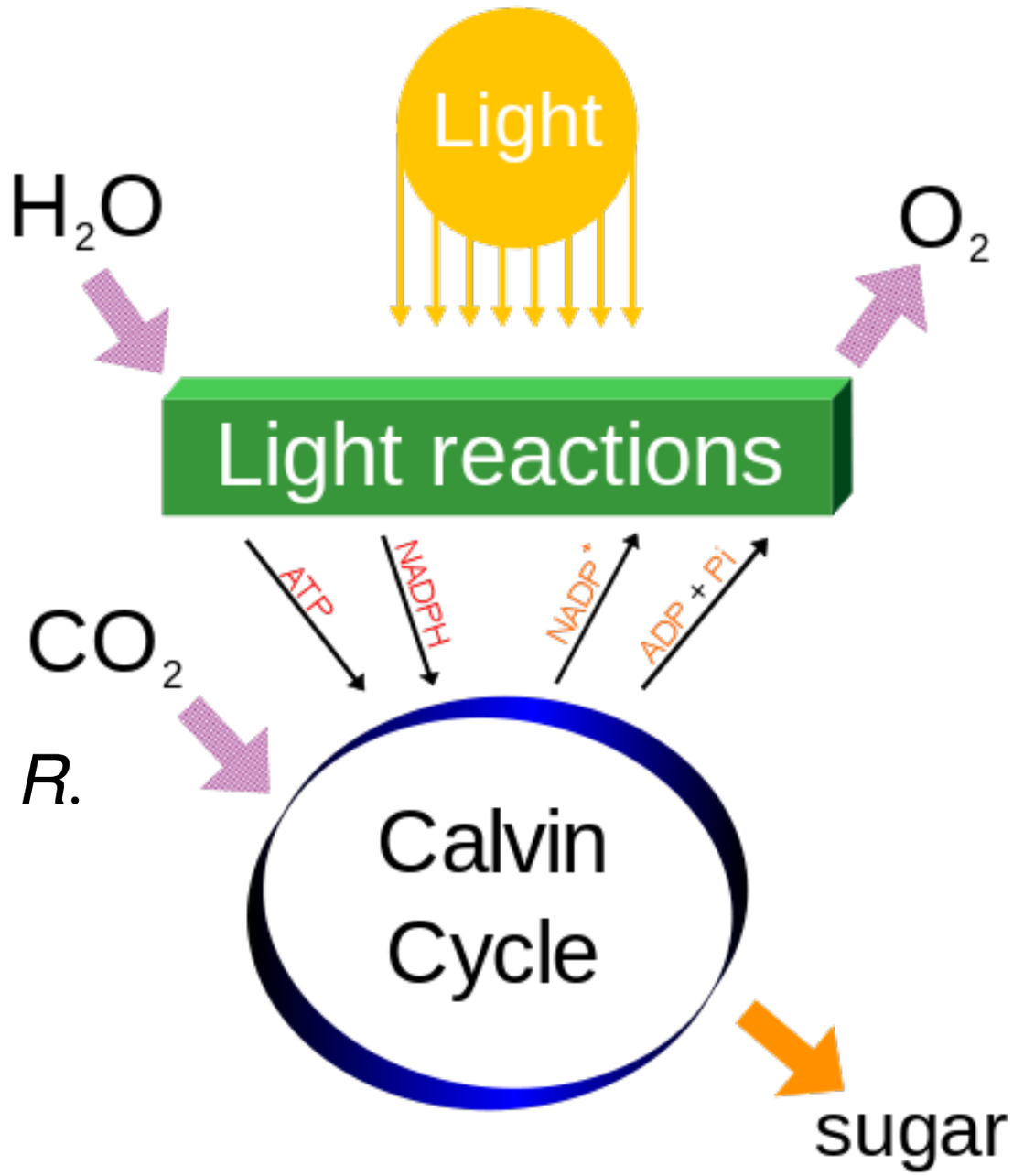
Photosynthesis

It is split into light and dark reactions!

It produces sugars that are subsequently used in cellular respiration.

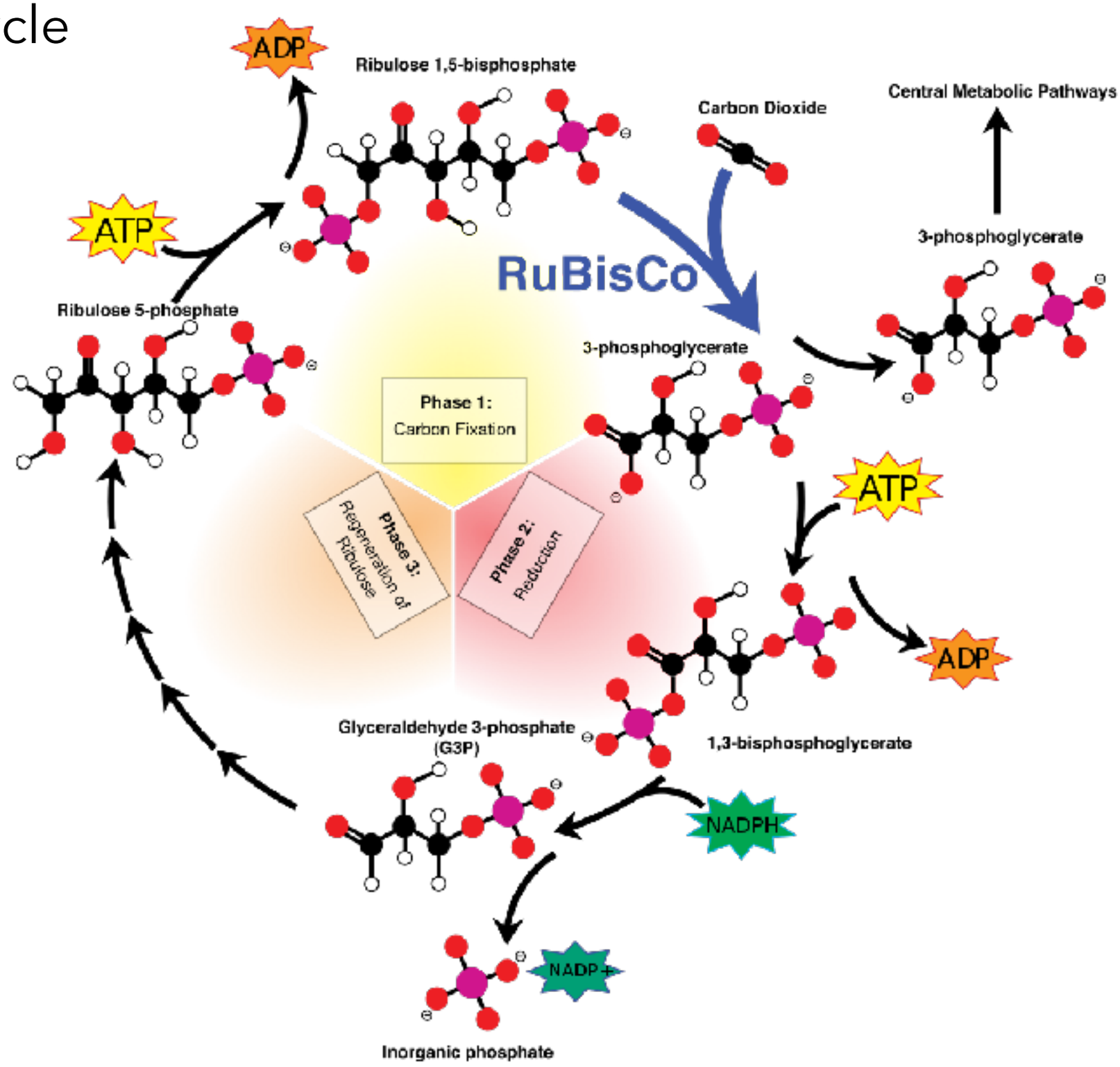
We can see on a leaf/needle scale the "net photosynthesis" *A*, is the difference between gross photosynthesis *P* and the respiration *R*.

$A = P - R$



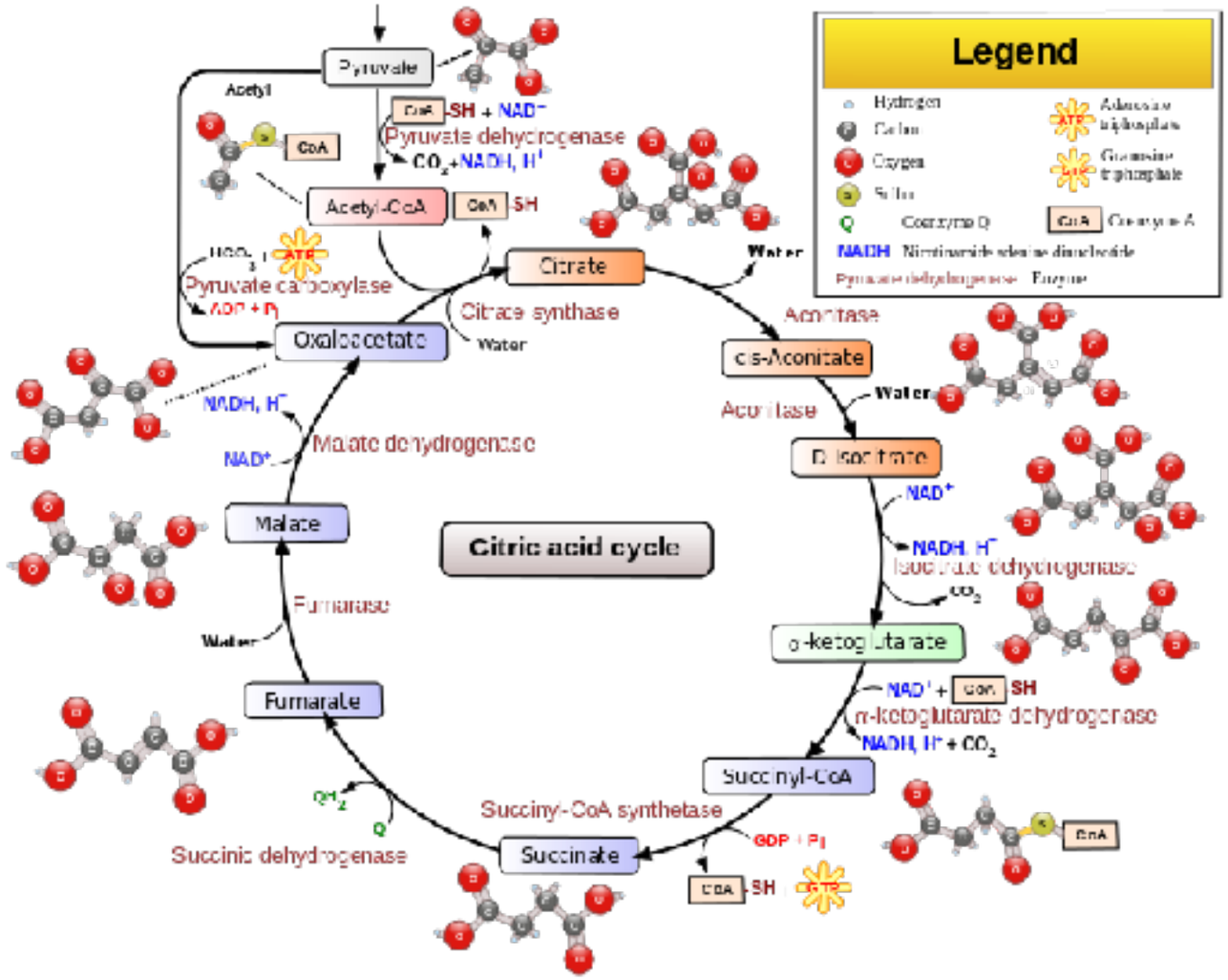
Photosynthesis

Calvin cycle

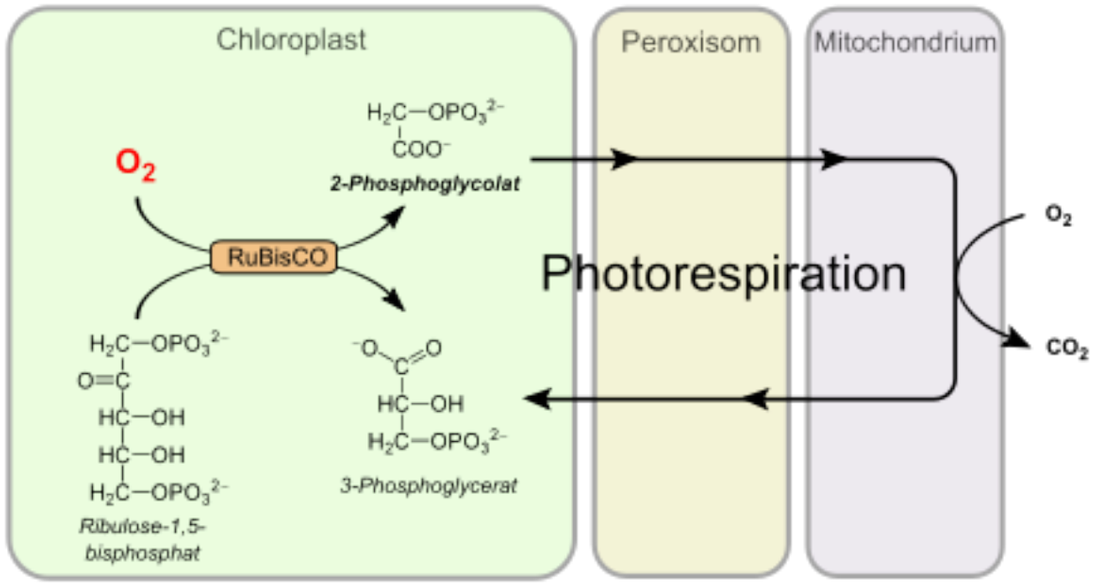


Photosynthesis

Respiration is also split into photorespiration and the dark (cellular aerobic) respiration.



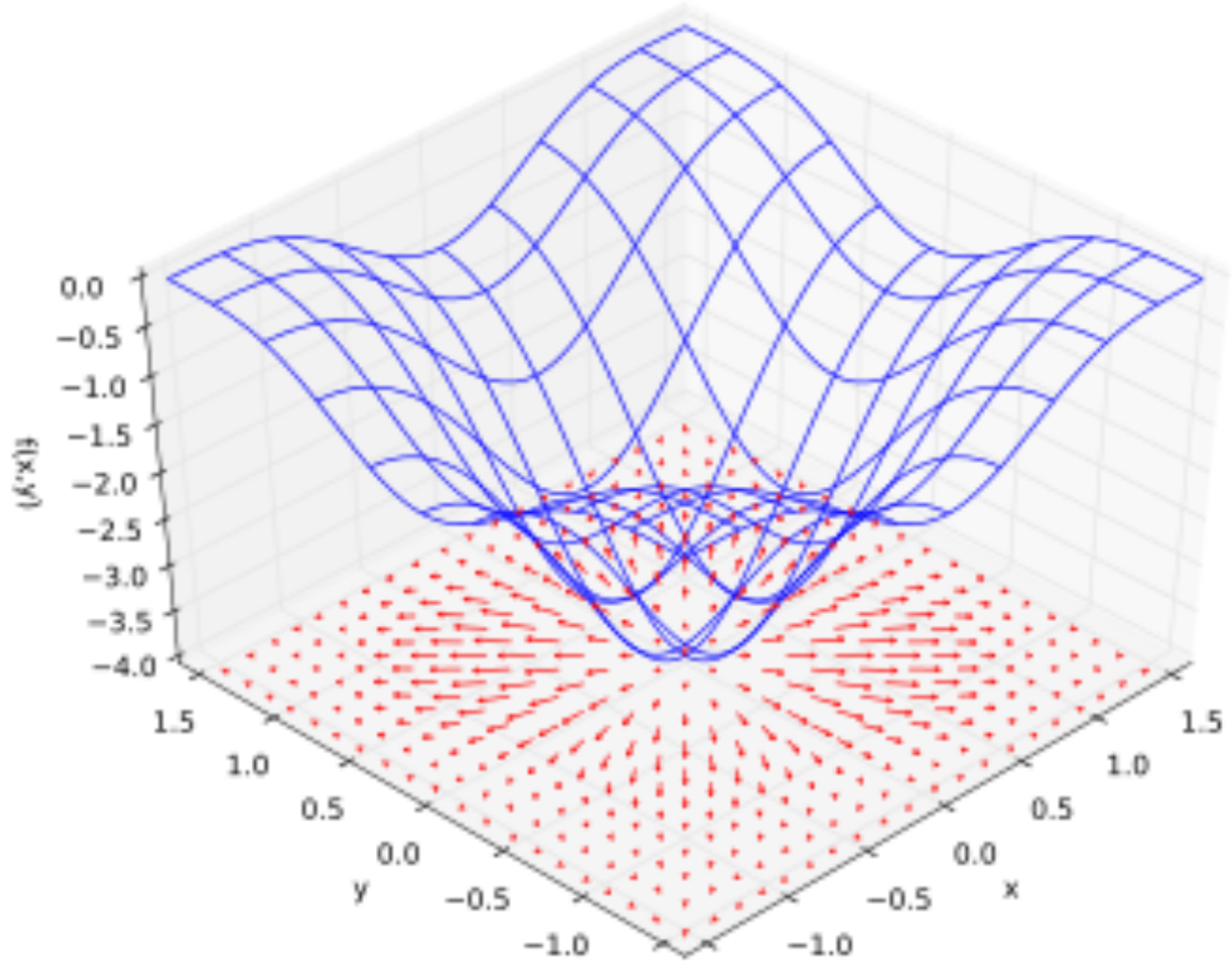
Use of sugar to produce energy and release CO_2.



Uses energy but does not form sugars.

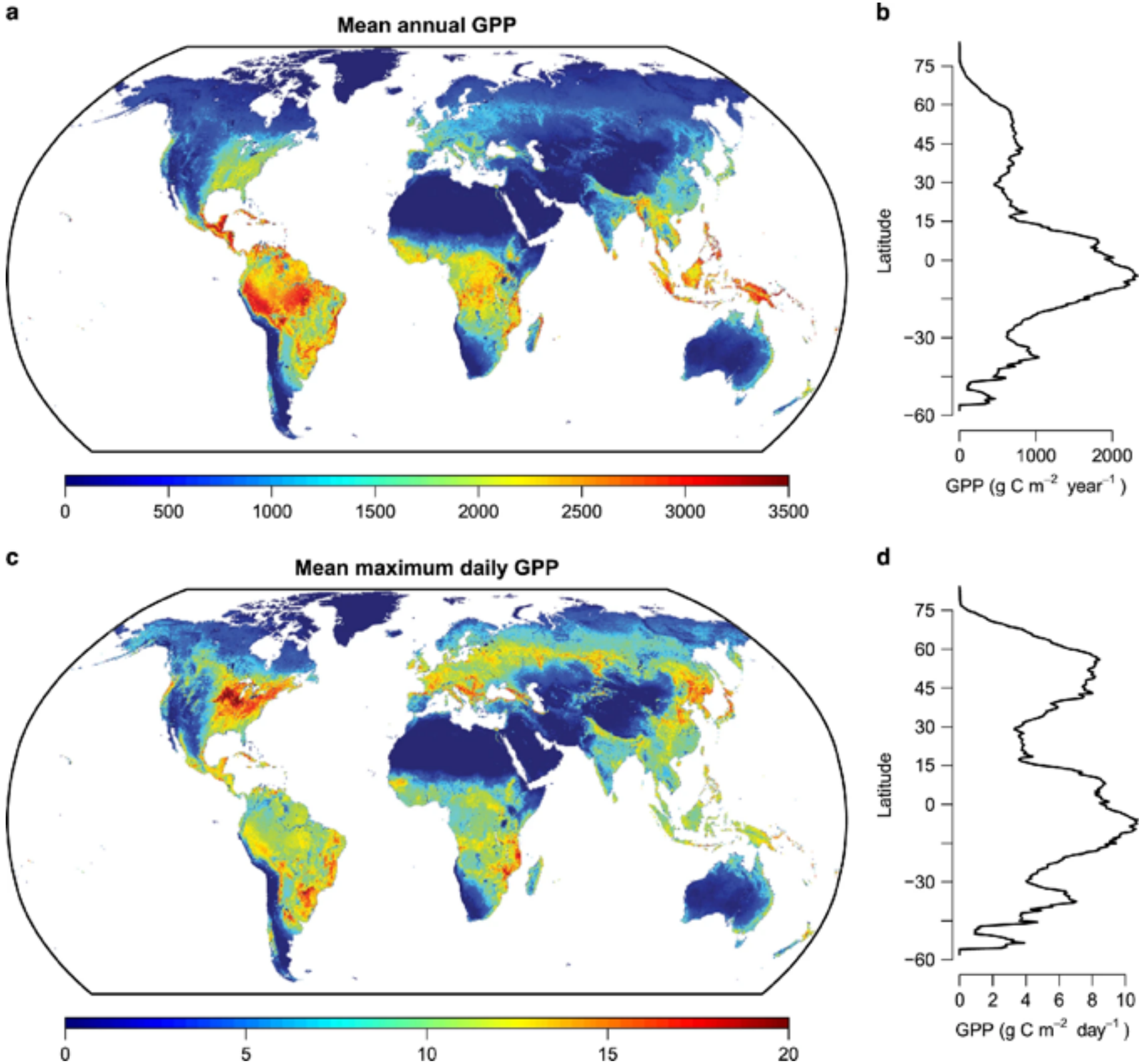
Photosynthesis

We need gradients in water vapour, oxygen and carbon dioxide to maintain transport of the molecules needed for the process and exchange with the environment.



Another important gradient:
The light energy is also used to build up a proton gradient over the thylakoid membrane inside the chloroplasts.

Photosynthesis on larger scales

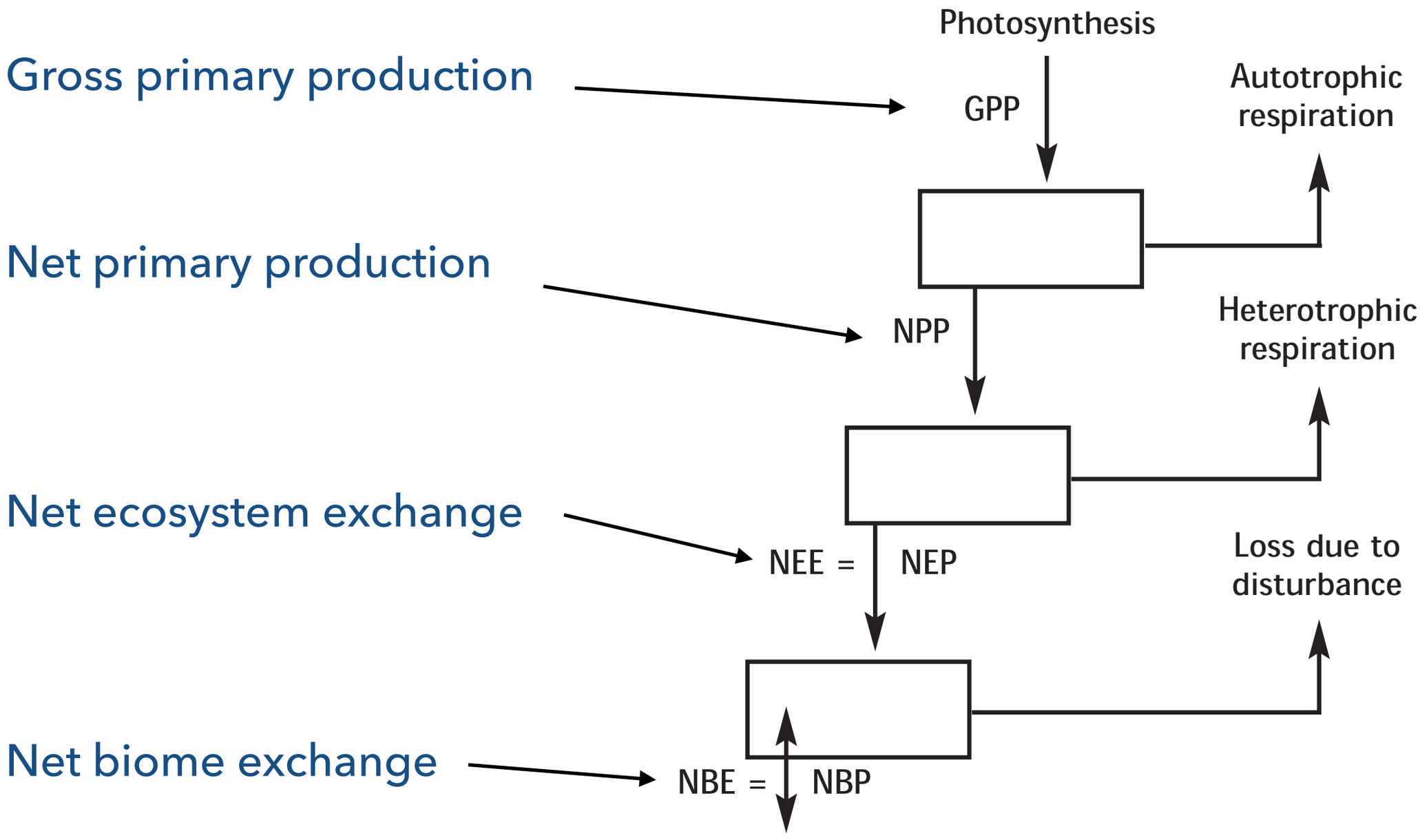


Zhang, Y., Xiao, X., Wu, X. *et al.*

A global moderate resolution dataset of gross primary production of vegetation for 2000–2016. *Sci Data* **4,** 170165 (2017).

https://doi.org/10.1038/sdata.2017.165

Photosynthesis on larger scales

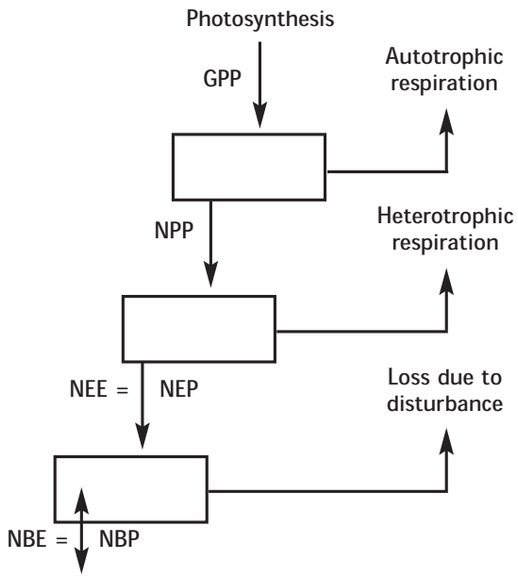


Photosynthesis on larger scales

Gross primary production GPP:
The total amount of carbon fixed in the process of photosynthesis.

Autotrophic respiration Ra:
Carbon used in plant internal metabolism. It's about half the carbon fixed.

Net primary production NPP:
Net production of organic carbon by plants. NPP = GPP - Ra



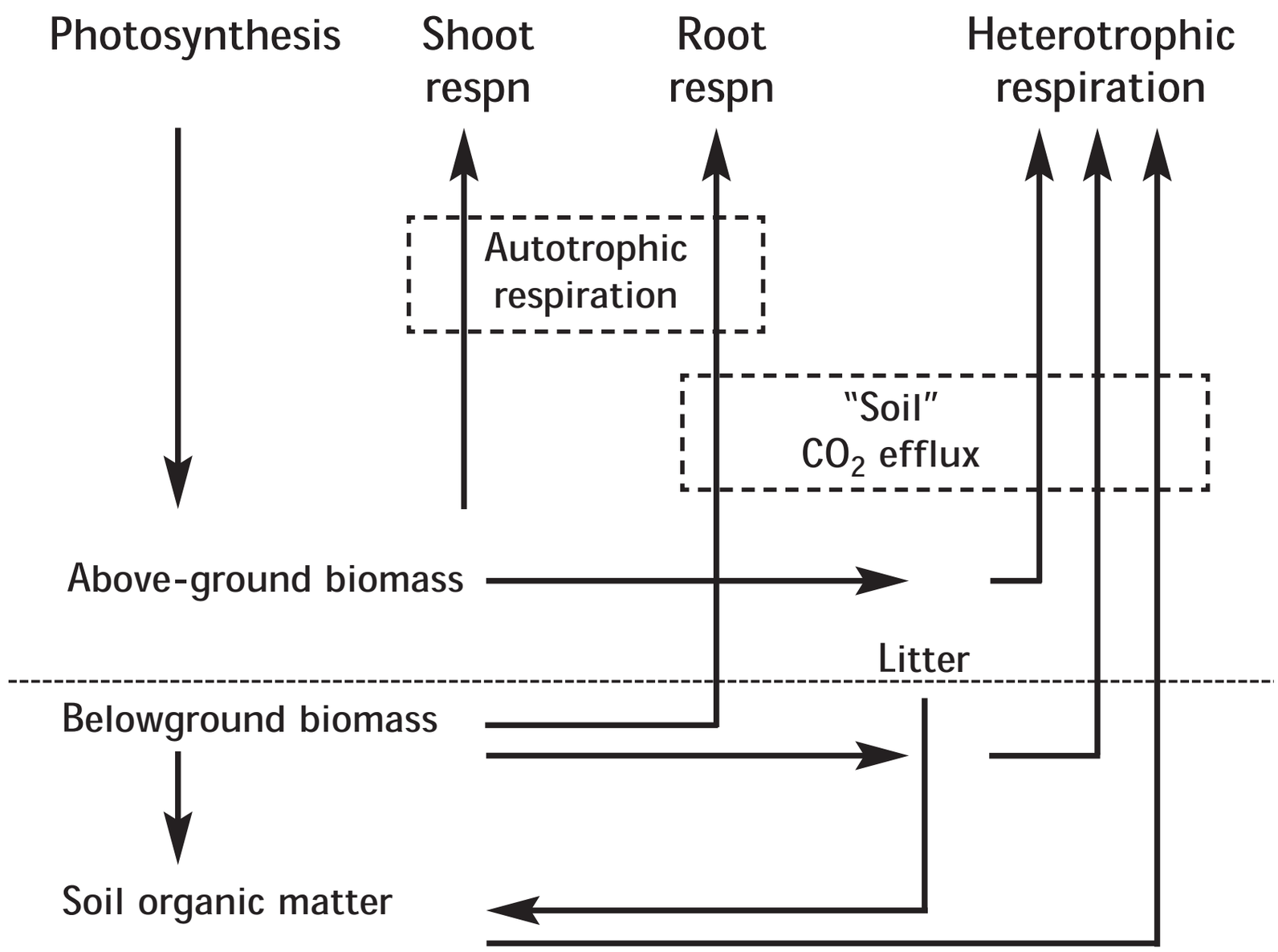
Net ecosystem exchange NEE or net ecosystem production NPP:
Net primary production minus the heterotrophic respiration. NEE = NEP = NPP - Rh

Heterotrophic respiration Rh:
Heterotrophic respiration refers to carbon lost by organisms other than plants in ecosystem.

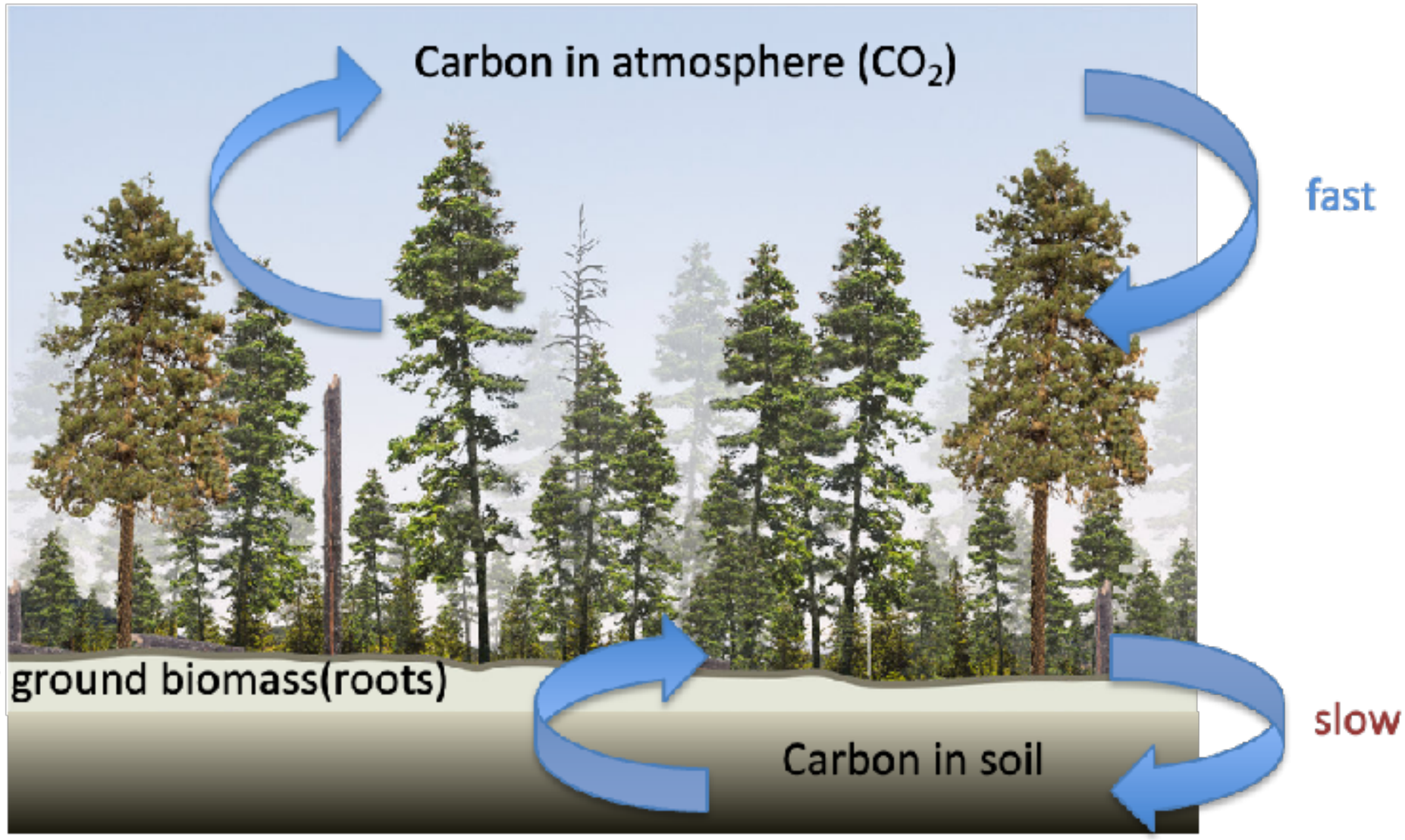
Net biome exchange NBE or net biome production NBP:
Change in carbon stocks including carbon losses by episodic natural or anthropogenic disturbances. NBE = NEE -Ld

Disturbance loss Ld:
Episodic loss of carbon by disturbances (storms, timber production,…)

Carbon balance and fluxes

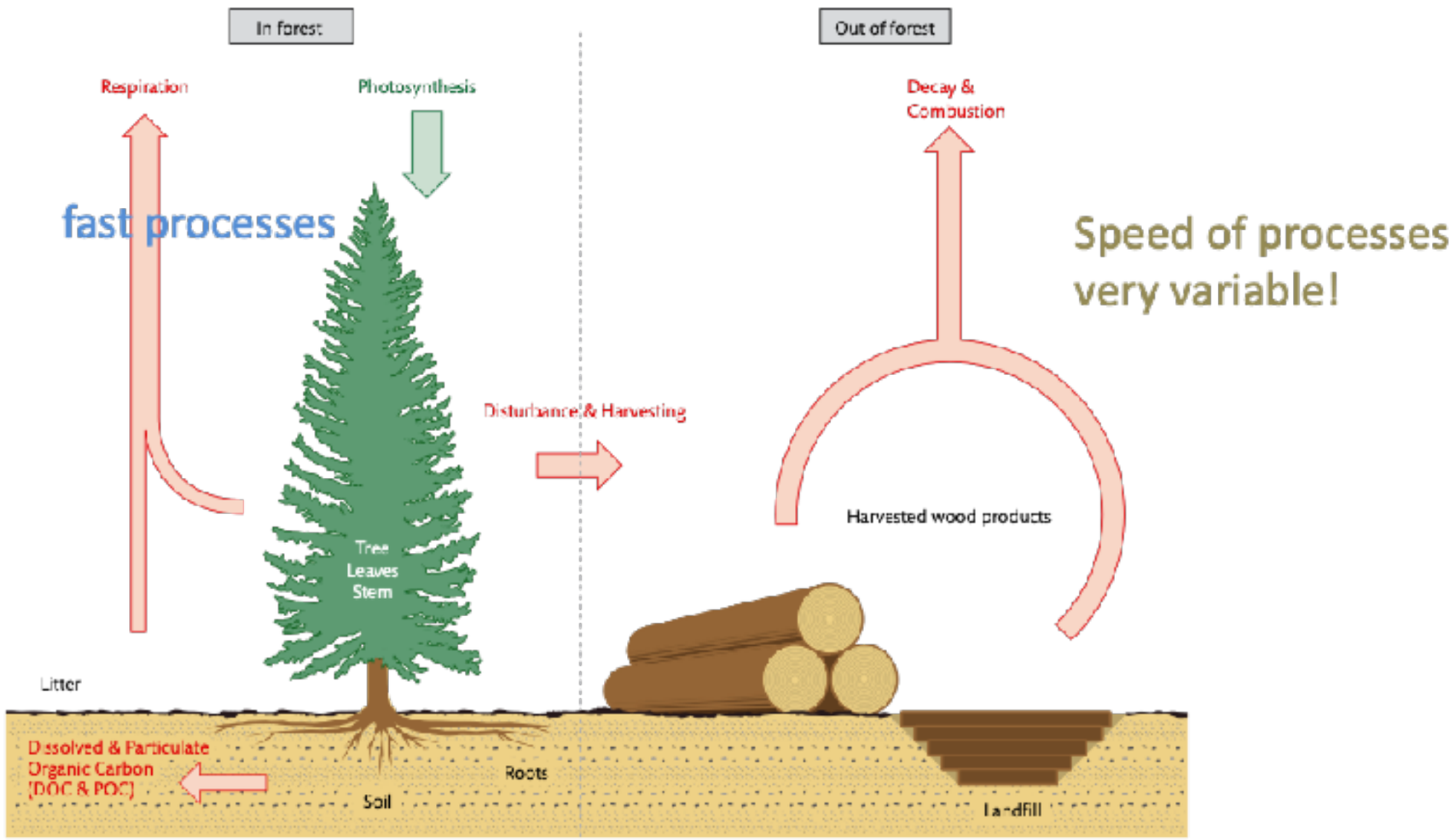


Carbon turnover in the forest



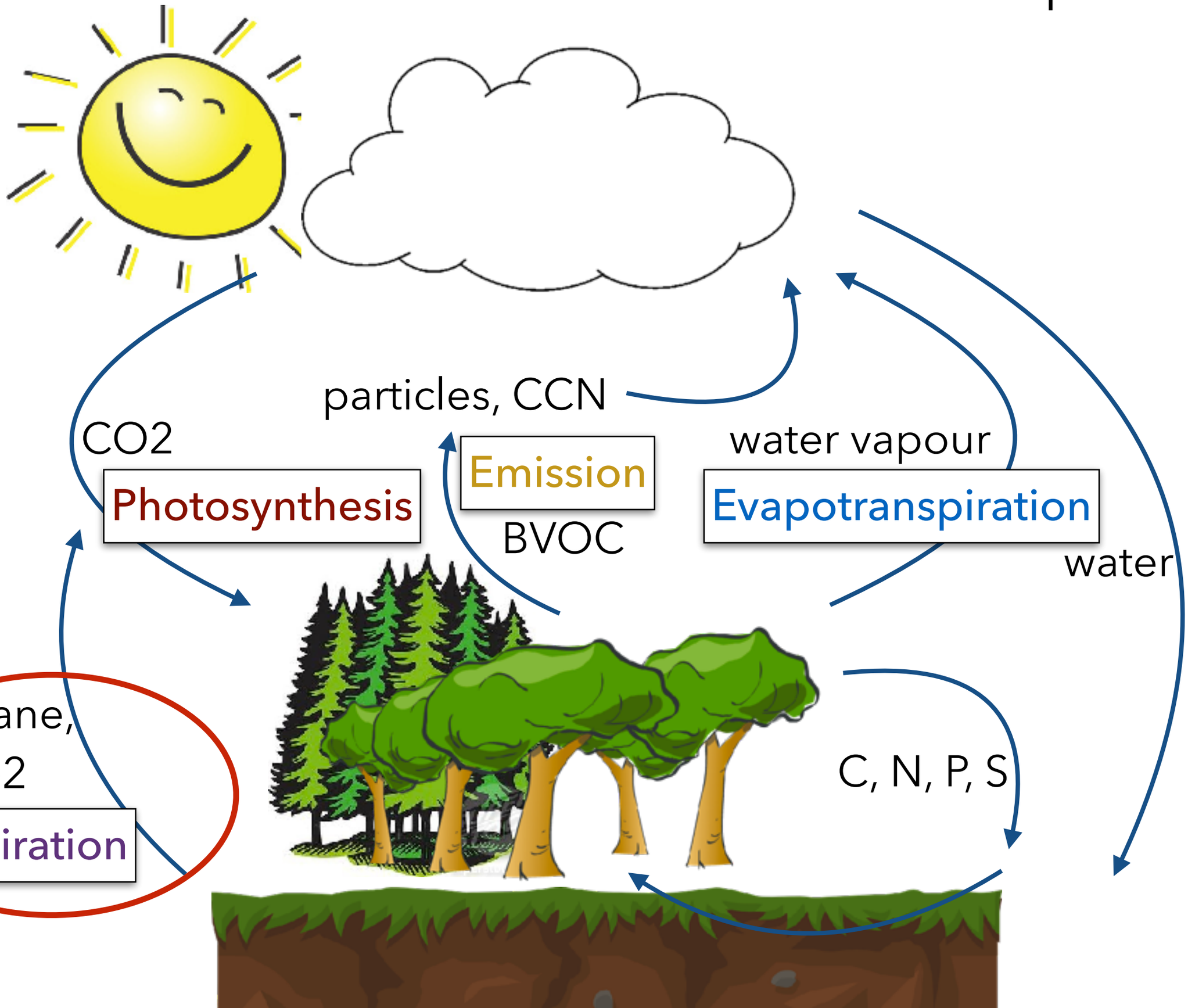
If we include human activity, the simple picture get more complicated

Figure 2.1 Main organic C stock components and C fluxes between components in forestry; disturbance includes natural (e.g. fire, landslip, flooding, storm). The green arrow indicates C flux into the forest; red arrows indicate fluxes out of the forest. For simplicity, vegetation other than trees is not shown, nor leachate losses from landfill.

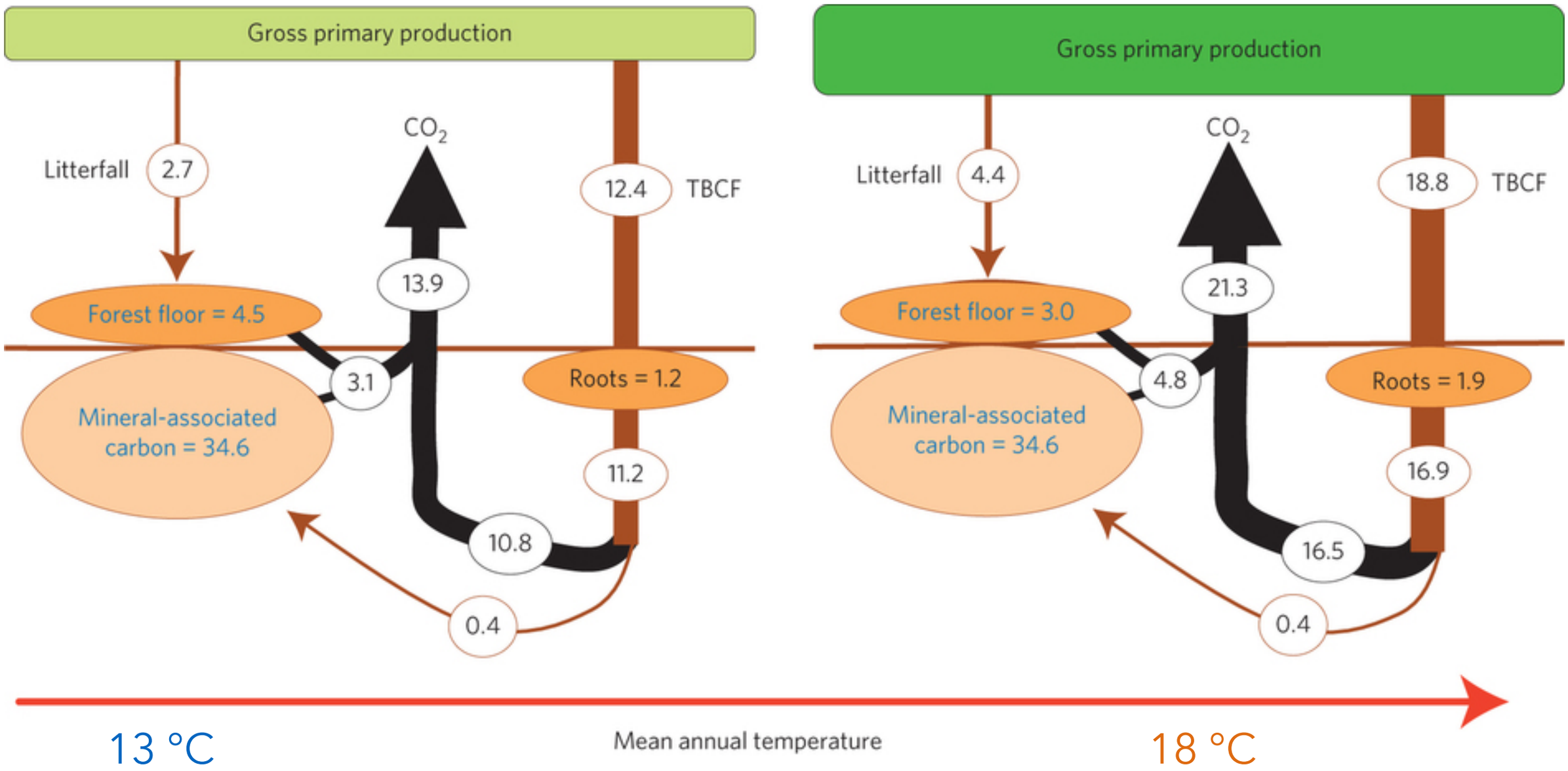


slow processes

Processes between the forest and the atmosphere



Carbon soil exchange process and climate warming



Nature Climate Change **4**, 822–827 (2014) doi:10.1038/nclimate2322

Soil respiration and rainfall / soil humidity

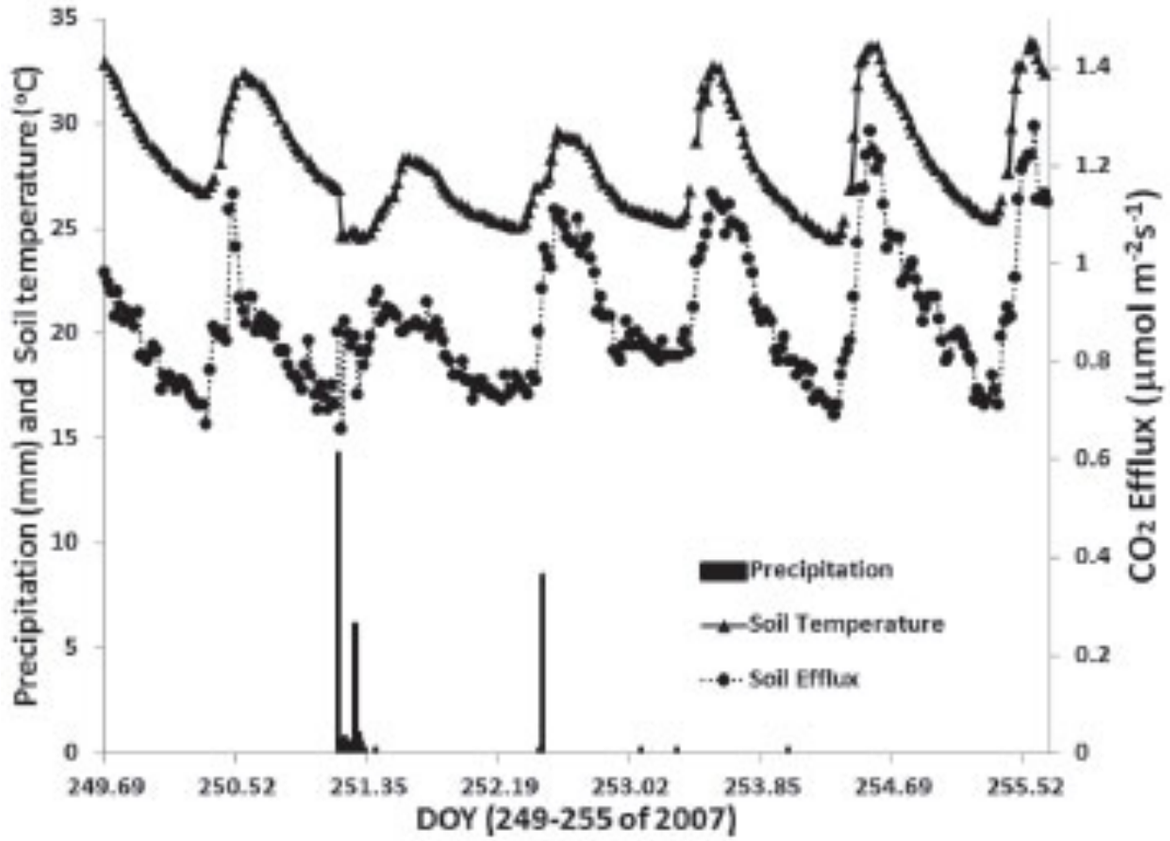
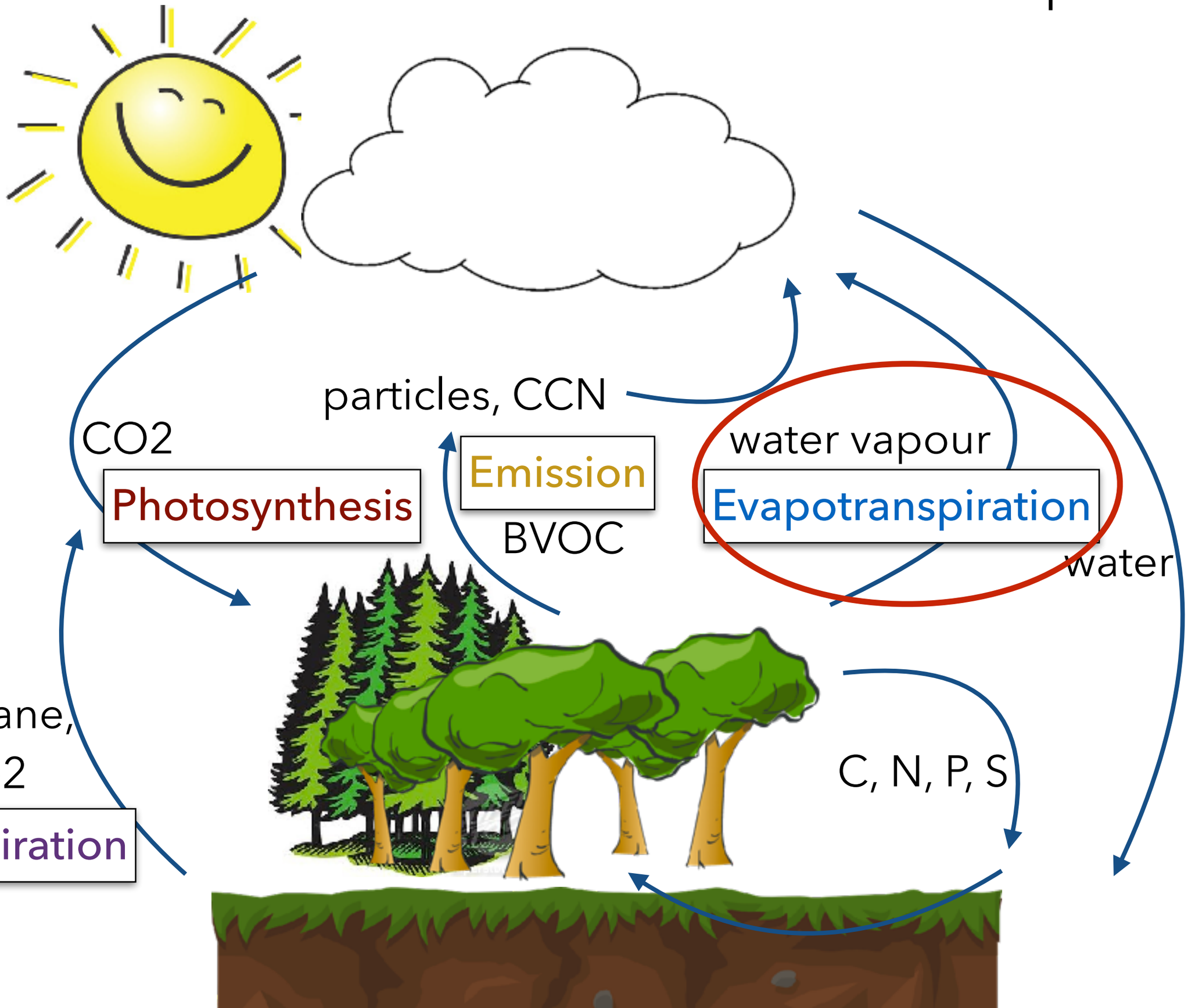
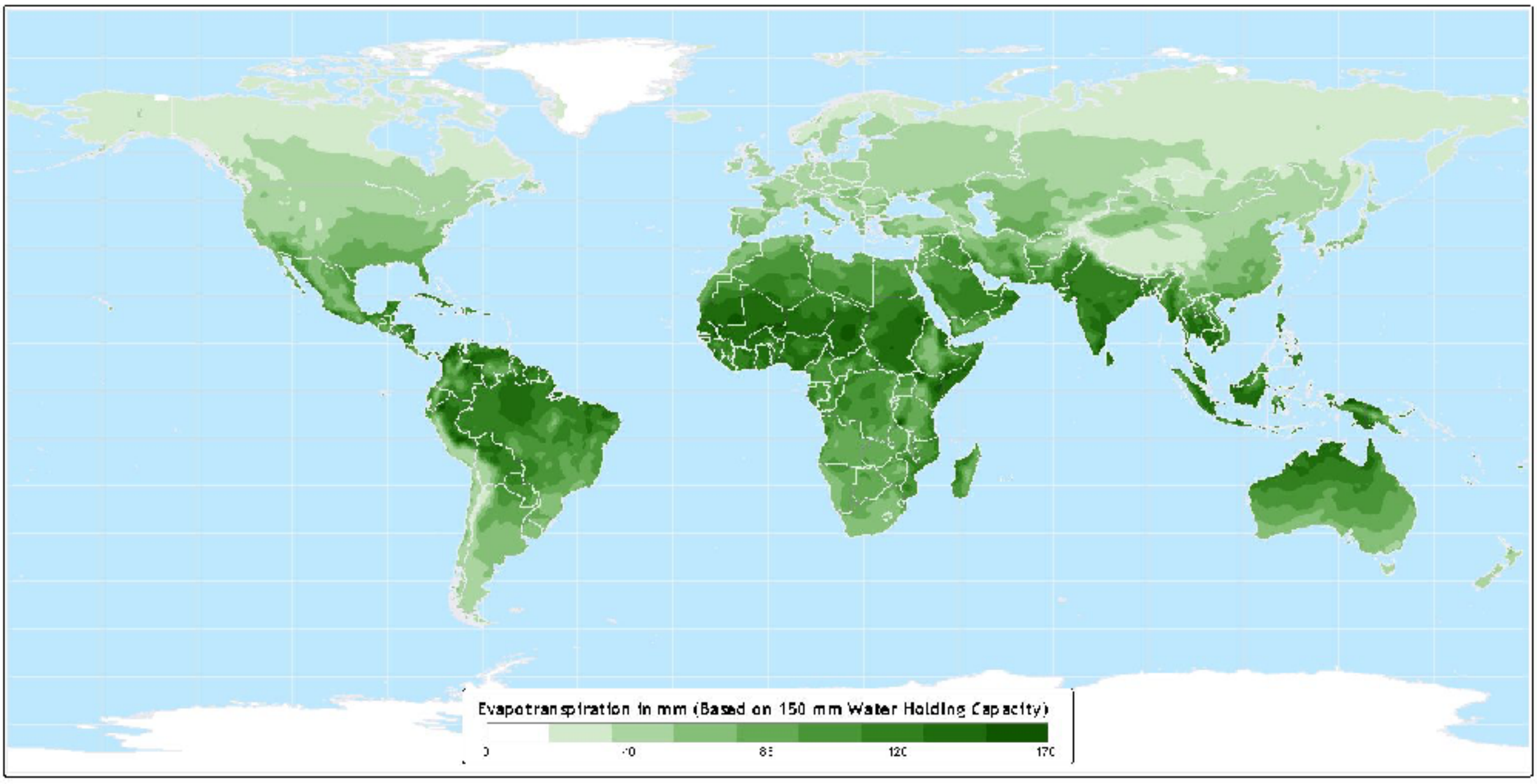


Figure 6 - Effect of rainfall events on the soil CO_2 efflux emission. The precipitation did not change the mean CO_2 emission, but the emission had a slight effect on the soil respiration, followed by soil temperature decrease for the SHF forest from Campina Reserve. In days of year (DOY) from 249-255 of 2007.

Processes between the forest and the atmosphere



Potential Evapotranspiration



Data taken from Willmott and Matsuura (2001)

Atlas of the Biosphere

Center for Sustainability and the Global Environment
University of Wisconsin - Madison

Some more numbers…

Most of the evaporation of moisture comes from the oceans, lakes and rivers! ~60% annual.

Few is directly sublimated from ice caps, snow and glaciers.

Plant's evapotranspiration makes about 40% moisture annually (in summer 50%, global land cover 30%!)

Forest's evapotranspiration is double than that of crops or water bodies!

Soils contain only a tiny fraction of the global water resource (~0.01%)

Water cycle

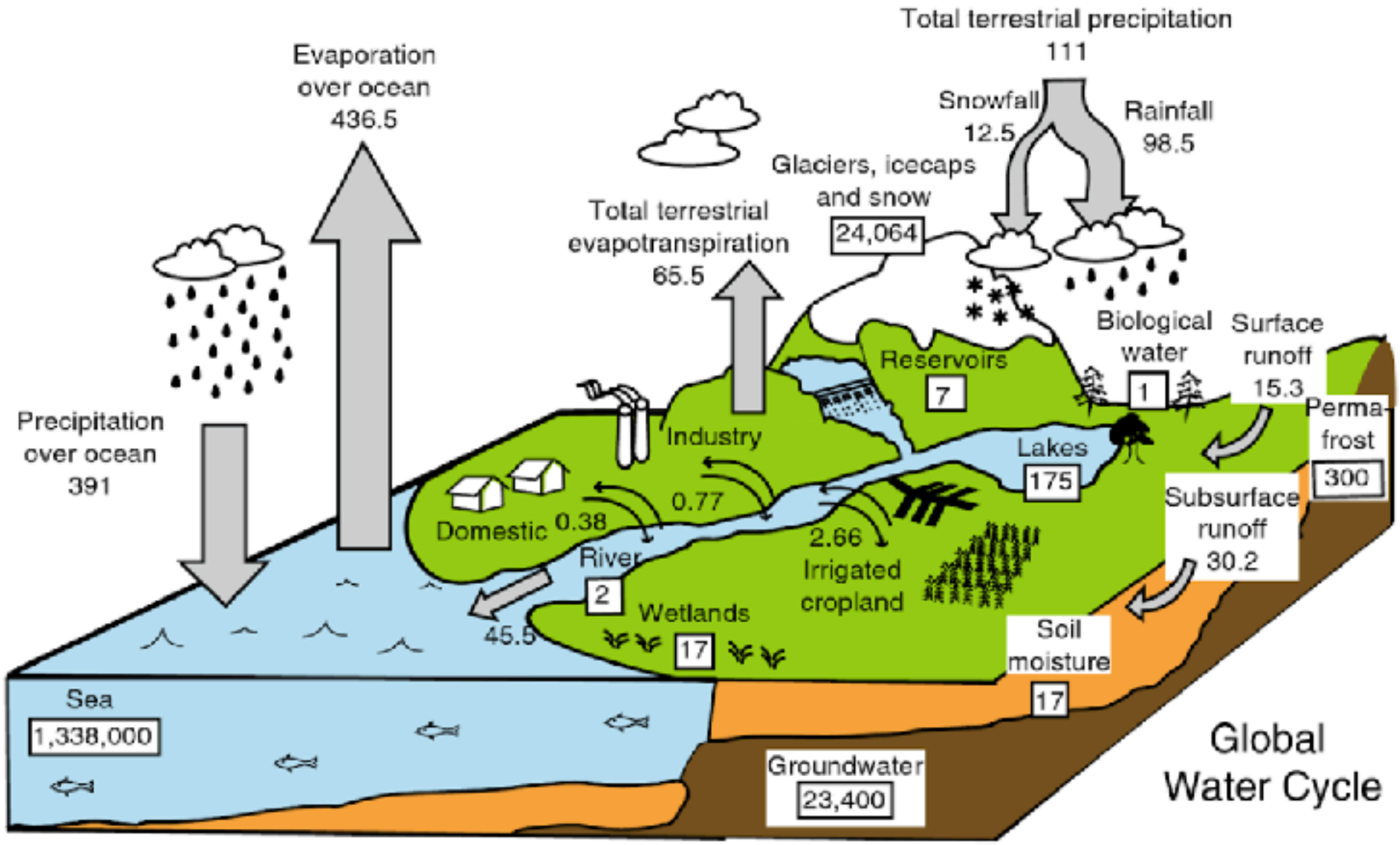


Fig. 14.3 The global water cycle, showing approximate magnitudes of the major pools (1,000 km^3; *boxes*) and fluxes (1,000 km^3 year^{-1}; *arrows*). Most water is in the ocean, ice, and groundwater, where it is not directly accessible to terrestrial organisms. The major water fluxes are precipitation, evapotranspiration, and runoff. Modified from Carpenter and Biggs (2009)

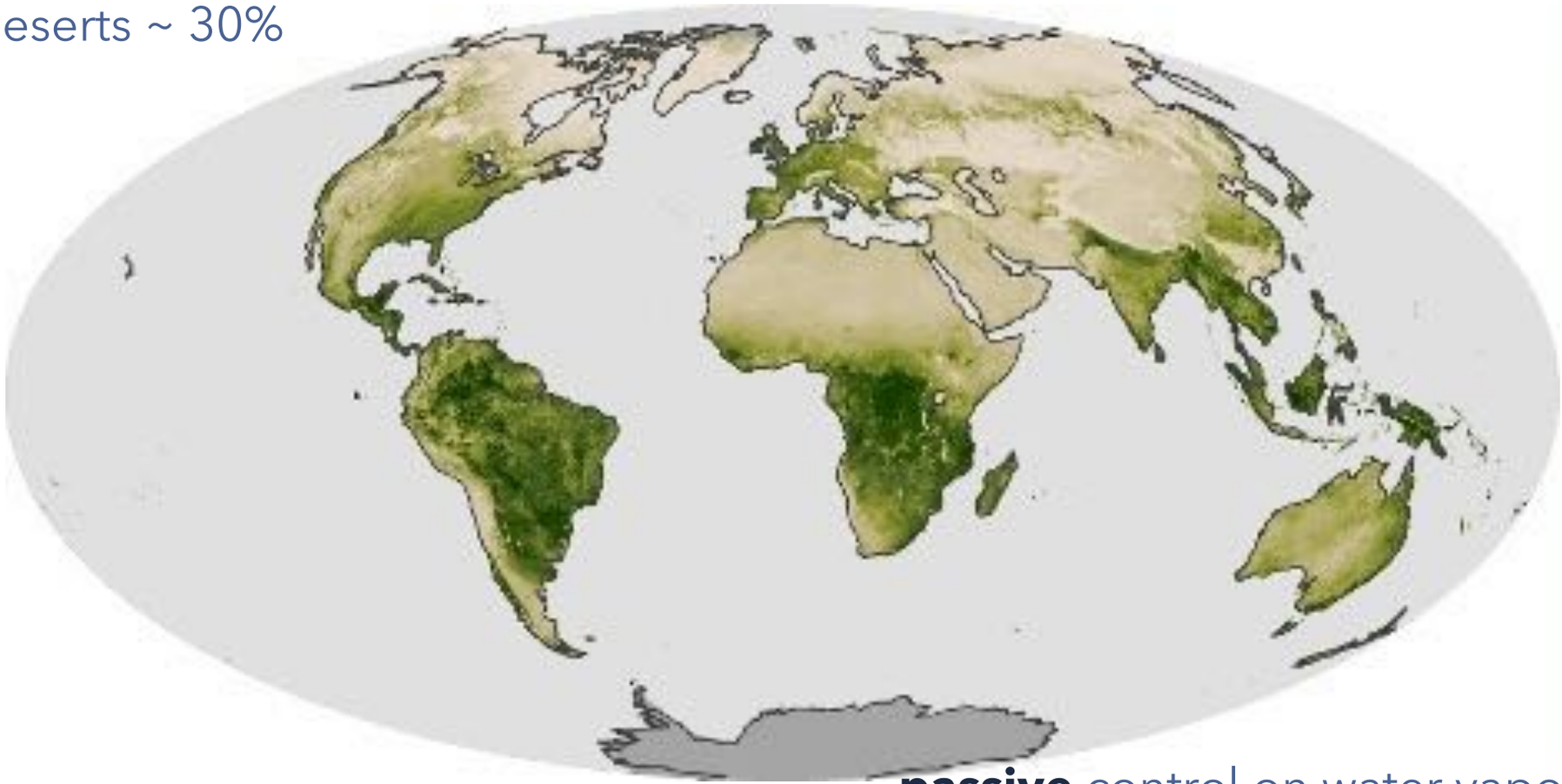
Principles of Terrestrial Ecosystem Ecology
By F Stuart Chapin III, Pamela A. Matson, Peter Vitousek

Active and passive processes

Land surface ~ 30%

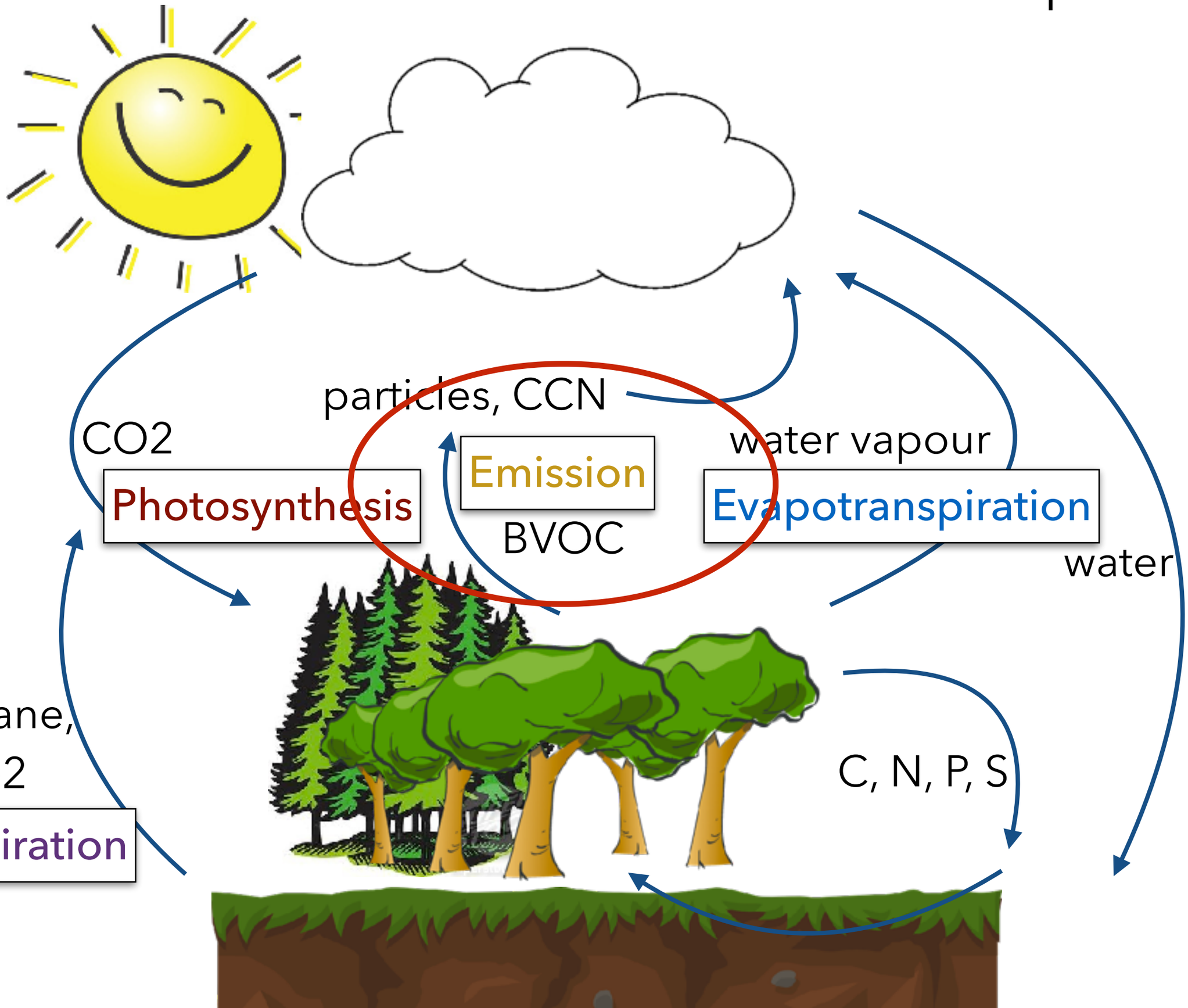
- Rain/temp. forest ~ 14%
- Boreal forest (Taiga) ~ 17%
- Agricultural land ~39%
- Deserts ~ 30%

→ **active** control on water vapour and carbon by plants --> **FORCING**



Ocean surface ~ 70% → **passive** control on water vapour and carbon --> **FEEDBACK**

Processes between the forest and the atmosphere



Hydrocarbons and volatile organic compounds

Fossil fuels

Hydrocarbon = ‘hydro(gen)’ (H) + ‘carbon’ (C)

Alcohol (ethanol)

formaldehyde

β-carotine

pesticides

terpenes

methane

Peroxy Acetyl Nitrate (PAN)

pinic acid

Vitamin A

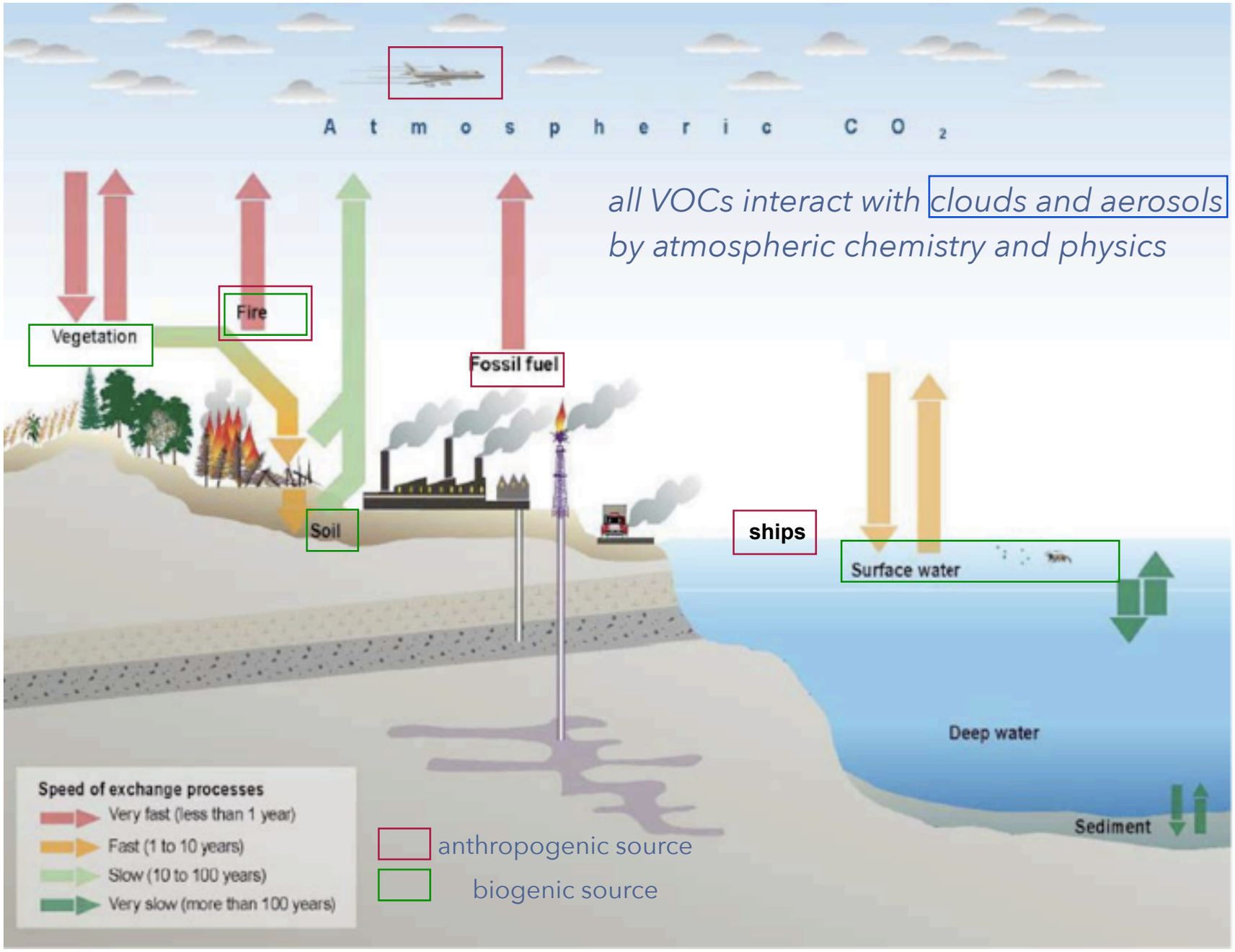
α-pinene

benzene

Organic compound = hydrocarbon (+ further species: nitrogen (N), oxygen (O), sulphur (S) etc).

Occurrence: in living matter and the exchanged gases

Sources of VOC

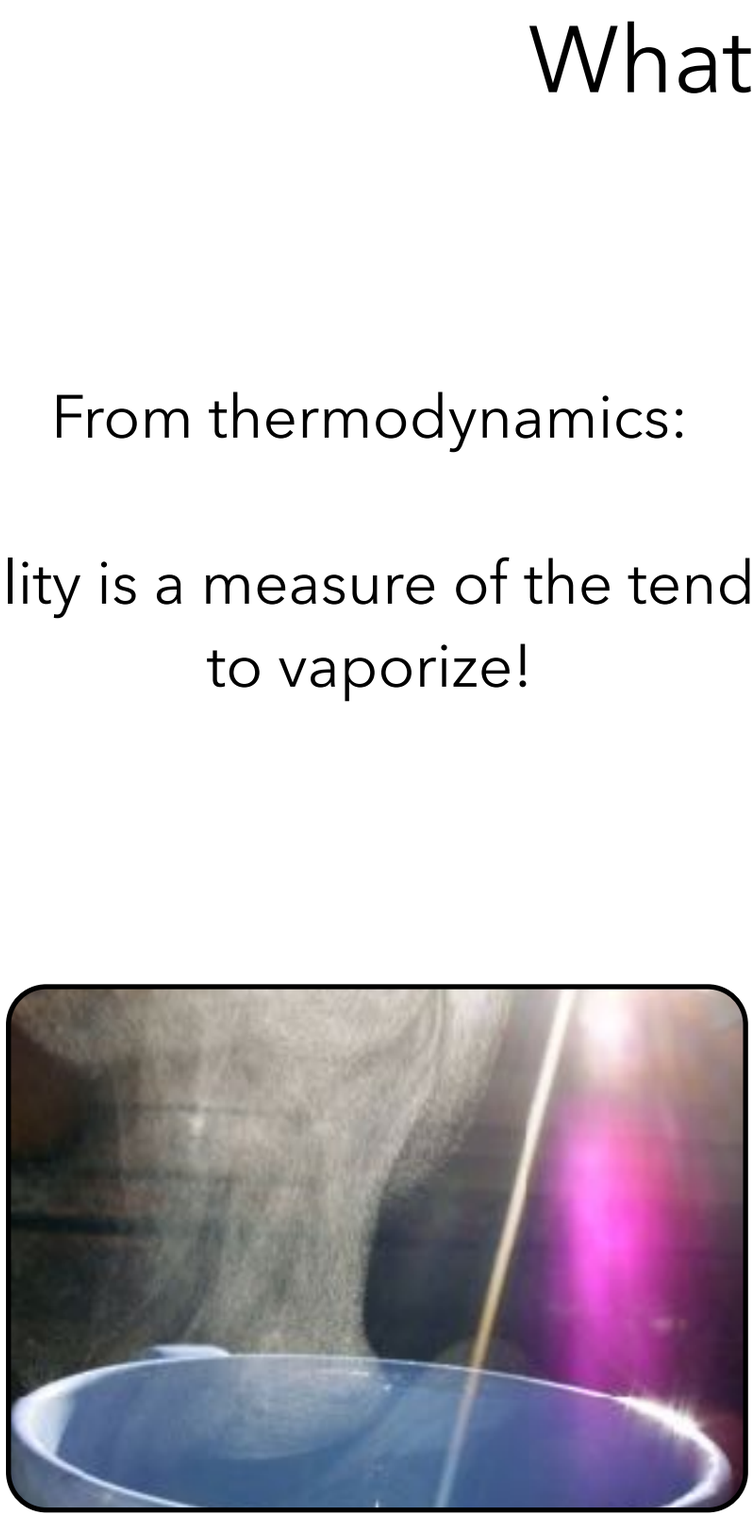


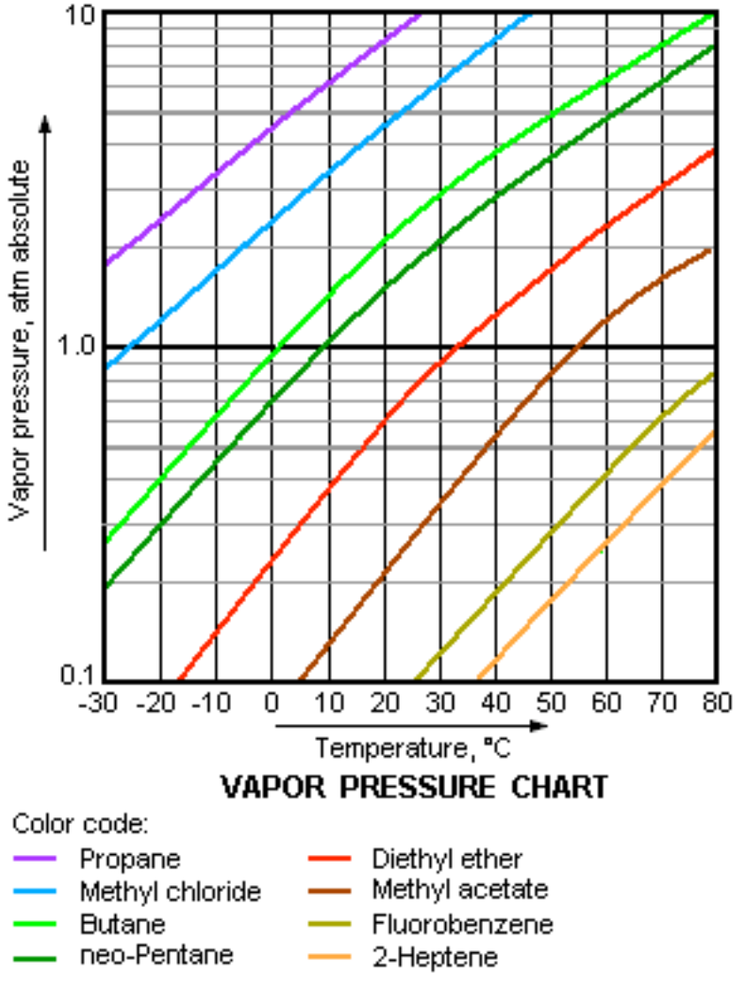
Source: modified http://www.defra.gov.uk/environment/airquality/publications/airqual-climatechange/pdf/chapter02.pdf

What is volatility?

From thermodynamics:

volatility is a measure of the tendency to vaporize!





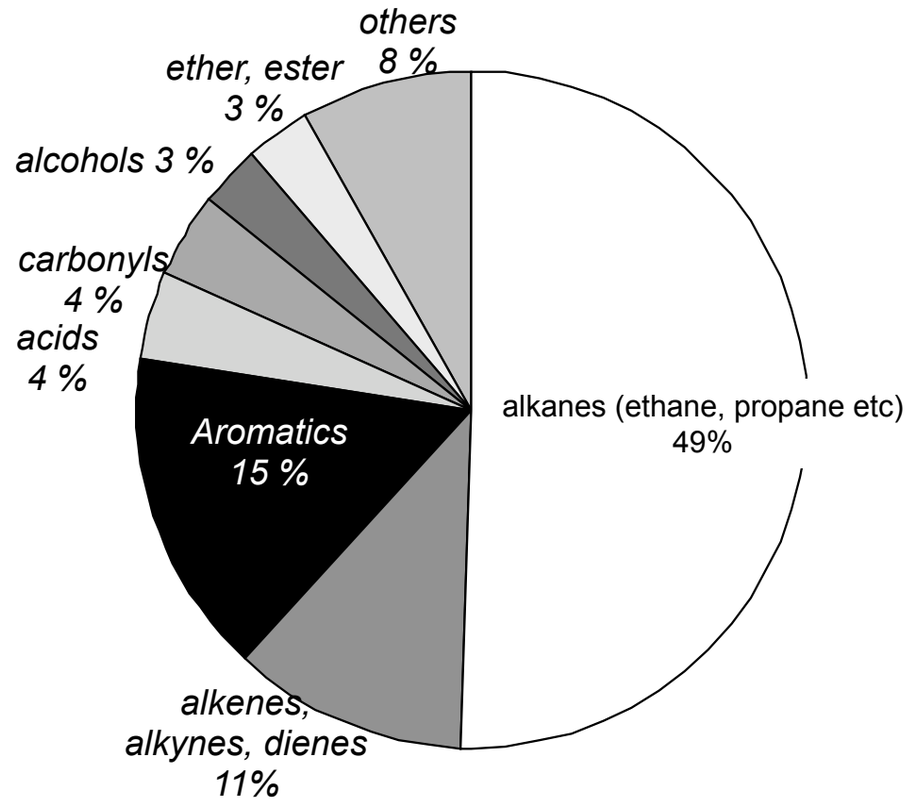
Anthropogenic VOC

Total sum

100-200 Tg Carbon yr^{-1}

Aromatics only

20 Tg Carbon yr^{-1}

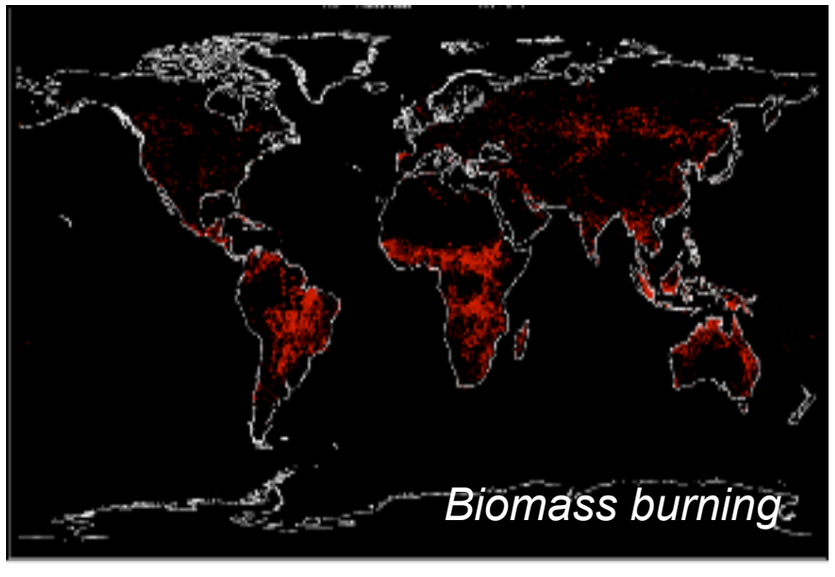


IPCC (2001)

Sources of anthropogenic VOC

traffic

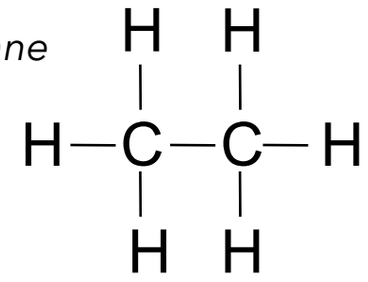
Solvents e.g. in:
nail polish,
parfumes,
printer cart-
ridges, tapes,
advertisement prod.

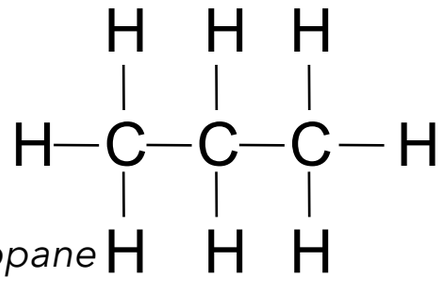


Anthropogenic alkanes

Saturated hydrocarbons (C_xH_y) excluding methane, emitted from all sources shown.

ethane





propane

...

Atmospheric fate

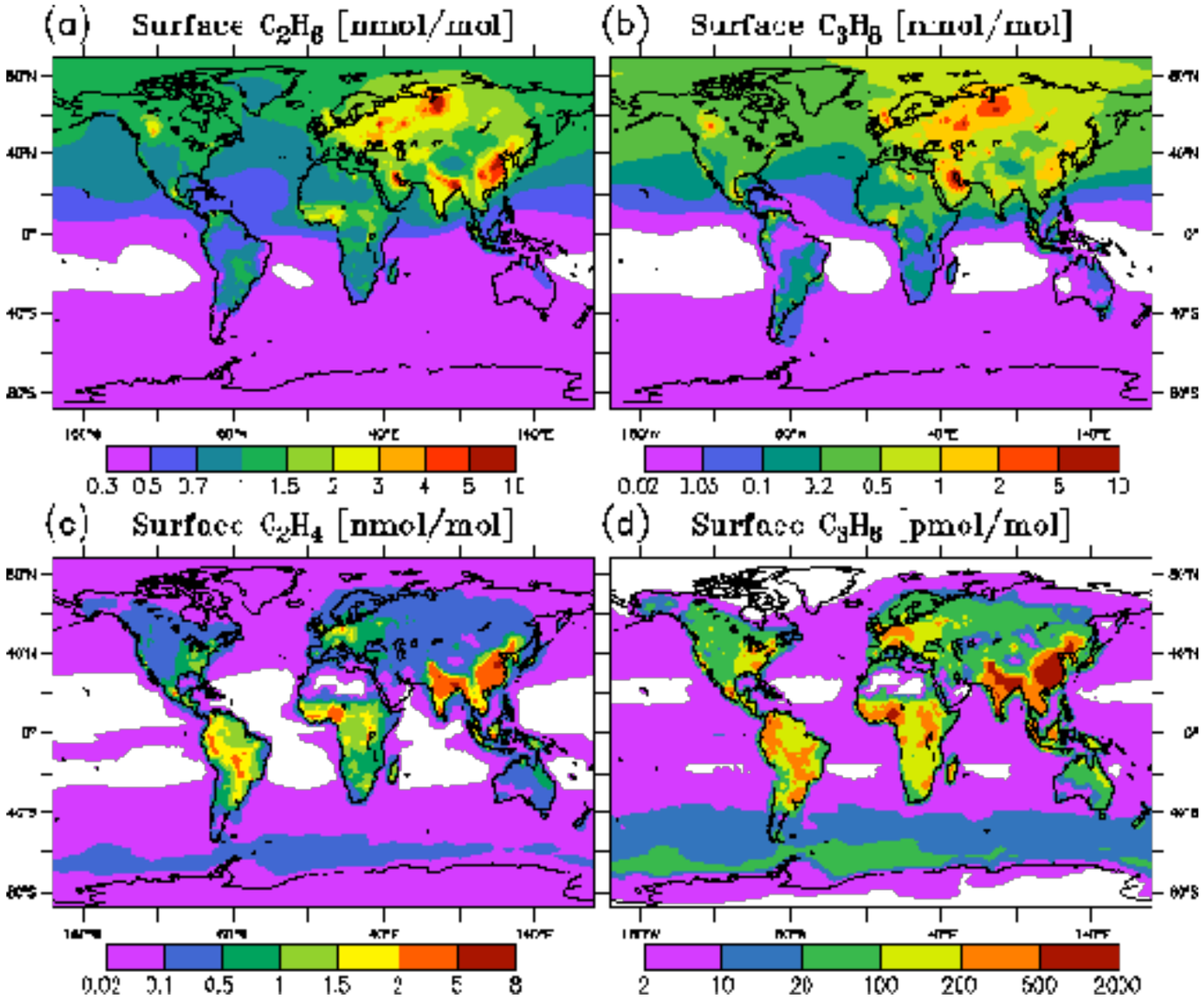
reacts only with OH, but slow (k_{OH}(198K)=2.55 x 10^{-13} cm^3 $molecule^{-1}$ s^{-1}

Long lived (days - months) ethane = 2.7 months, propane = 28 days

Global distribution of surface ethane and propane

Summer

Winter



von Kuhlmann, 2002

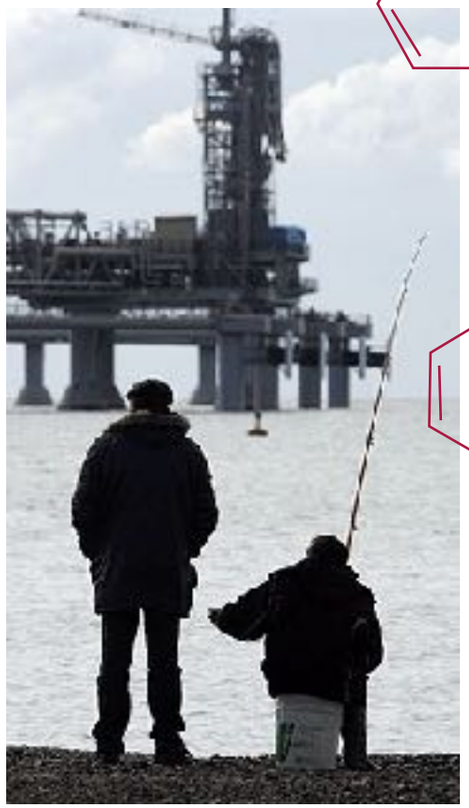
The simulation clearly shows the hot spots at metropolitan areas, industries, harbours, oil refineries and the transportation pattern of the long lived gases

More anthropogenic VOC

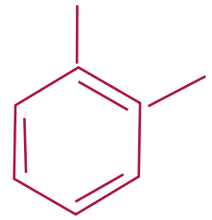
The gases you inhale in cities behind a vehicle.

Emitted by fossil fuel combustion and biomass burning

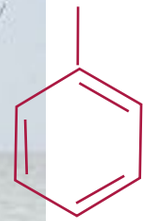
Benzene



Xylene

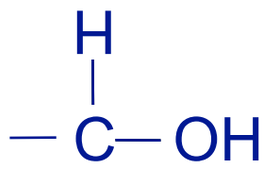


Toluene



- *reaction with OH (and O_3 for styrene)*
- *short live times (1h-2d)*
- *local air pollution*
- *aerosol formation*

Anthropogenic water soluble VOC



formic acid
ethanol (wine, beer etc)
formaldehyde (HCHO)
acetone

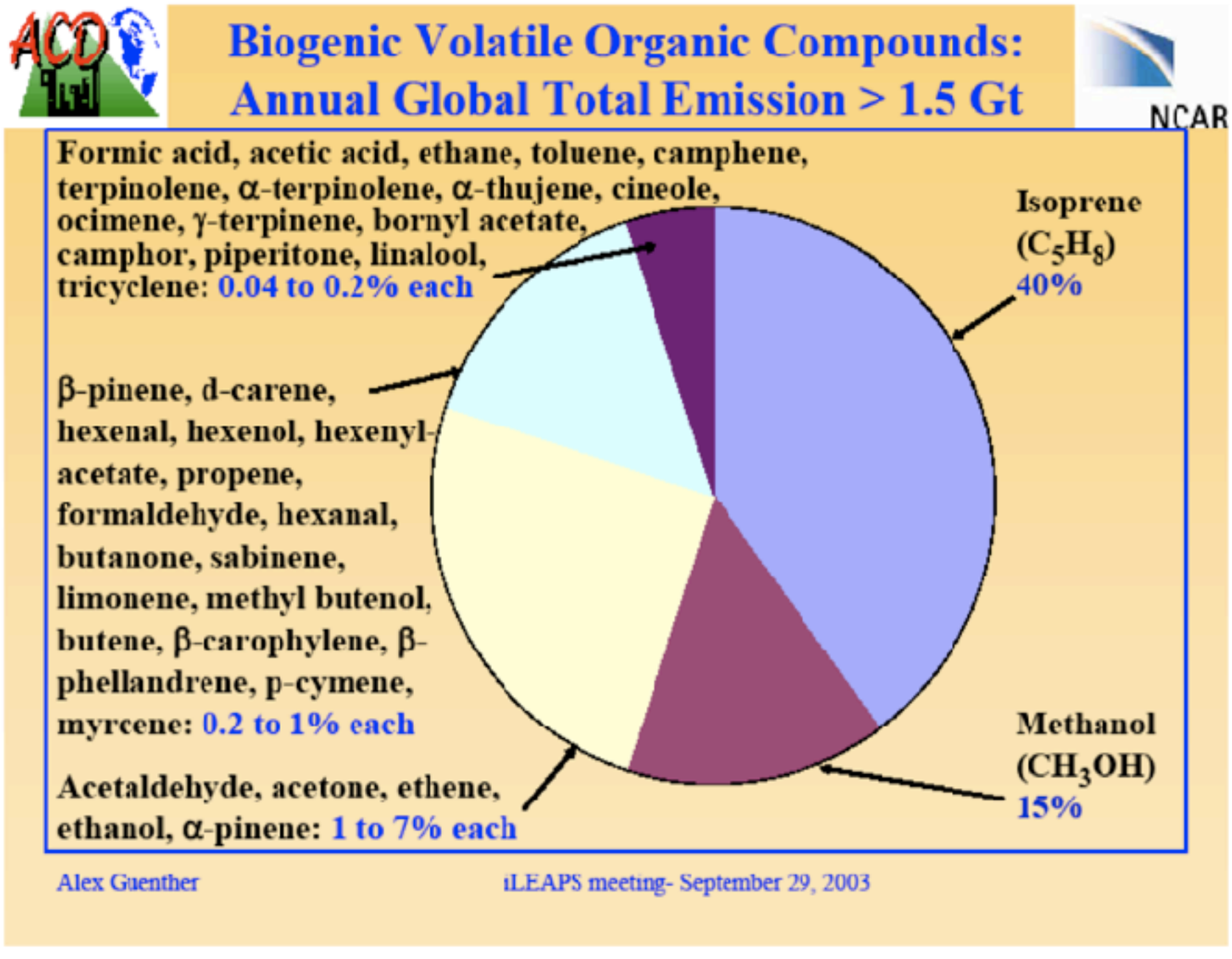
Atmospheric chemical lifetime

long, more than 3 days up to months!
(Exception Aldehydes, some hours)

Main sink are clouds and wash out!

Long range transport!

Global biogenic VOC = BVOC



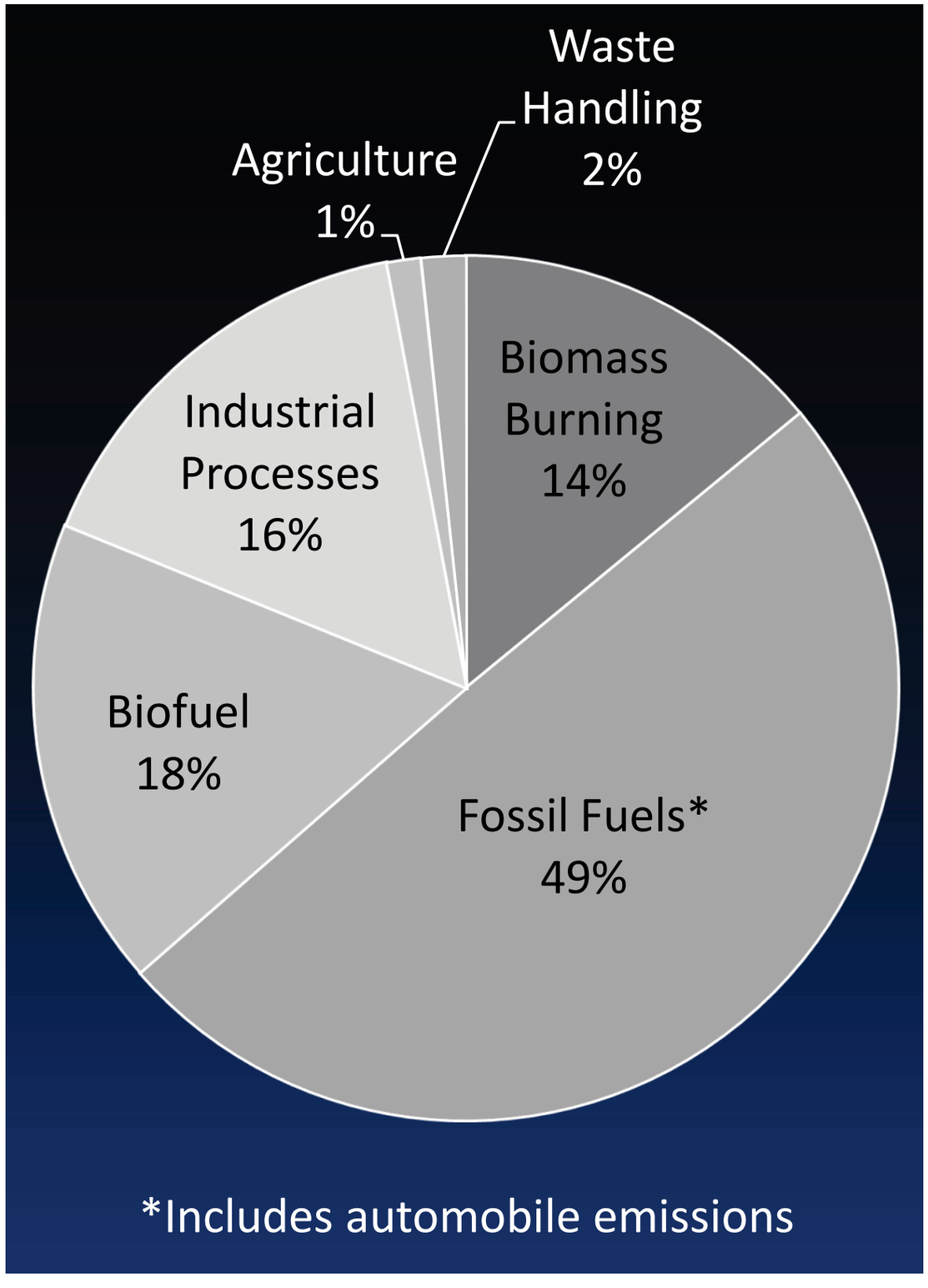
BVOC vs anthropogenic VOC

90 Tg year^{-1}

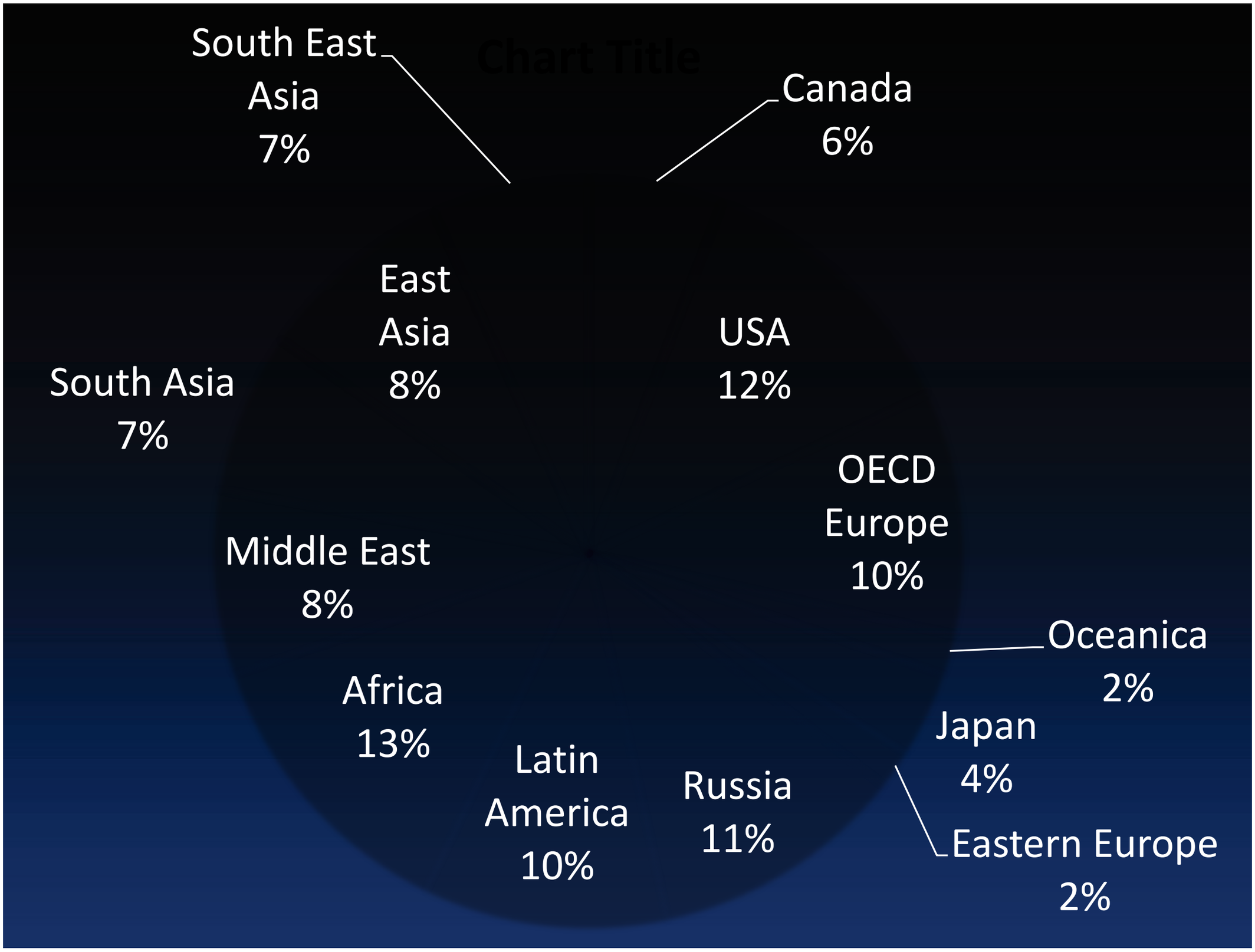
760 Tg year^{-1}

These numbers come from 2014!

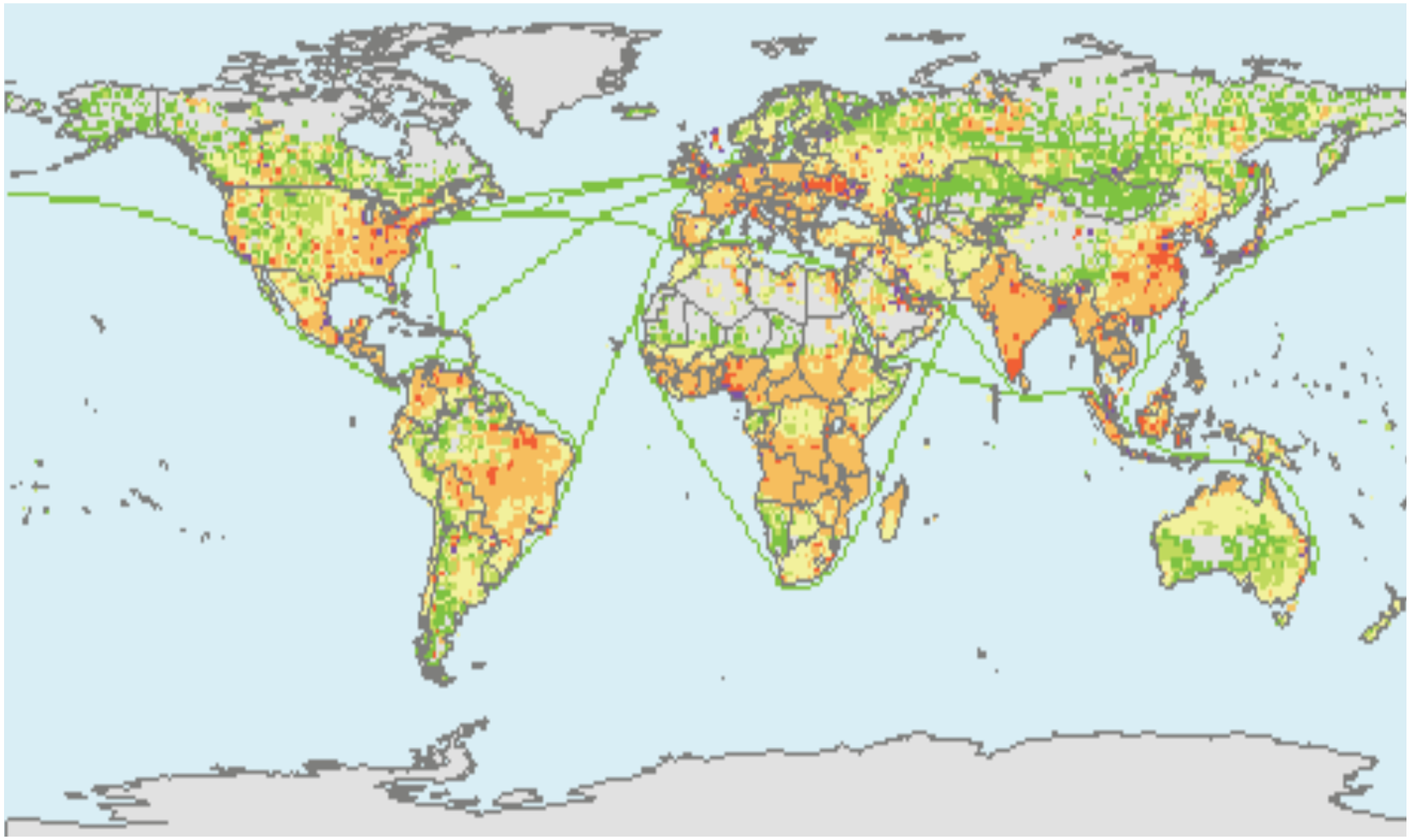
Breakdown of global anthropogenic sources



Anthropogenic VOC emission per region



Non-methane VOC emission density



Legend

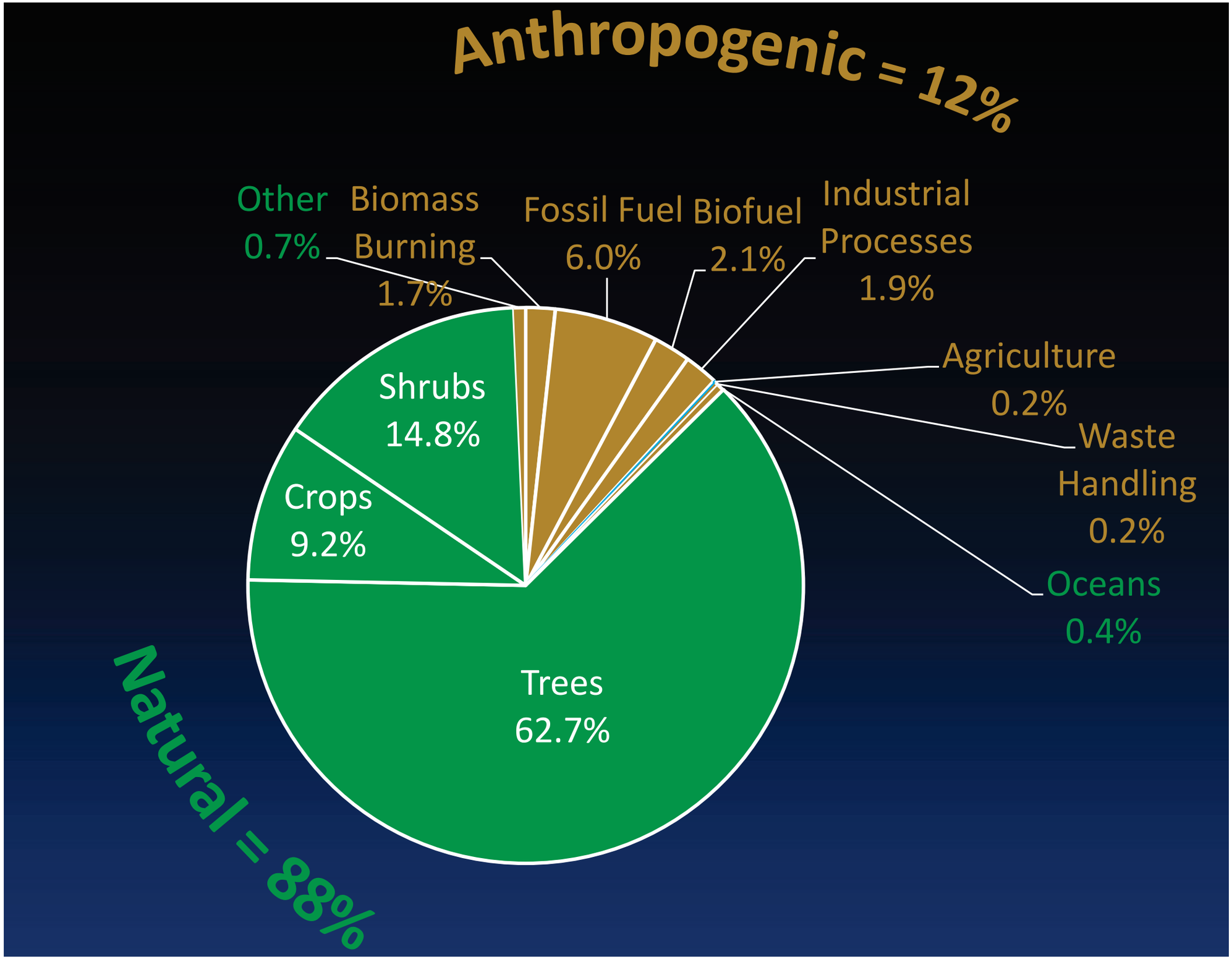
NMVOC Total 2000

- 0 – 0.1 Gg NMVOC per cell
- 0.1 – 1
- 1 – 2
- 2 – 10
- 10 – 50
- 50 – 100
- 100 – 2,000 Gg NMVOC per cell

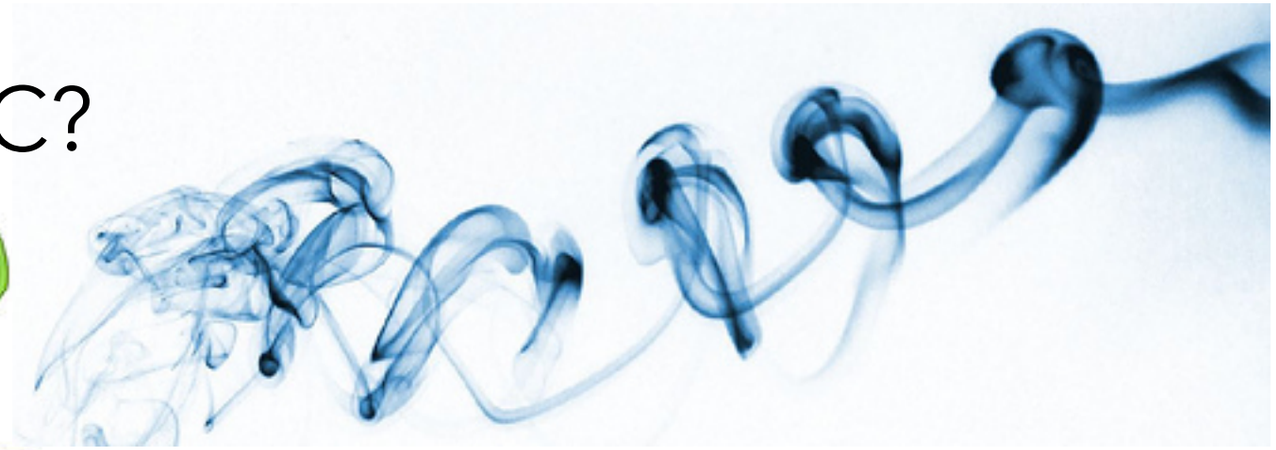
Units = Gigagrams of NMVOC
(1 Gigagram = 10^9 grams = 1,000,000,000 grams)

Methane (~572 Tg/yr) is a source that needs to be handled separately!

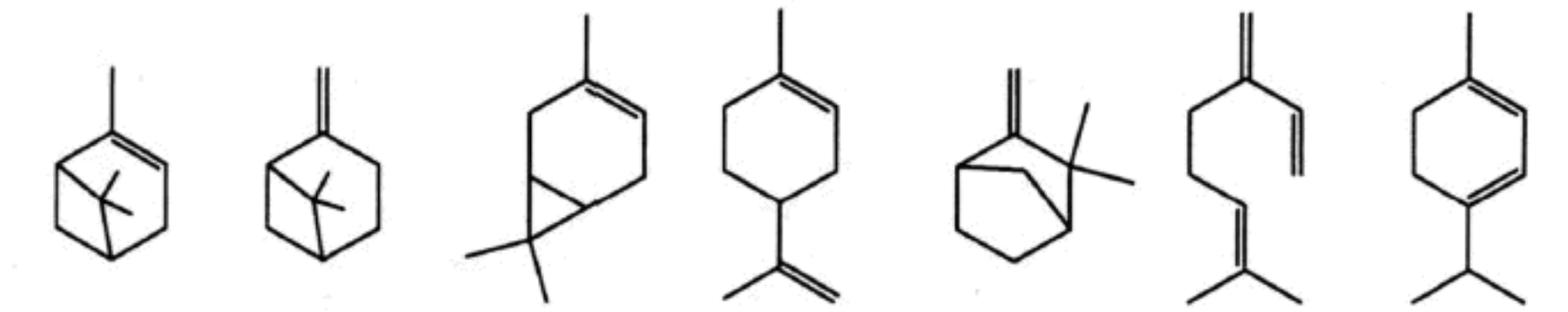
Emission sources



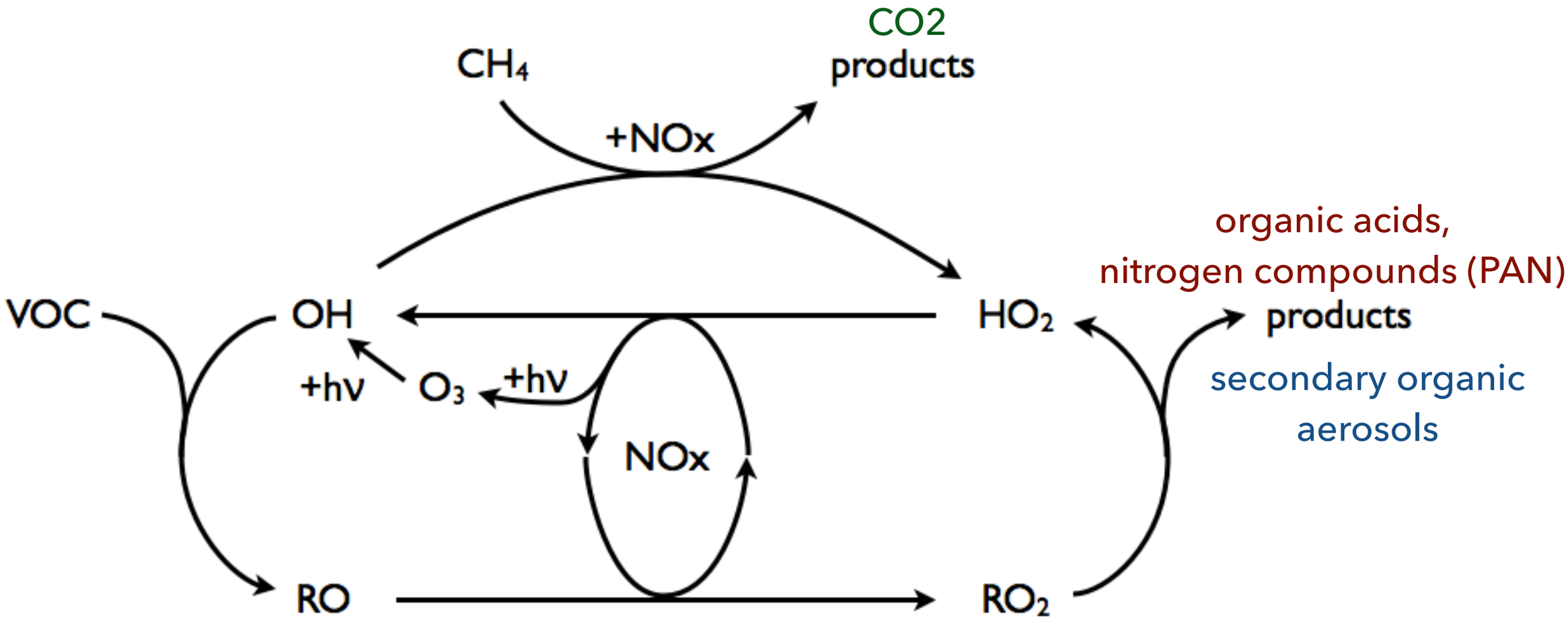
What is a BVOC?



Different plants emit so called
Volatile organic compounds = VOC
as they are originated from biological organism
they are called
Biogenic volatile organic compound = BVOC



The role of BVOC in atmospheric processes

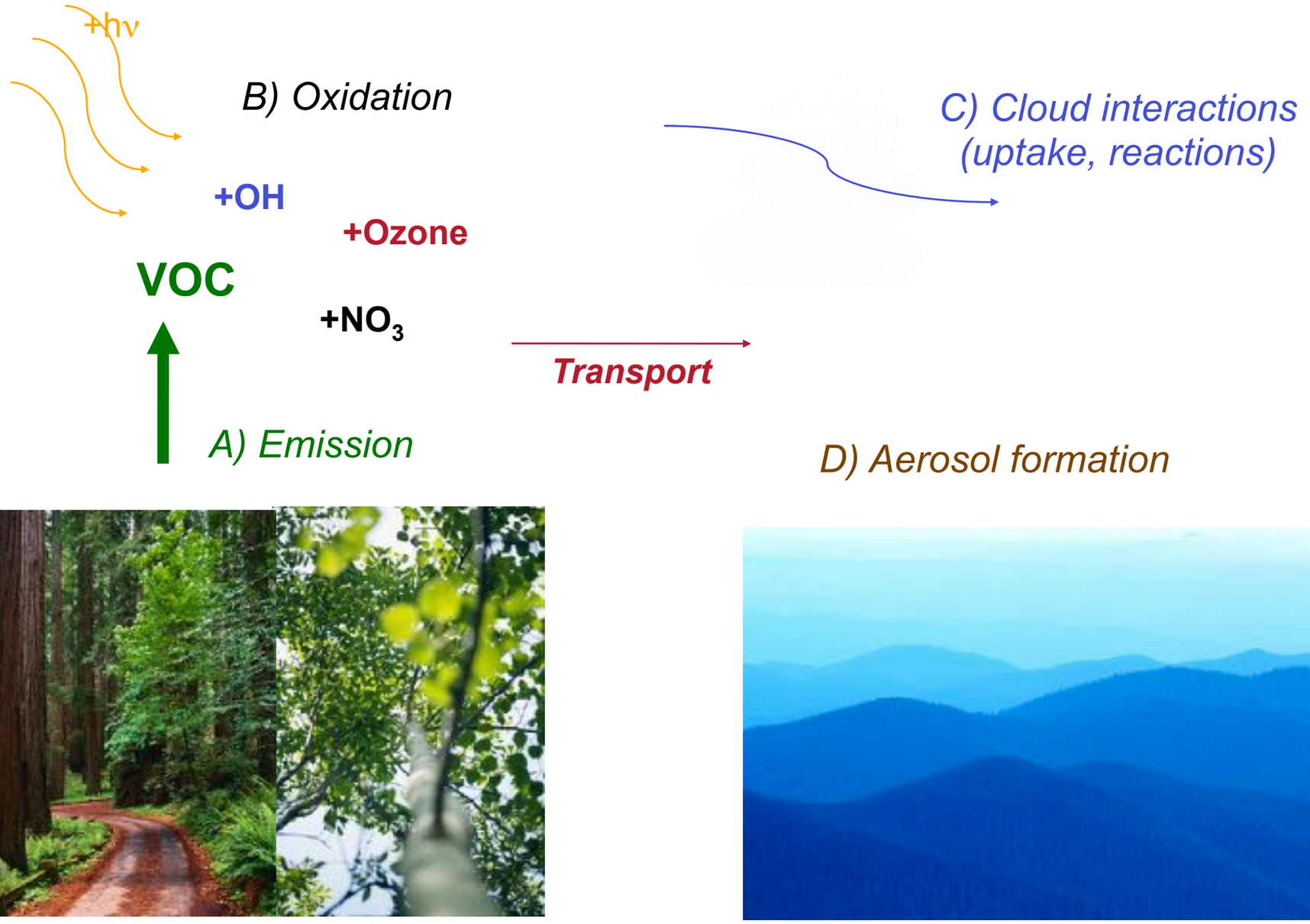


-volatiles are originated mostly from natural sources (~760 GT/yr vs ~90 GT/yr man made, 2014)

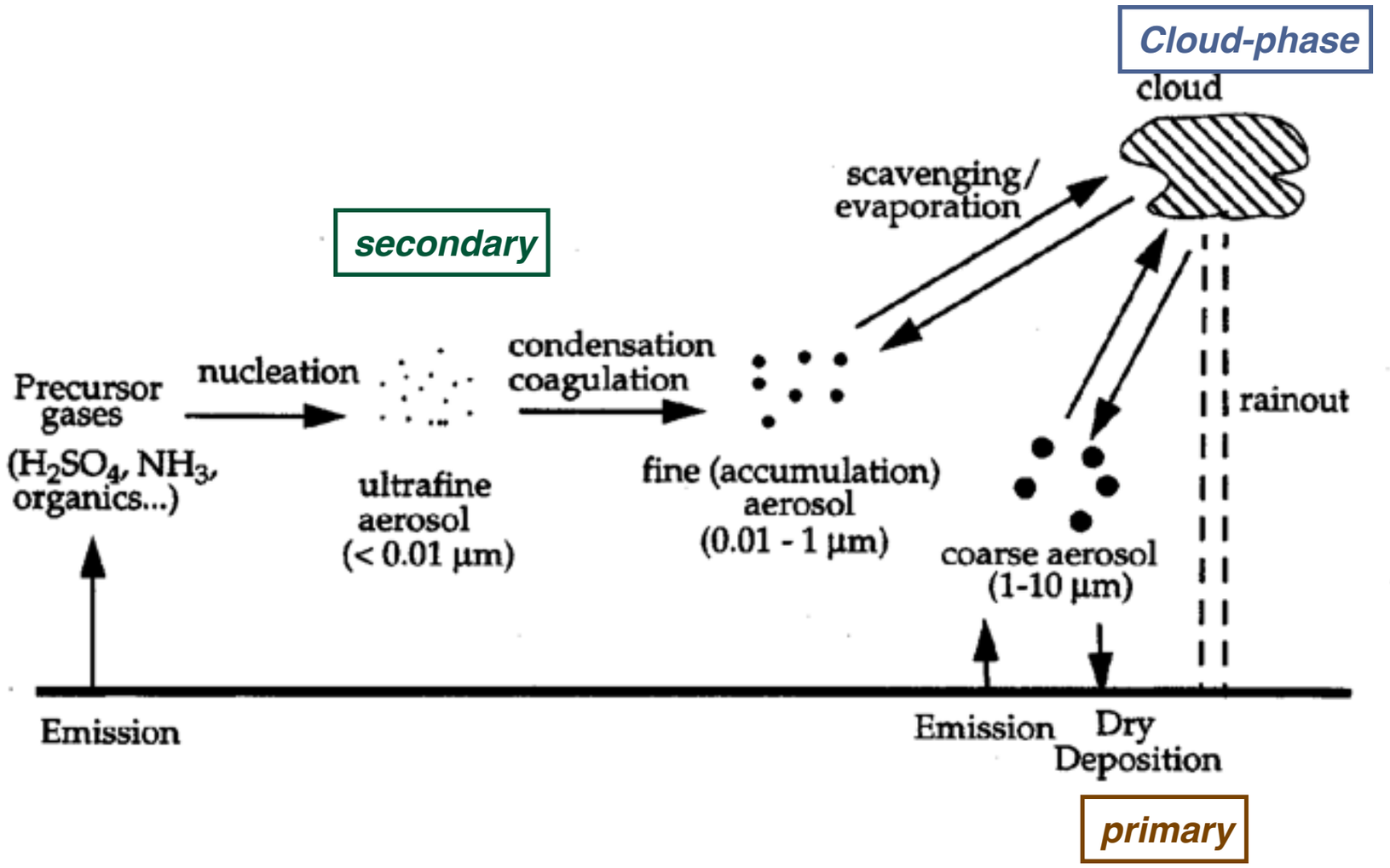
-tropospheric ozone and hydroxyl radicals formed by sunlight and the processes above

-nitrogen oxides are mostly originated from burning processes, large fraction man-made

BVOC fate after emission



Short overview on aerosol effects



Environmental importance: health (respiration), visibility, radiative balance, cloud formation, heterogeneous reactions, delivery of nutrients…

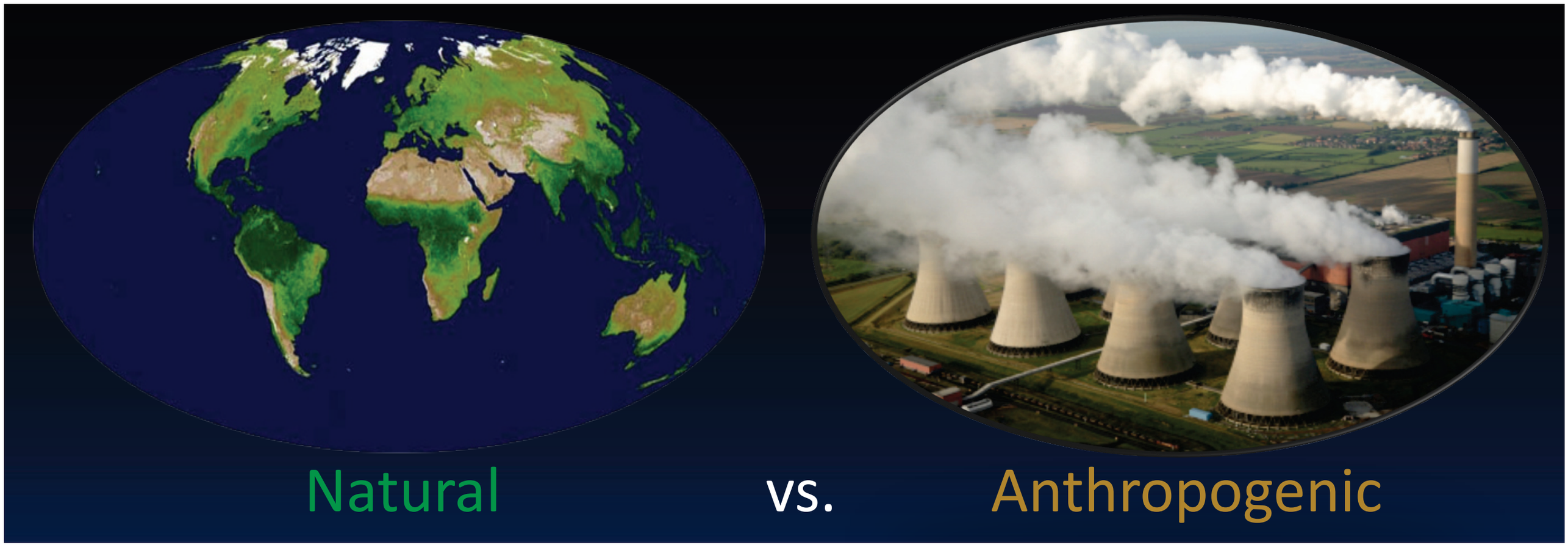
D.J. Jacob

Impact of plant originated BVOC emissions on visibility

(c) U.S. forest service (http://webcam.srs.fs.fed.us/tools/winhaze/)

If 88% are emitted from natural sources…

Why should we be concerned on that 12% fraction we emit ?



Natural vs. Anthropogenic

Natural sources are spread over the whole planet what the global forest cover indicates.

Anthropogenic sources are “concentrated” in areas where humans live. They form together with other pollutants unhealthy conditions.

Lecture