Forests in the climate system

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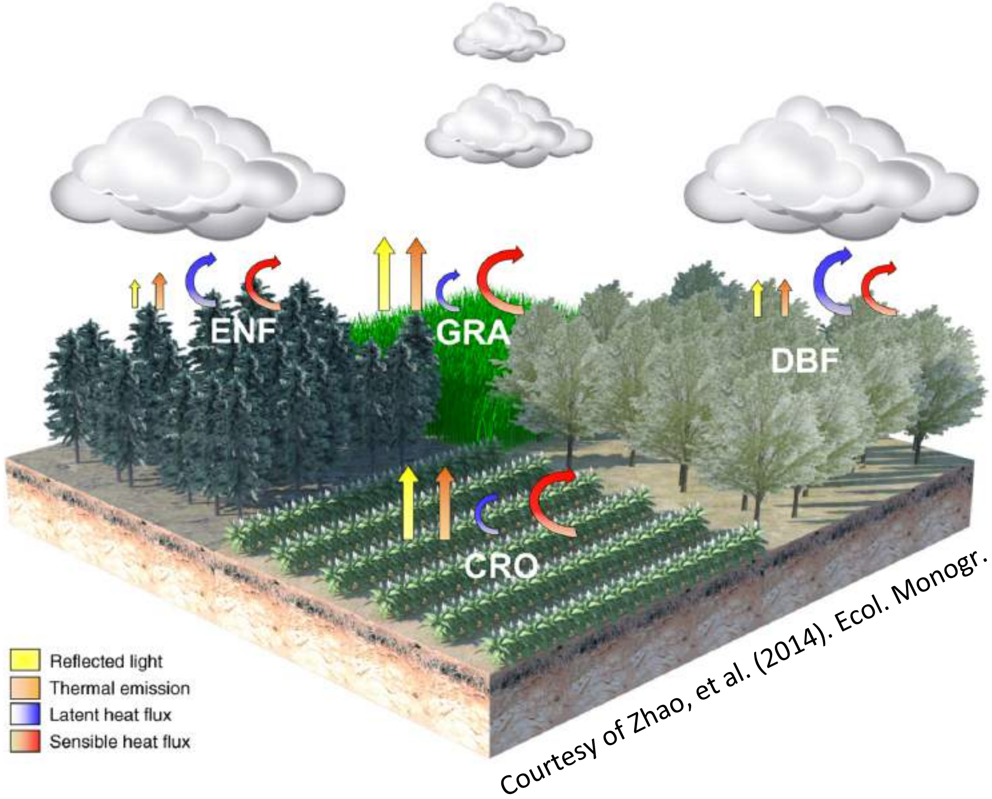
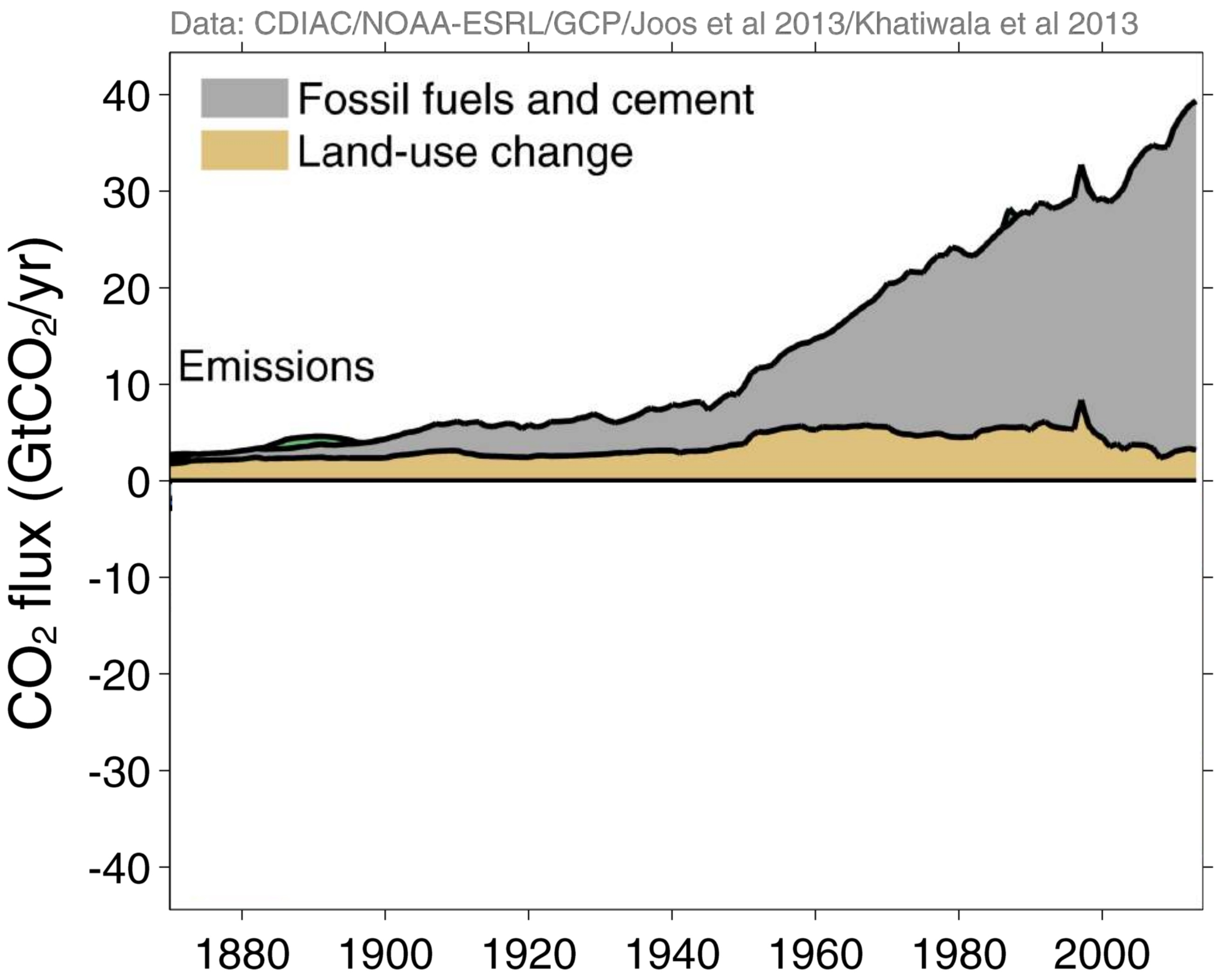


Environment, Sustainable Agriculture and Forest Management
Padova 26/04/2016

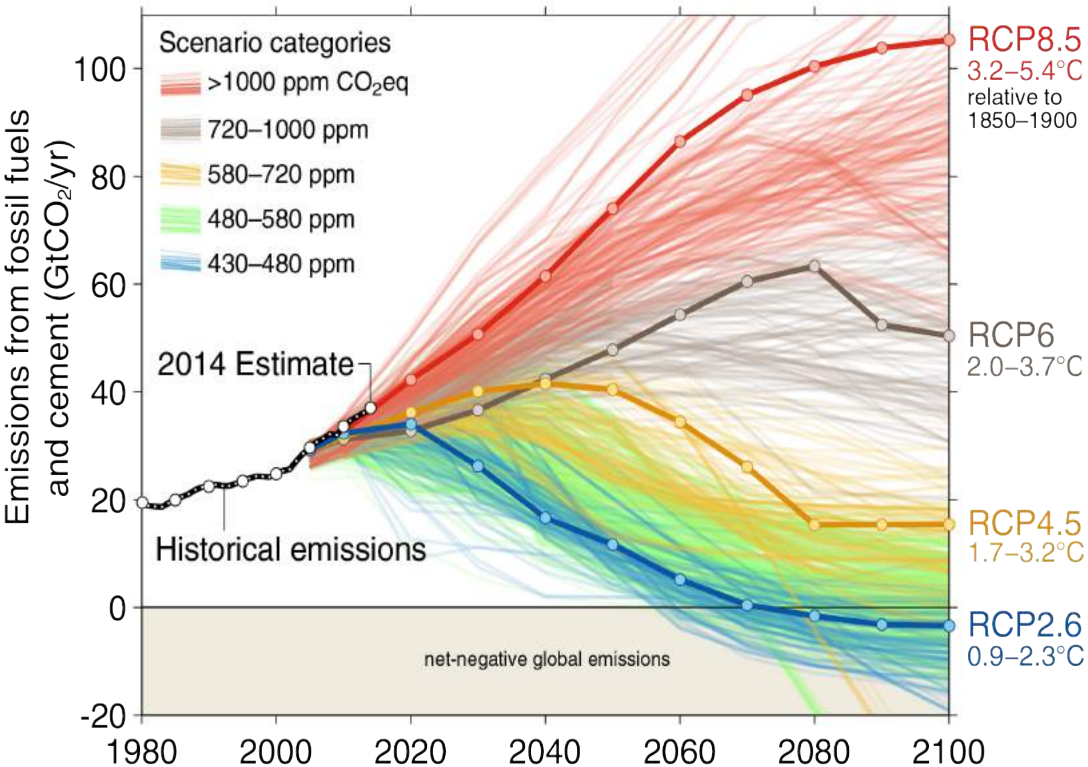
The anthropocene

The perturbed planetary biogeochemistry



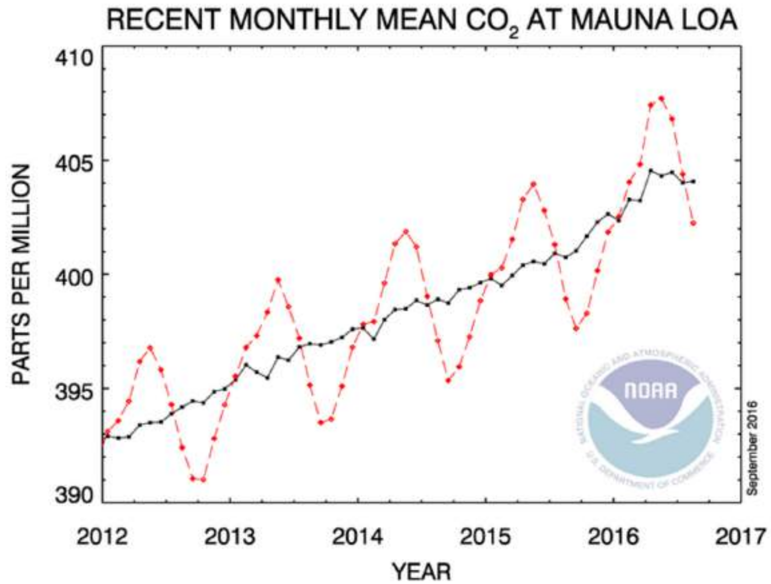
Source: [Global Carbon Budget 2014]

The perturbed planetary biogeochemistry



Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014



August 2016: 402.25 ppm

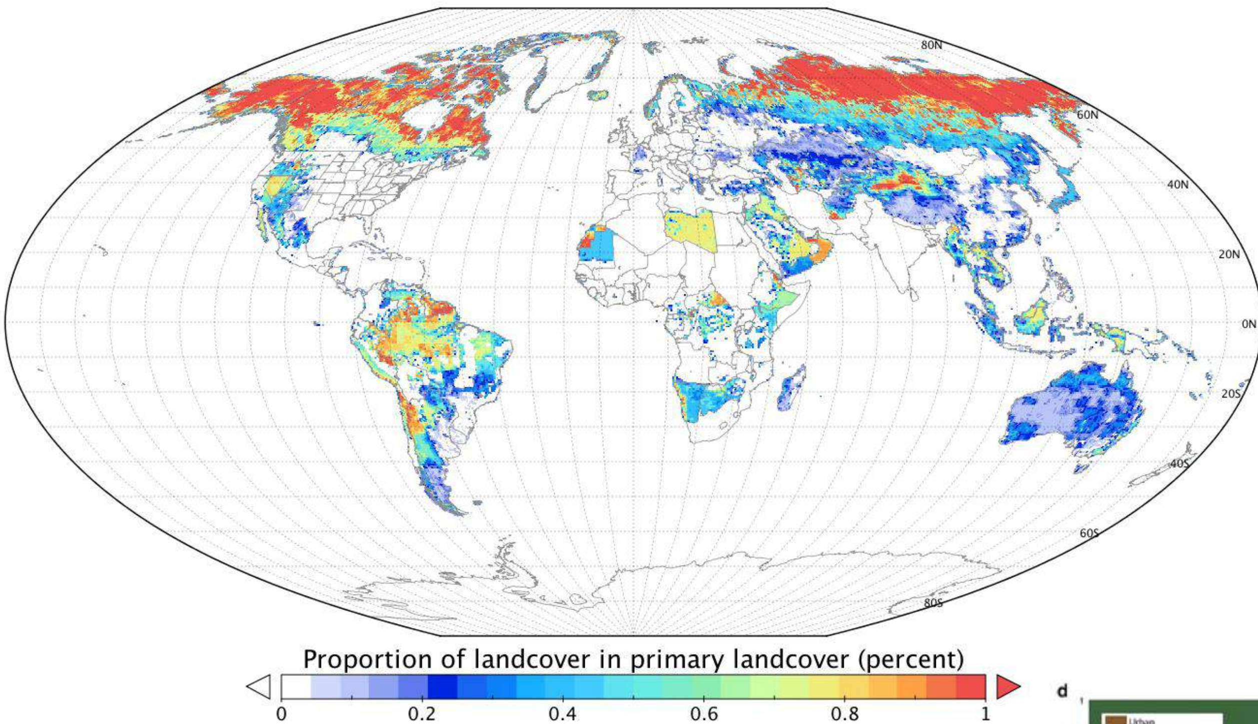
August 2015: 398.93 ppm

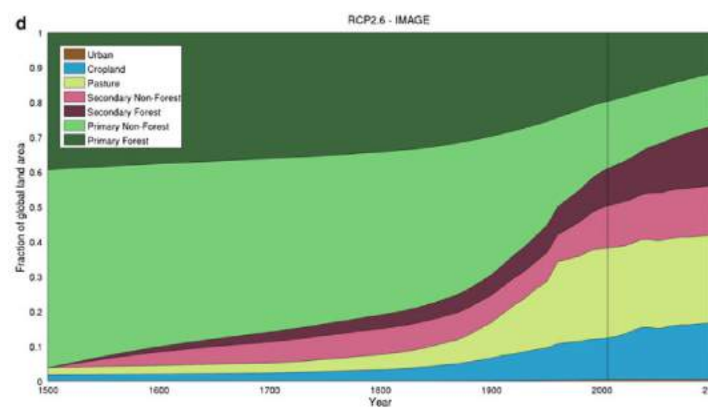
Last updated: September 6, 2016

Land use and land cover change

Only 30% of the land surface is still in primary state!
It was 70% in 1900..

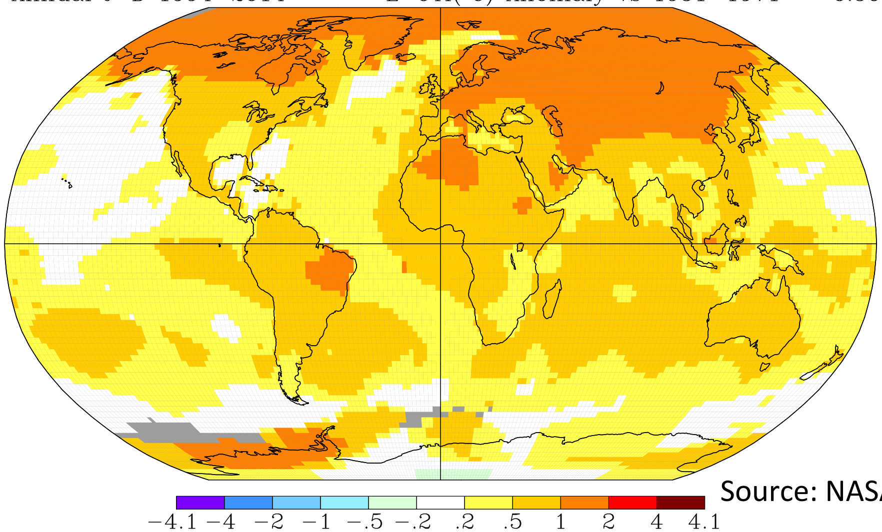
Year 2100



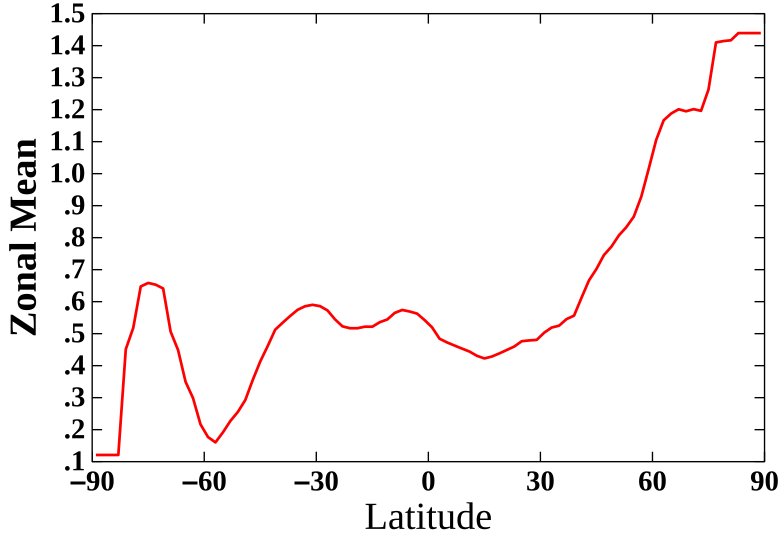


G. C. Hurtt et al 2011. Clim. Change

The perturbed climate system



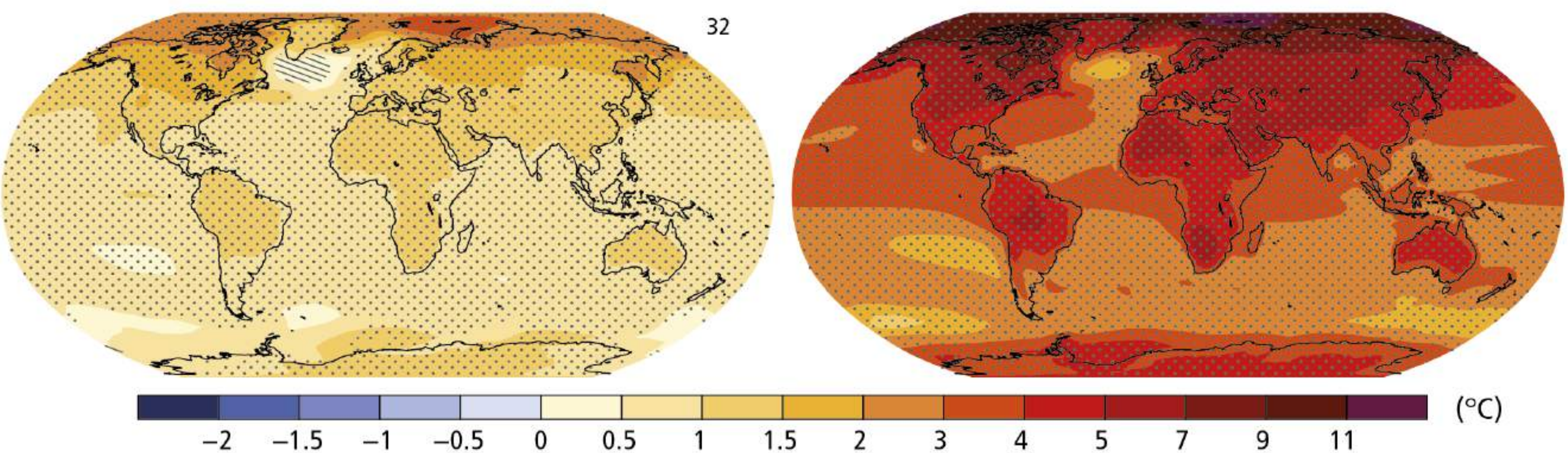
Source: NASA/GISS



RCP2.6

RCP8.5

Change in average surface temperature (1986–2005 to 2081–2100)

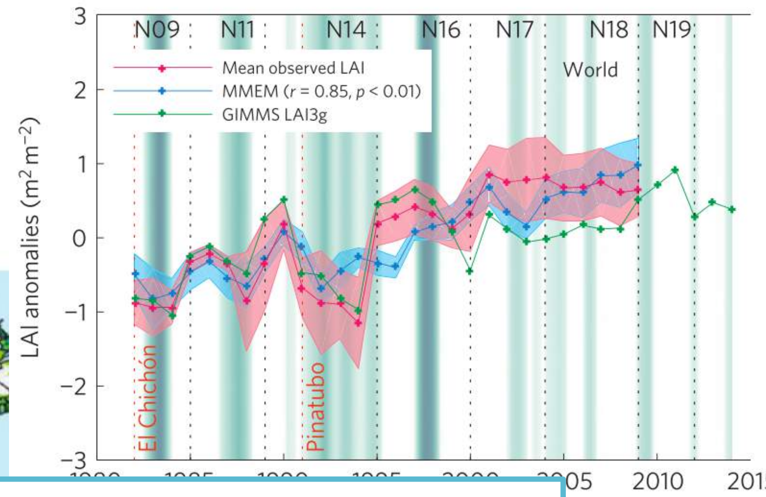


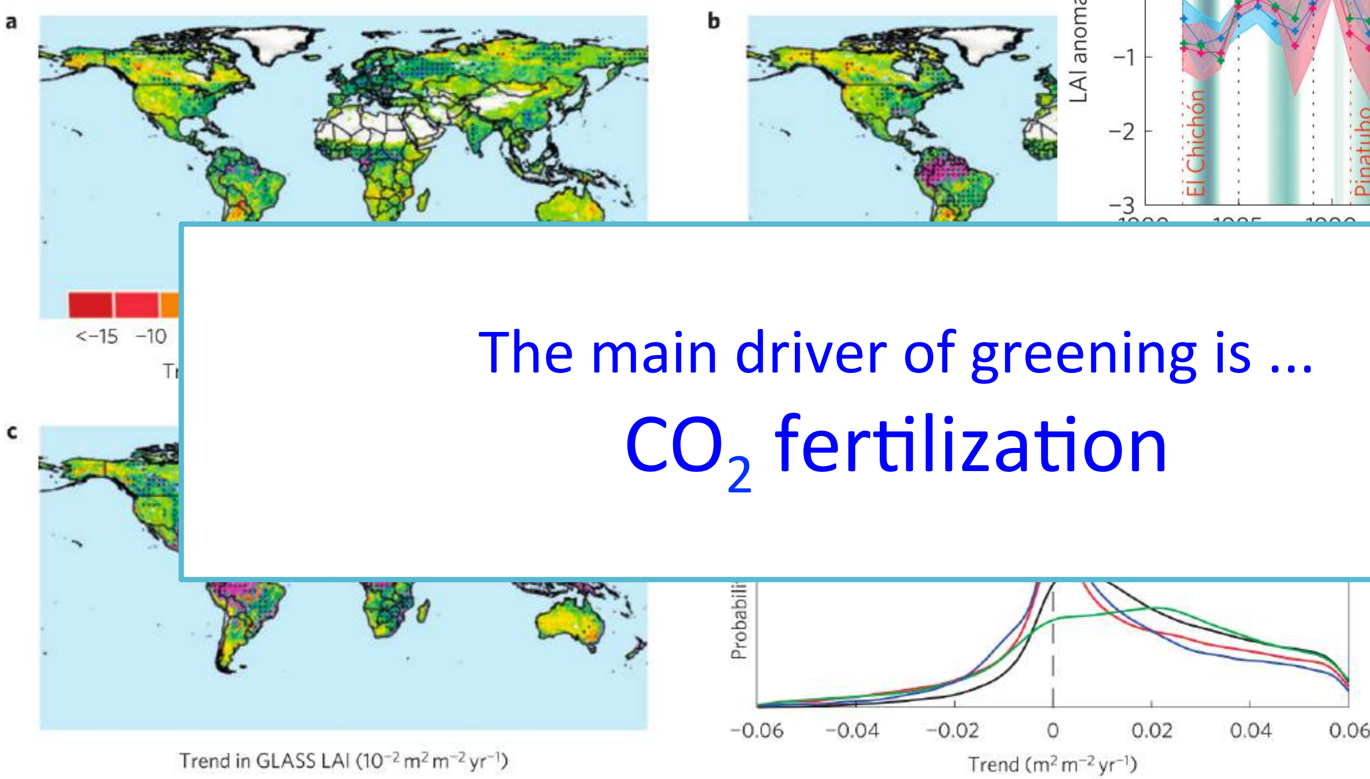
Source: IPCC, AR5

Emerging signals from the biosphere

The Planet is “greening”

Global persistent positive trend in leaf area index





The main driver of greening is ...

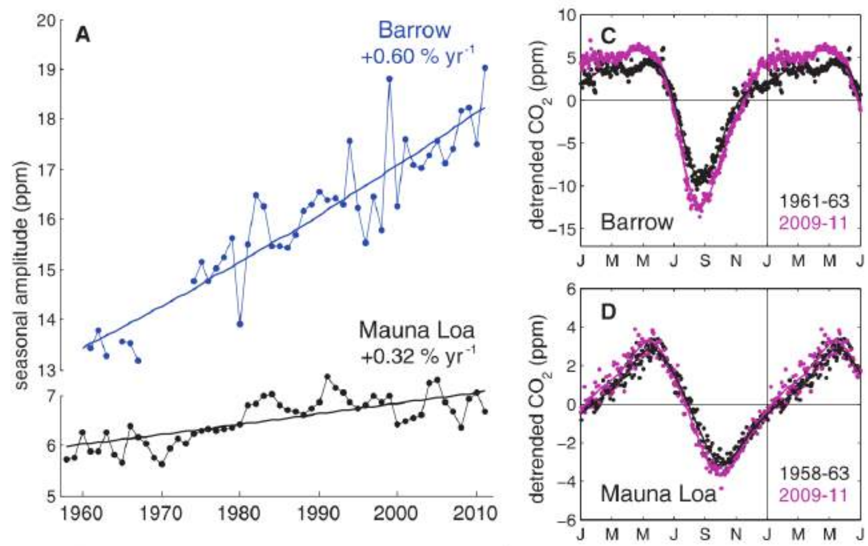
CO_2 fertilization

Zhu, Z. et al., 2016. Greening of the Earth and its drivers. Nat. Clim. Chang. 6, 791–795.

Land biogeochemistry: C fluxes and pools in different latitudes

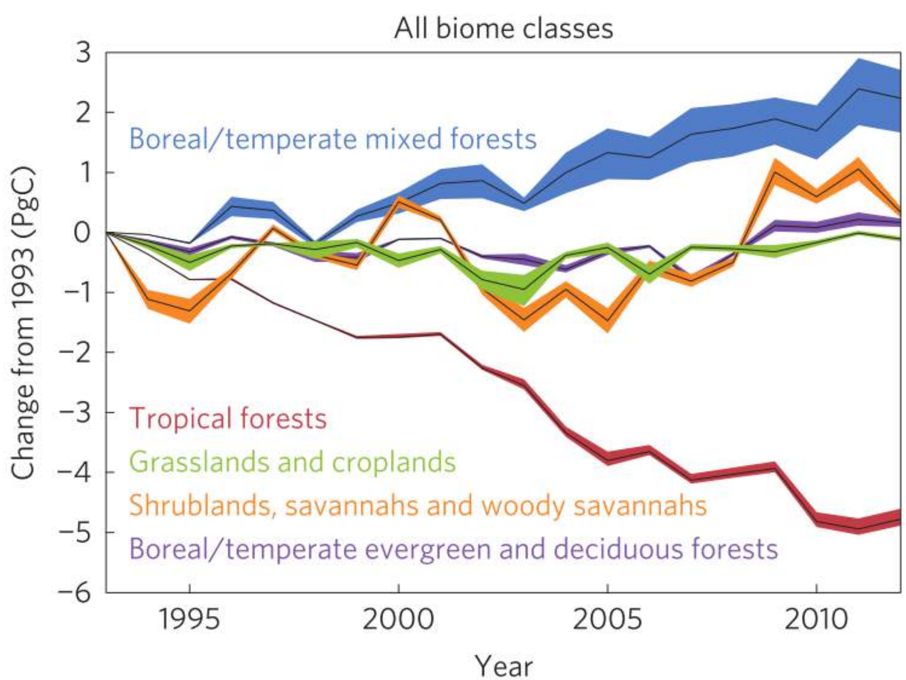
Enhanced seasonal exchange of CO_2 by northern ecosystems since 1960

Graven et al. Science 341 (2013).

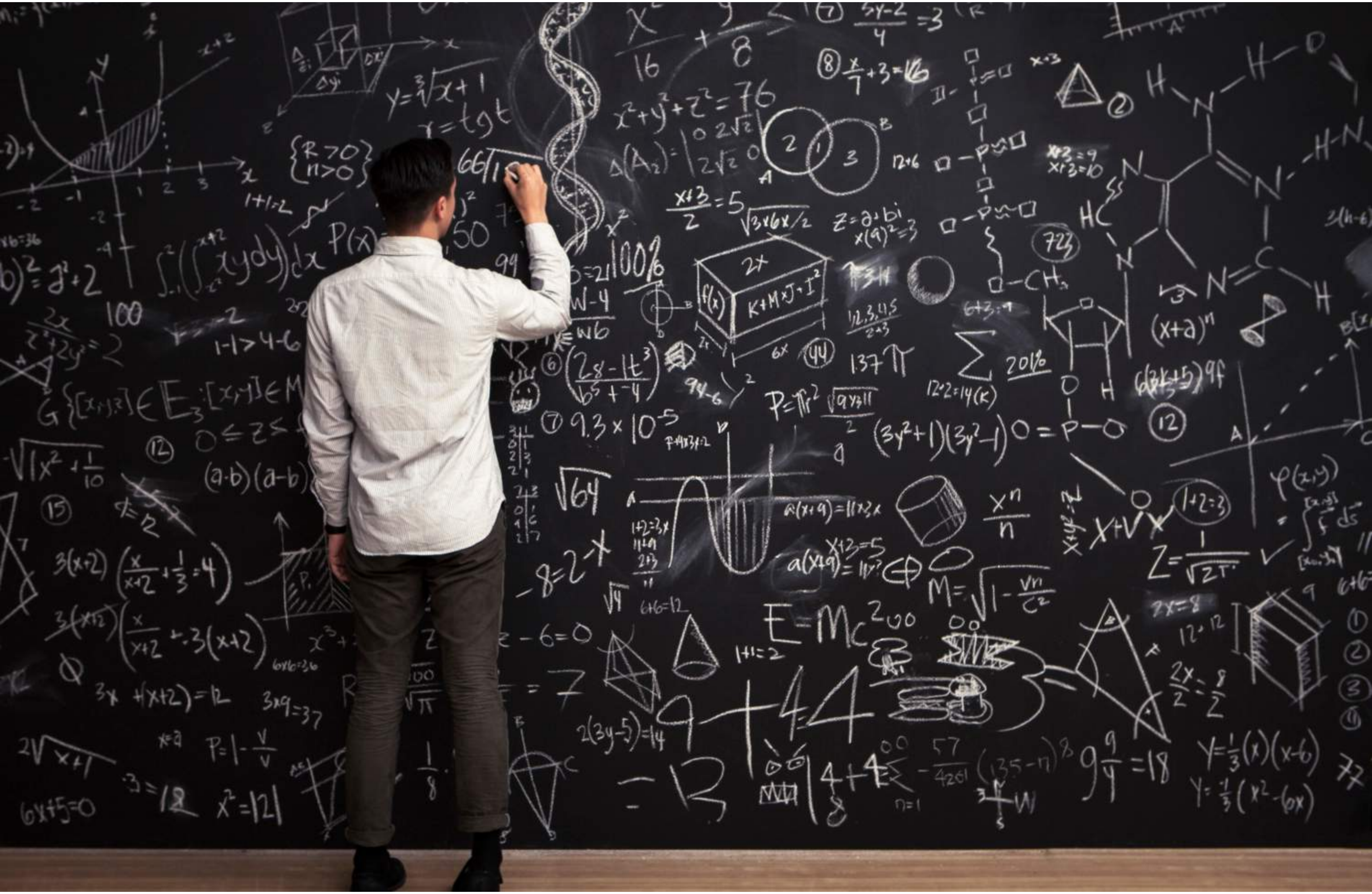


Recent trends in global biomass

Liu et al. Nat. Clim. Chang. 5, (2015)



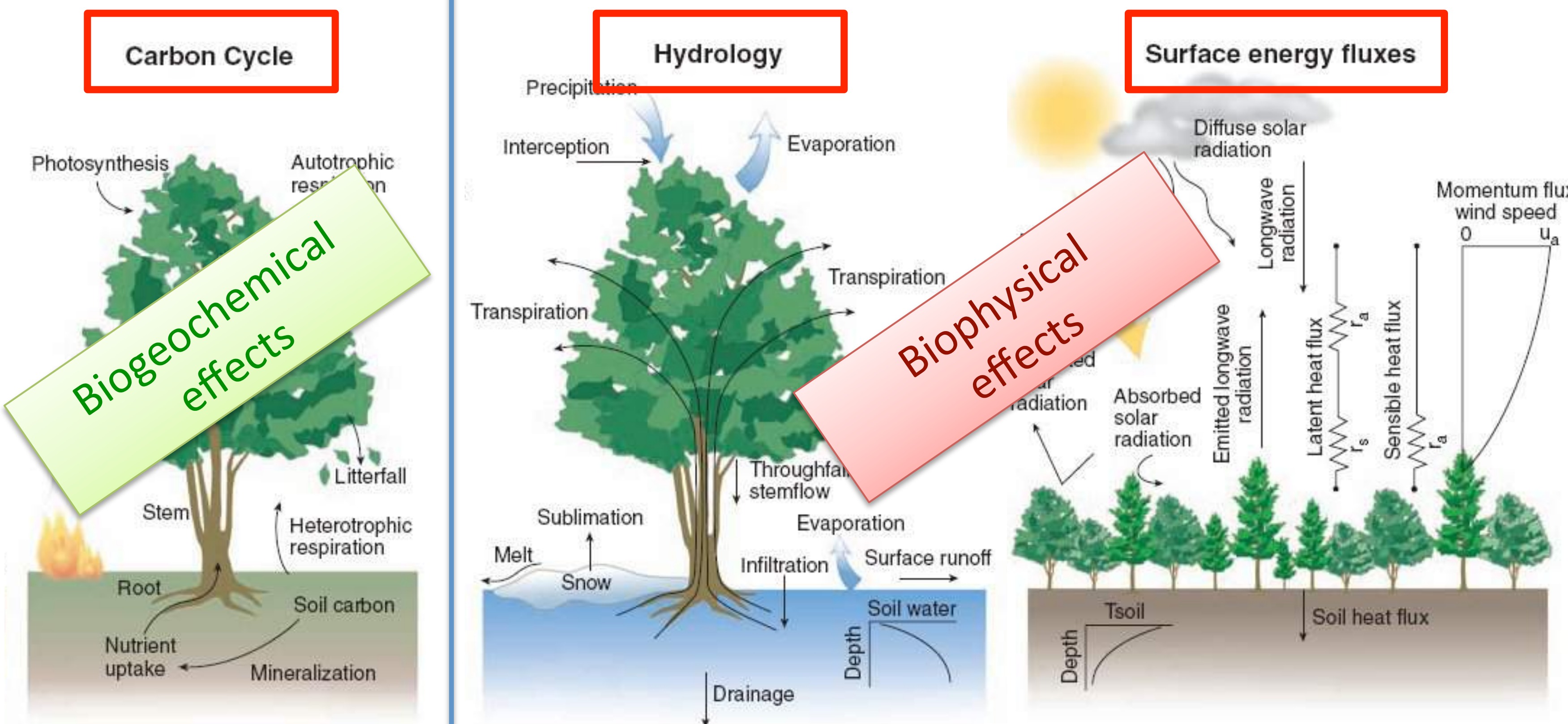
Interpreting the signals



A comprehensive view of the forests' role in the climate system

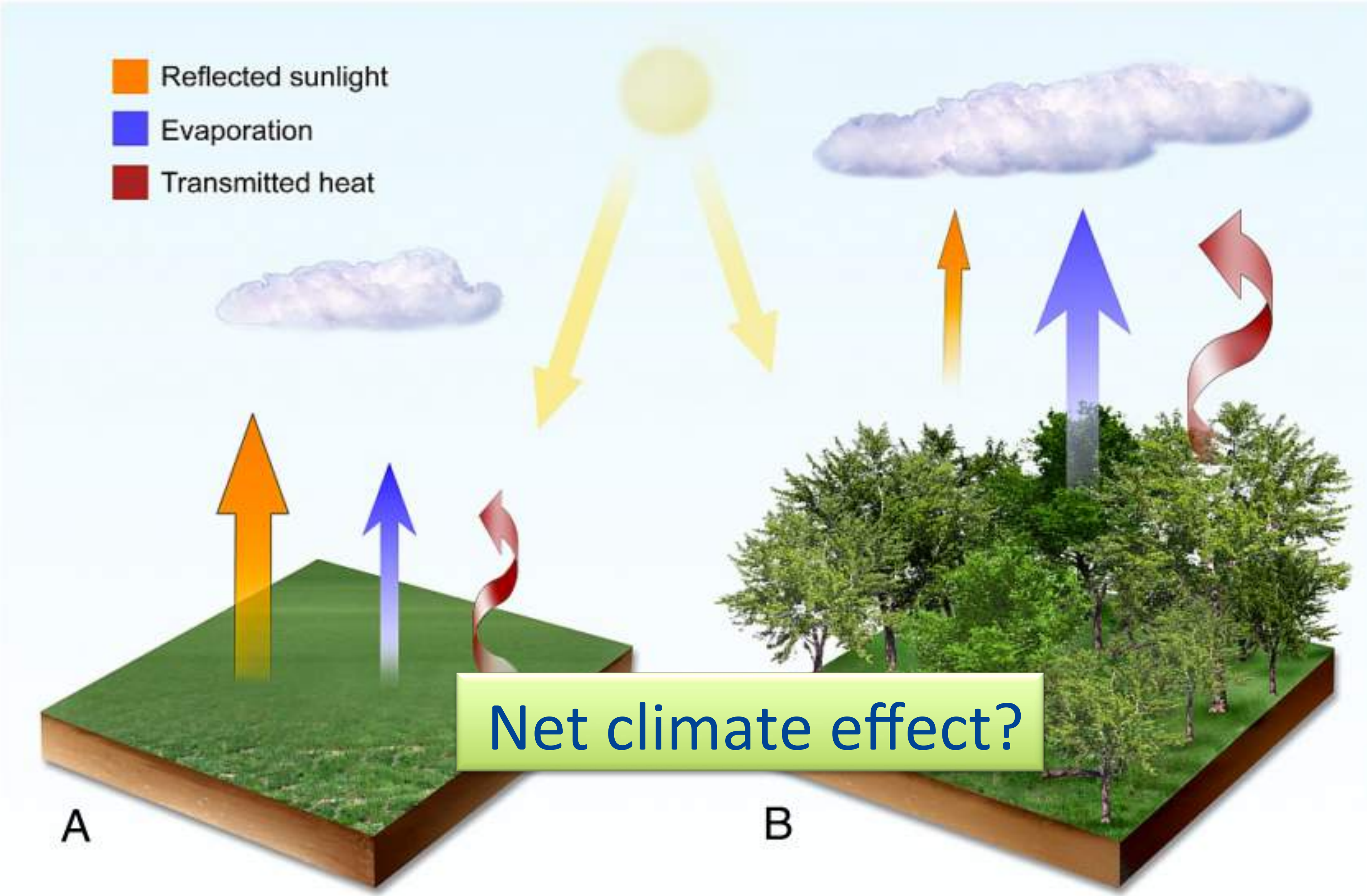
Considered in climate treaties

Not accounted in land based mitigation policies



Bonan G.B. Science 2008, 320:1444-1449

What is the role of forest in the climate system?



We are living in a data-rich era!

- Vegetation structural and physiological properties (biomass, tree height, SIF, GPP)
- Surface biophysics (e.g. albedo, LST, ET, H)
- Atmospheric GHG concentrations

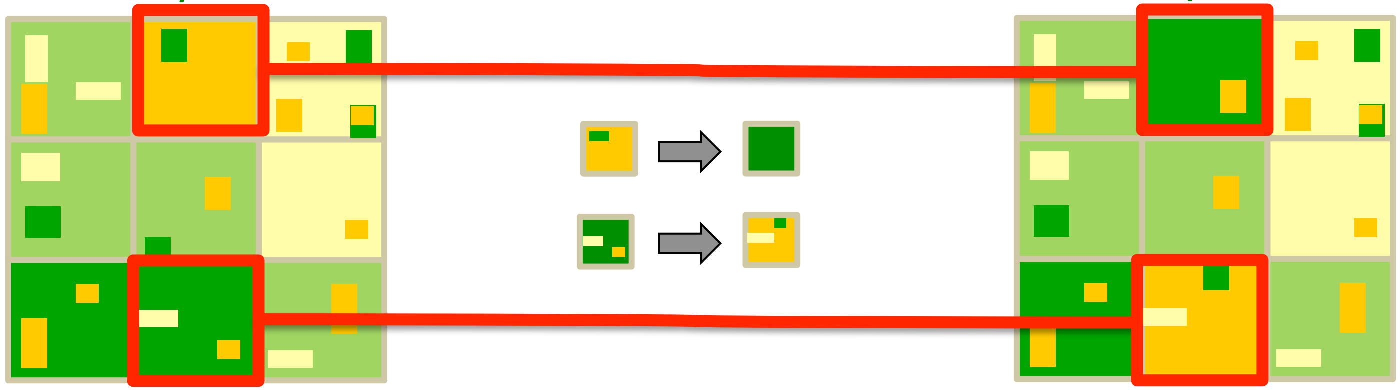
The analysis presented are all based on satellite observations..

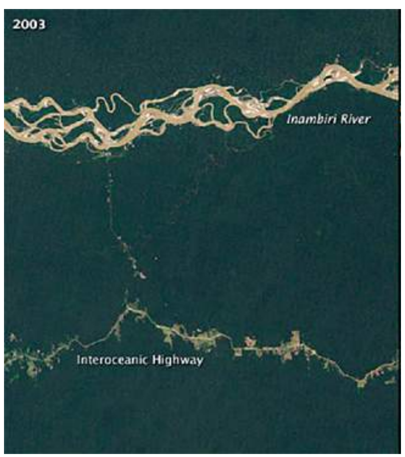
Detecting the signal of forest cover from satellite observations

Detecting the signal of temporal changes in forest cover

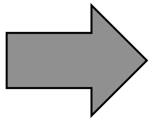
Reality at time 1

Reality at time 2

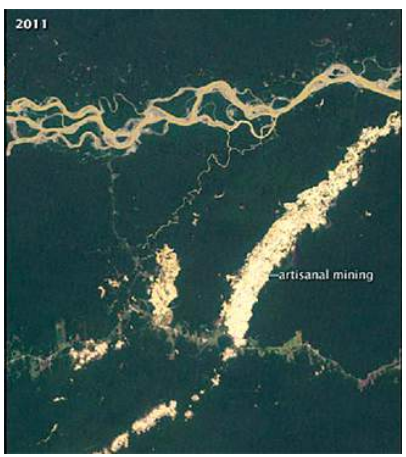




ΔT

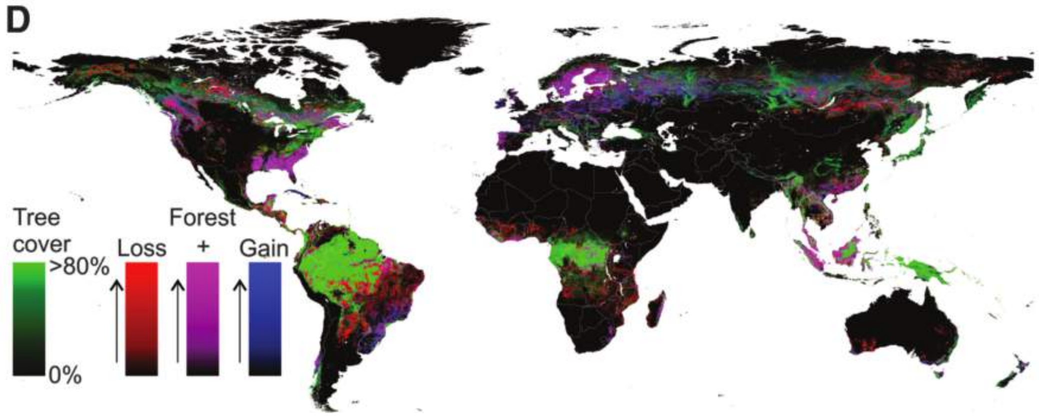


climate+land use



Forest cover change

Annual observations based on LANDSAT
30m resolution (2000-2012)



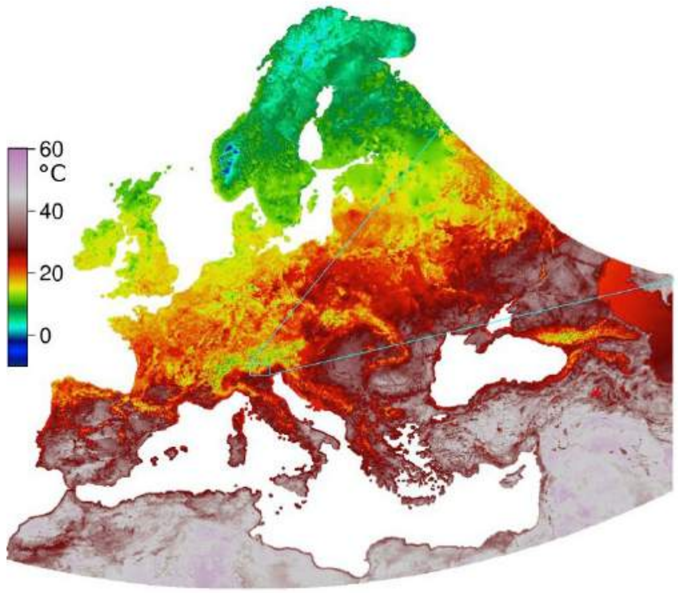
M. C. Hansen et al. Science. 342, 850–3 (2013).

Surface temperature

MODIS AQUA

Daytime and night-time

1Km resolution (2002-present)

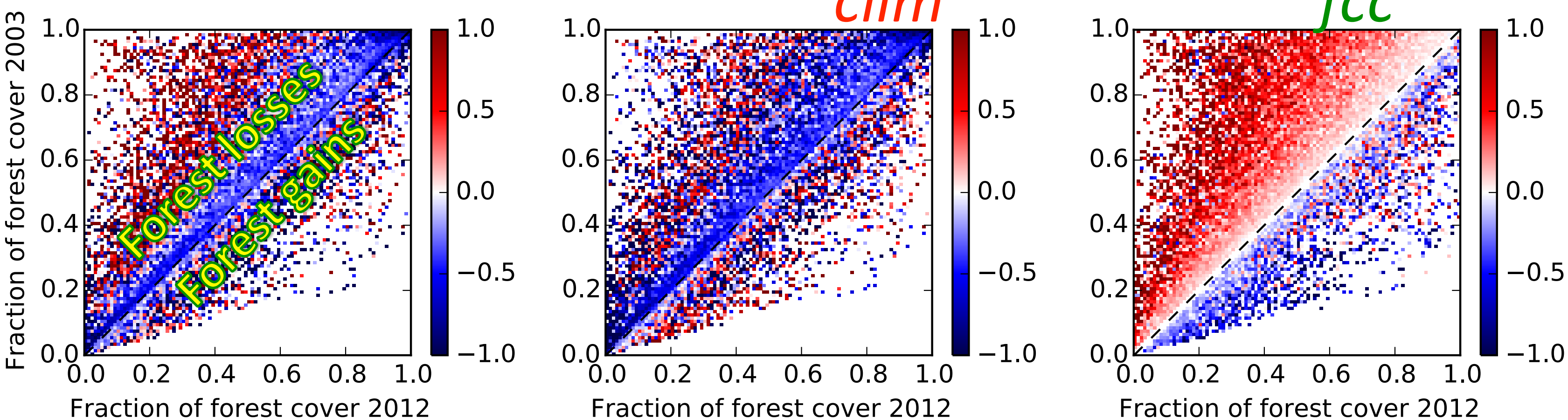


Detecting the climate signal from observations

temperature variation | climate variability | change in forest cover

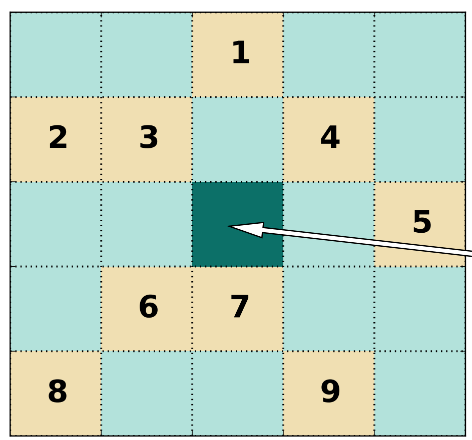
$$\Delta T = \Delta T_{clim} + \Delta T_{fcc} \quad \rightarrow \quad \Delta T - \Delta T_{clim} = \Delta T_{fcc}$$

$$\Delta T \quad - \quad \Delta T_{clim} \quad = \quad \Delta T_{fcc}$$



The signal due to climate variability

ΔT_{clim}



Δfcc<2%, $\Delta T_{res} = \Delta T$

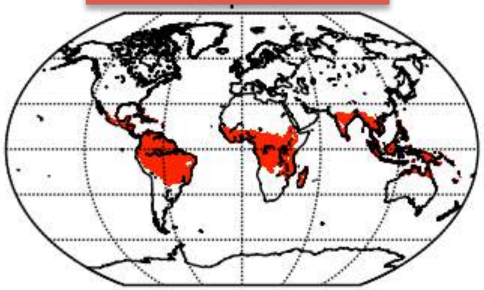
Δfcc>2%

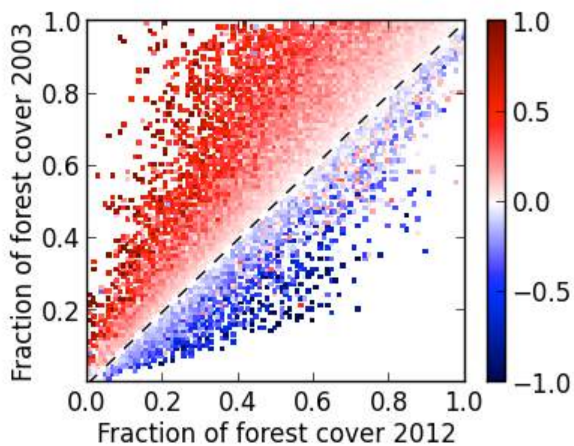
$$\Delta T_{res} = \frac{\sum_{i=1}^{9} \frac{\Delta T_i}{d_i}}{\sum_{i=1}^{9} \frac{1}{d_i}}$$

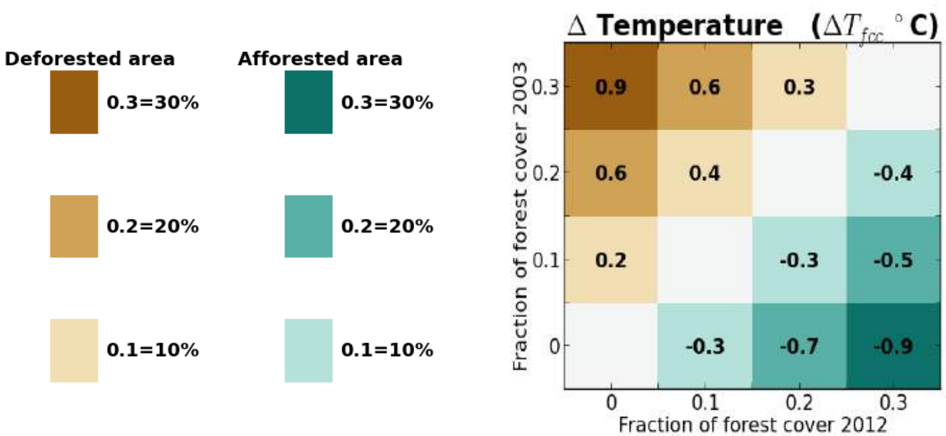
Detecting the climate signal of changes in forest cover

Assessment of the variation in average, maximum and minimum air temperatures

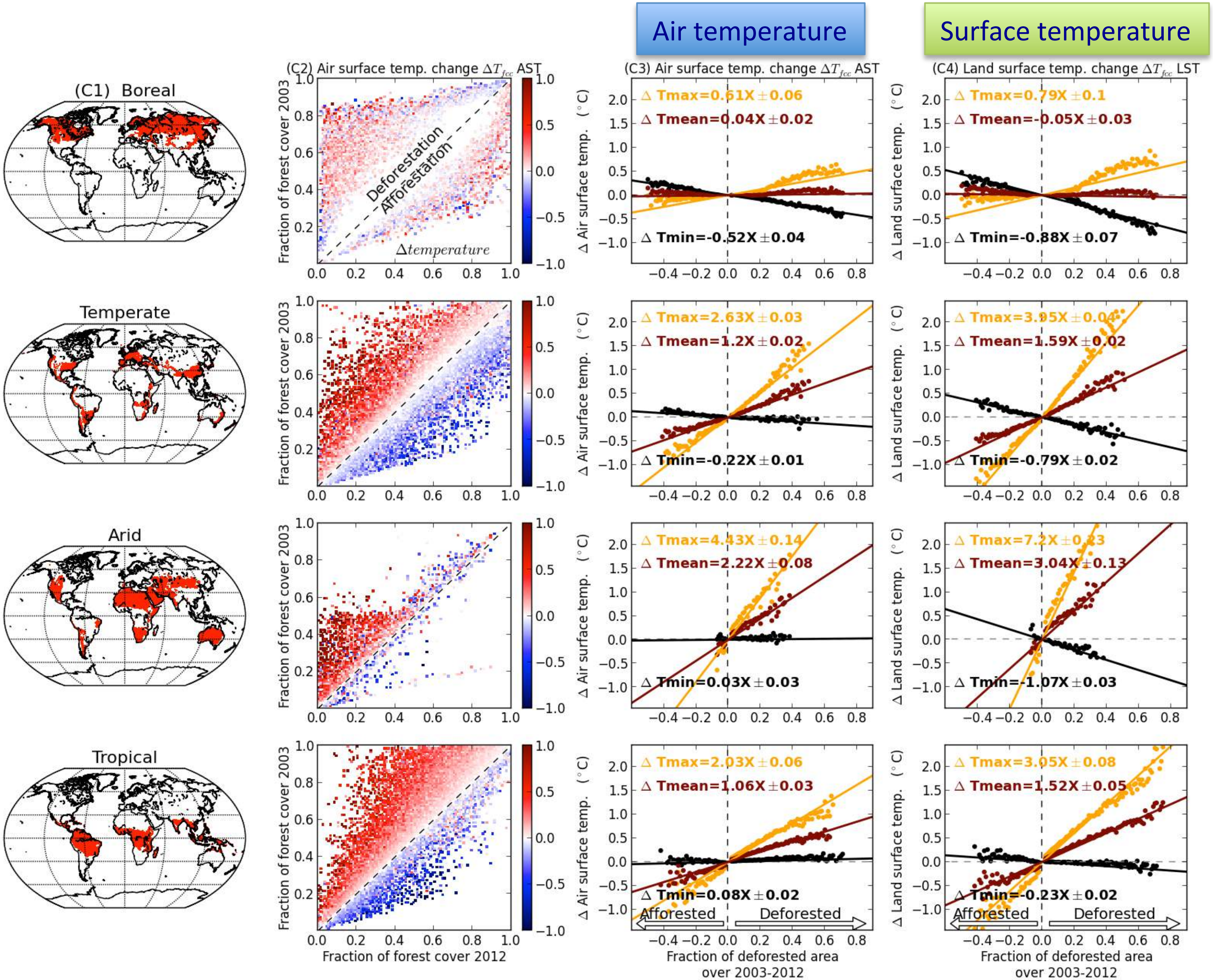
Tropical zone



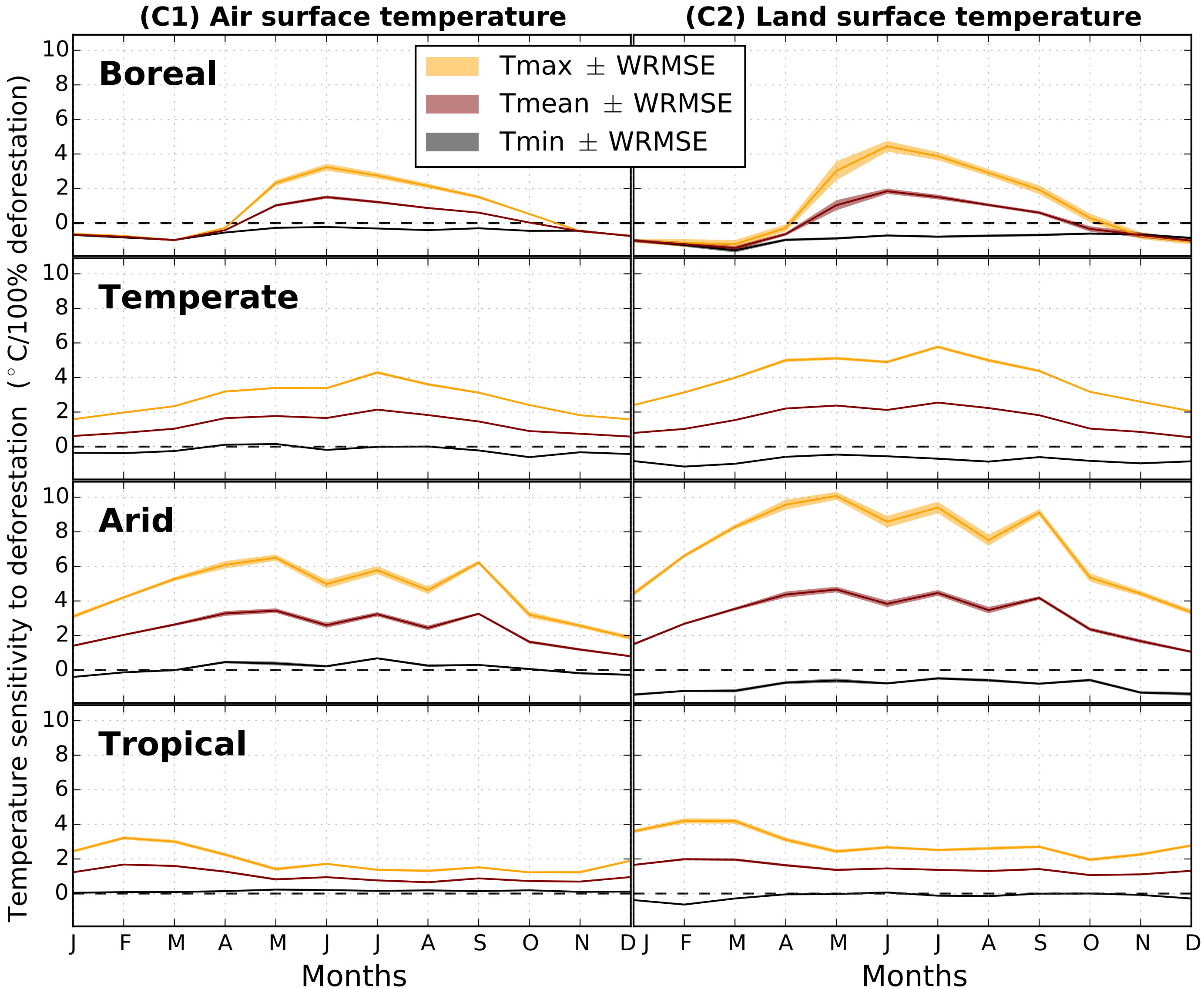




Biophysical climate signals in the different climate zones

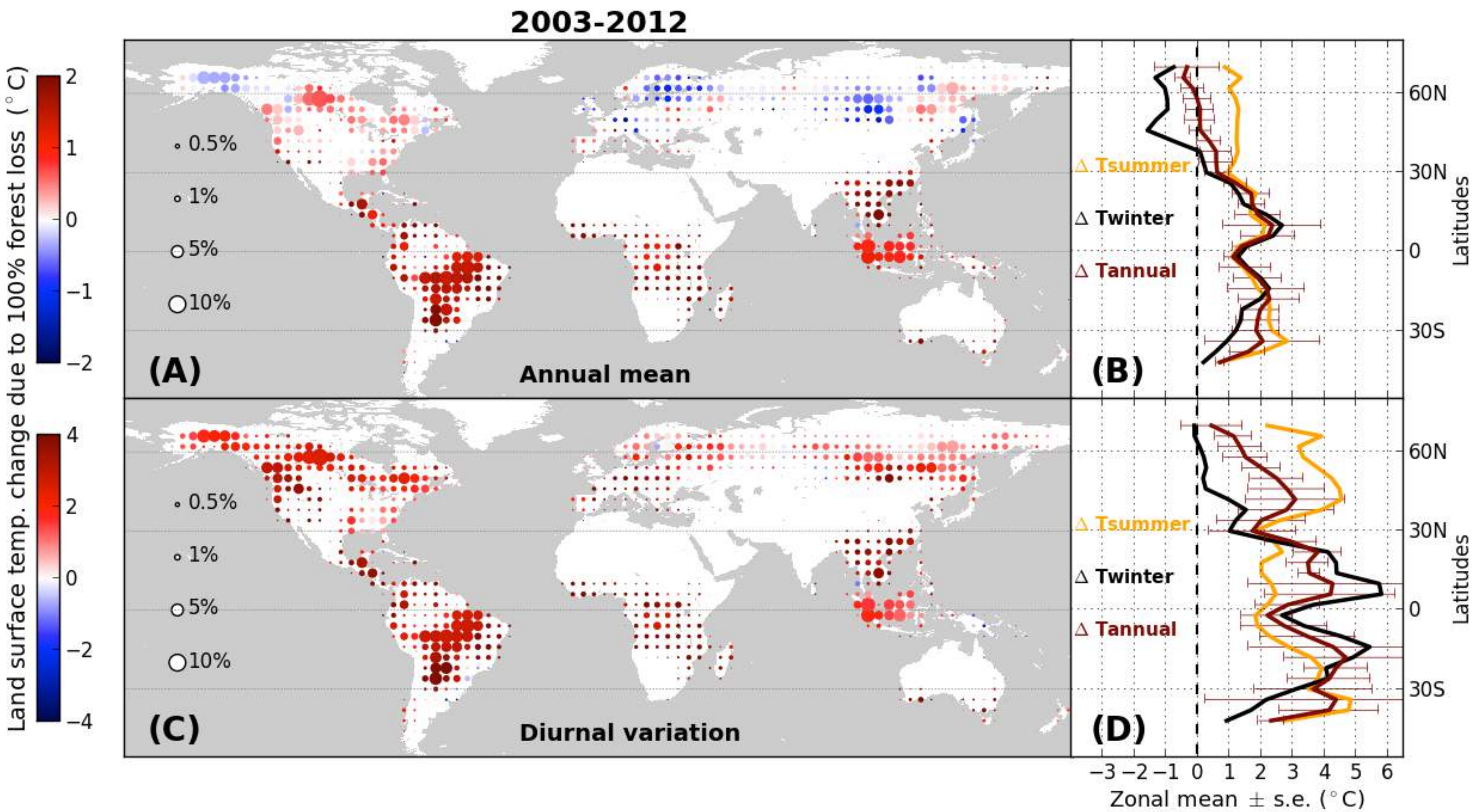


The seasonality of the biophysical climate signal of forest cover



Regional estimates of the biophysical climate signal of deforestation

Changes in air temperature due to forest losses in the decade 2003-2012



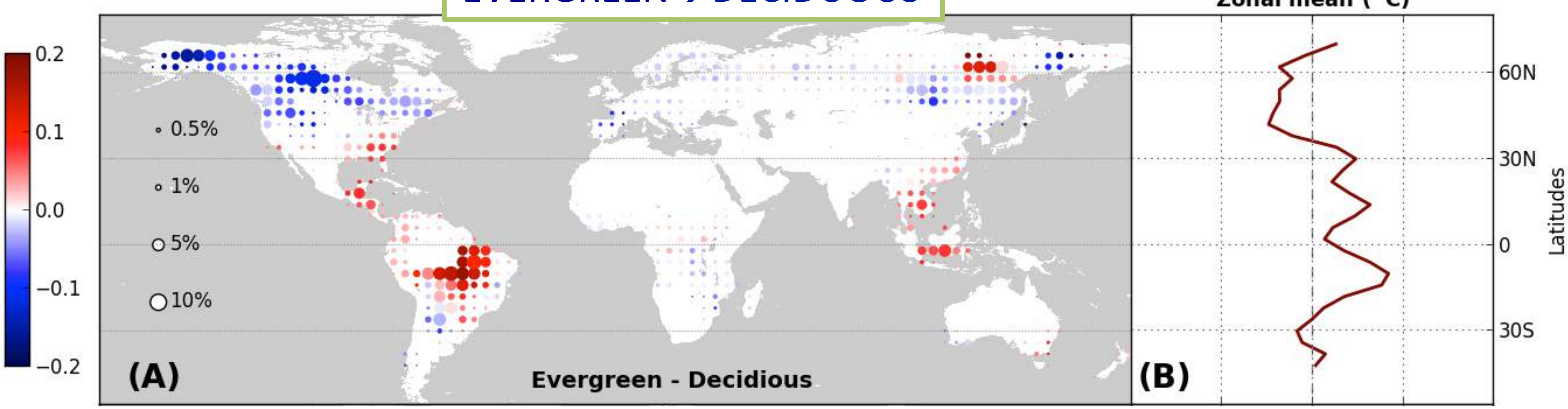
Biophysical climate signal of changes in species composition

Europe's forest management did not mitigate climate warming

Kim Naudts,[1*†] Yiying Chen,[1‡] Matthew J. McGrath,[1] James Ryder,[1] Aude Valade,[2] Juliane Otto,[1§] Sebastiaan Luyssaert[1||]

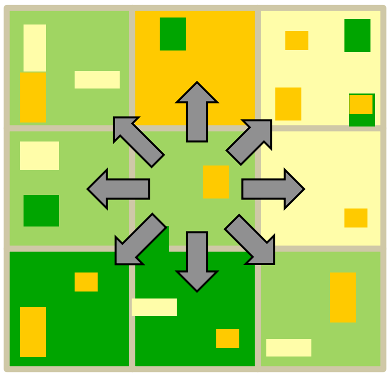
Afforestation and forest management are considered to be key instruments in mitigating climate change. Here we show that since 1750, in spite of considerable afforestation, wood extraction has led to Europe's forests accumulating a carbon debt of 3.1 petagrams of carbon. We found that afforestation is responsible for an increase of 0.12 watts per square meter in the radiative imbalance at the top of the atmosphere, whereas an increase of 0.12 kelvin in summertime atmospheric boundary layer temperature was mainly caused by species conversion. Thus, two and a half centuries of forest management in Europe have not cooled the climate. The political imperative to mitigate climate change through afforestation and forest management therefore risks failure, unless it is recognized that not all forestry contributes to climate change mitigation.

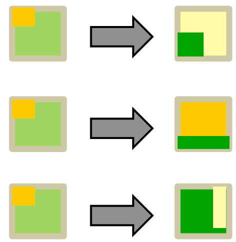
EVERGREEN→DECIDUOUS



Detecting the land signal from observations

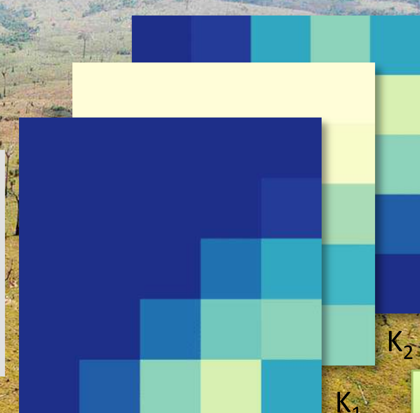
Space for time analogy





- \+ No need of land use change to detect signals
- \+ Factor out climate variability
- \- Spatial gradients are attributed to land cover
- \- Complex un-mixing of signal in fragmented landscapes

$$Z_1 = b_1K_{1,1} + b_2K_{2,1} + b_3K_{3,1}$$
$$Z_2 = b_1K_{1,2} + b_2K_{2,2} + b_3K_{3,2}$$
$$\dots$$
$$Z_{25} = b_1K_{1,25} + b_2K_{2,25} + b_3K_{3,25}$$

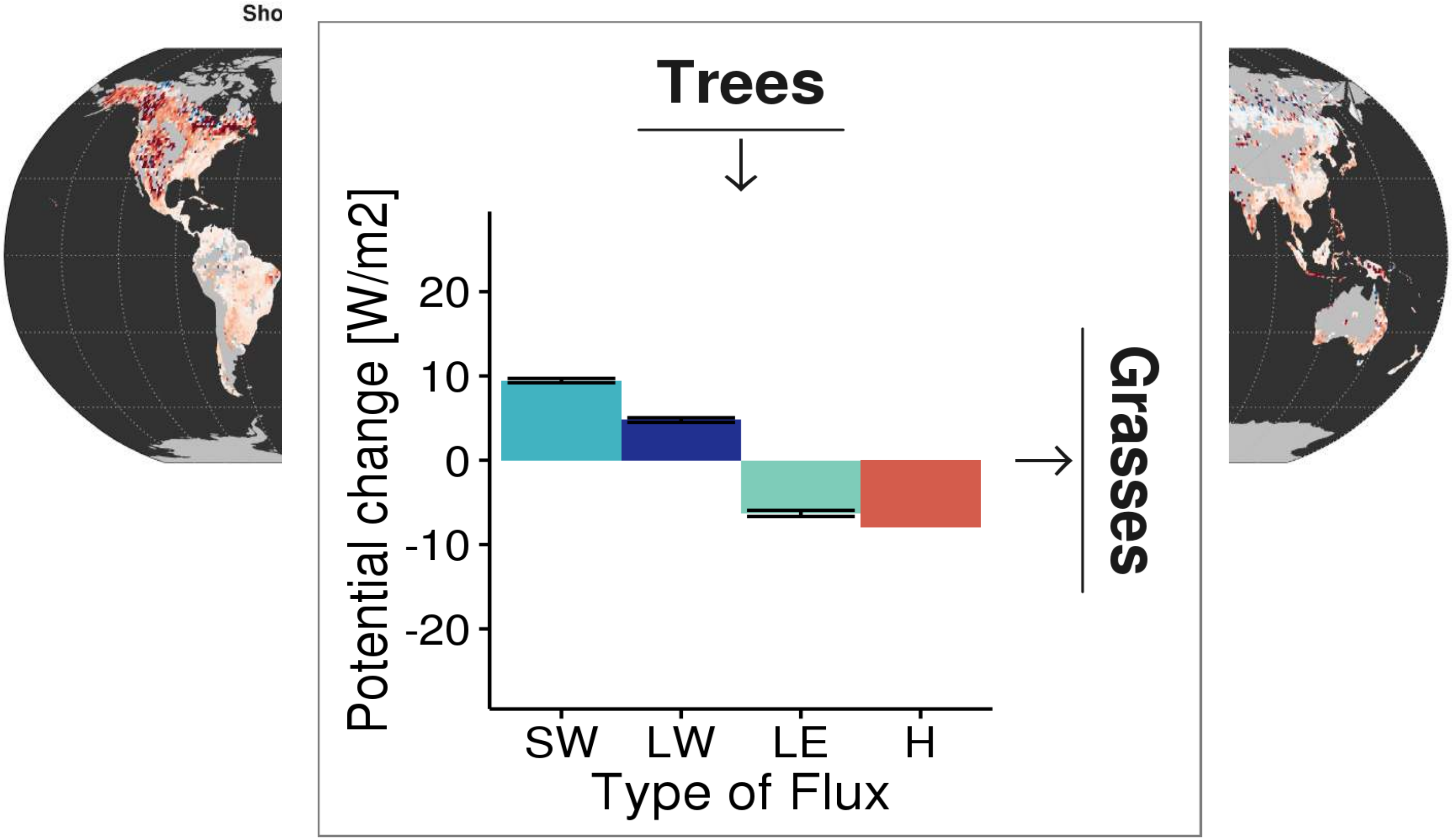


25 pixels => 25 values for Z which can be LST, LE, albedo
[spatial resolution: 0.05 dd]

Various fractions of PFTs (here 3) which add up to 1
[spatial resolution: 0.05 dd]

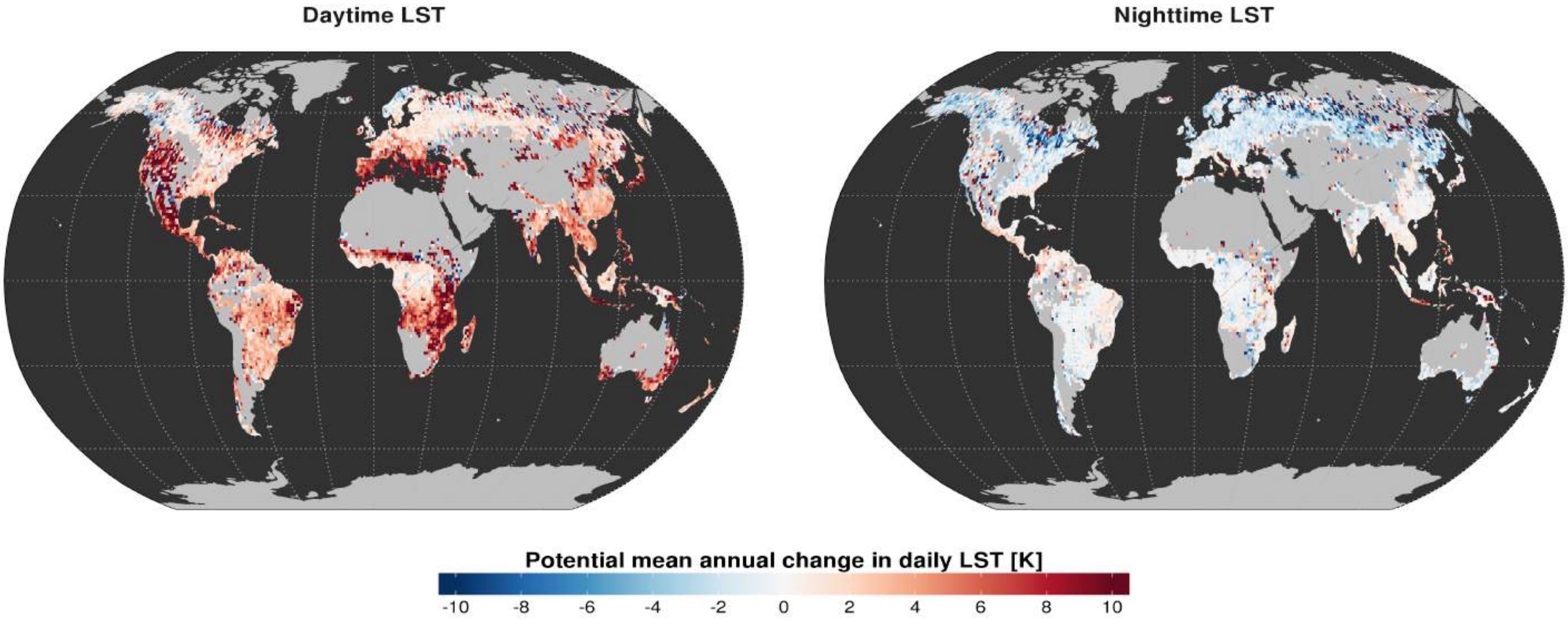
Impact of deforestation on the surface energy balance

$$SW_{net} + LW_{net} = LE + H$$



Conversion Forests->Grasslands/Croplands

Effect on daytime and nighttime surface temprature



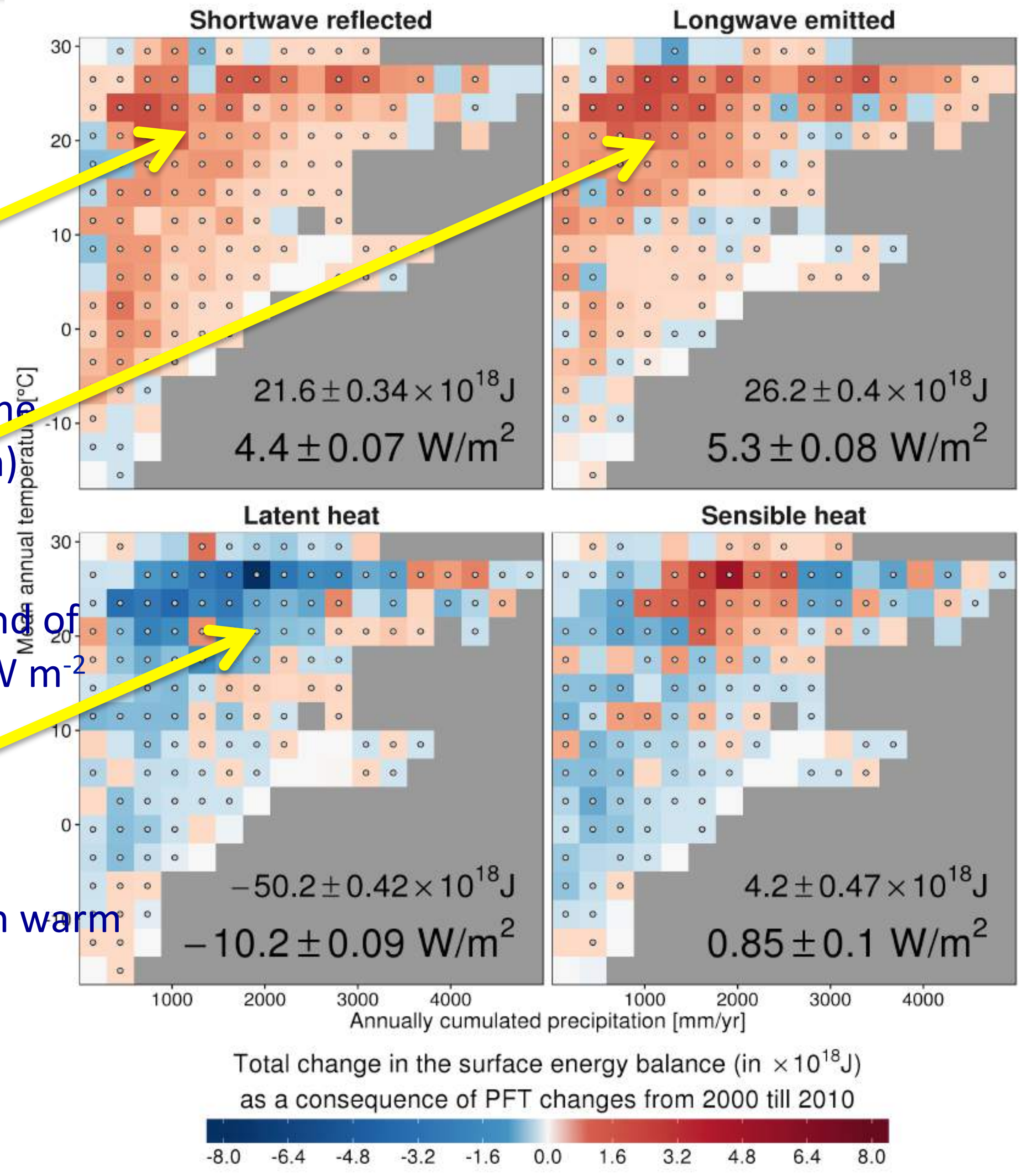
The footprint of vegetation changes on the surface energy budget

Satellite observations of the changes in the global surface energy balance due to land cover change during 2000-2010

- Increased albedo (and therefore the reflectance of shortwave radiation)

- Increased surface temperature (and of longwave emission) of about 5.3 W m^{-2}

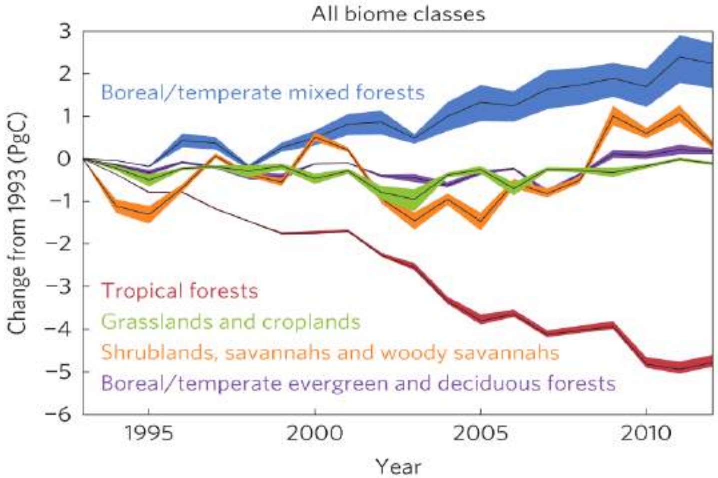
- The reduction of net radiation is compensated by a reduction of evapotranspiration, in particular in warm climates (tropical, arid)



The biophysical climate value of forest carbon

Global dataset of forest biomass

- from satellite passive microwave observations
- spatial resolution 0.25°, period 1993-2013

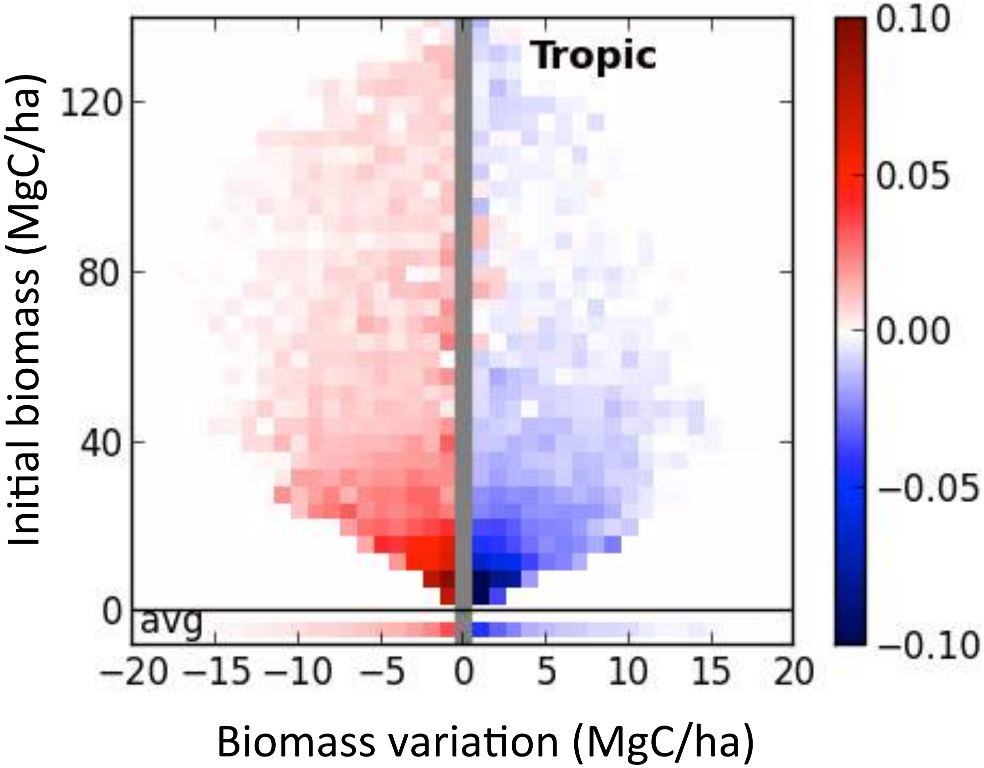


Temperature changes due to biomass variations

temperature variation | climate variability | change in forest biomass

$$\Delta T = \Delta T_{clim} + \Delta T_{biomass}$$

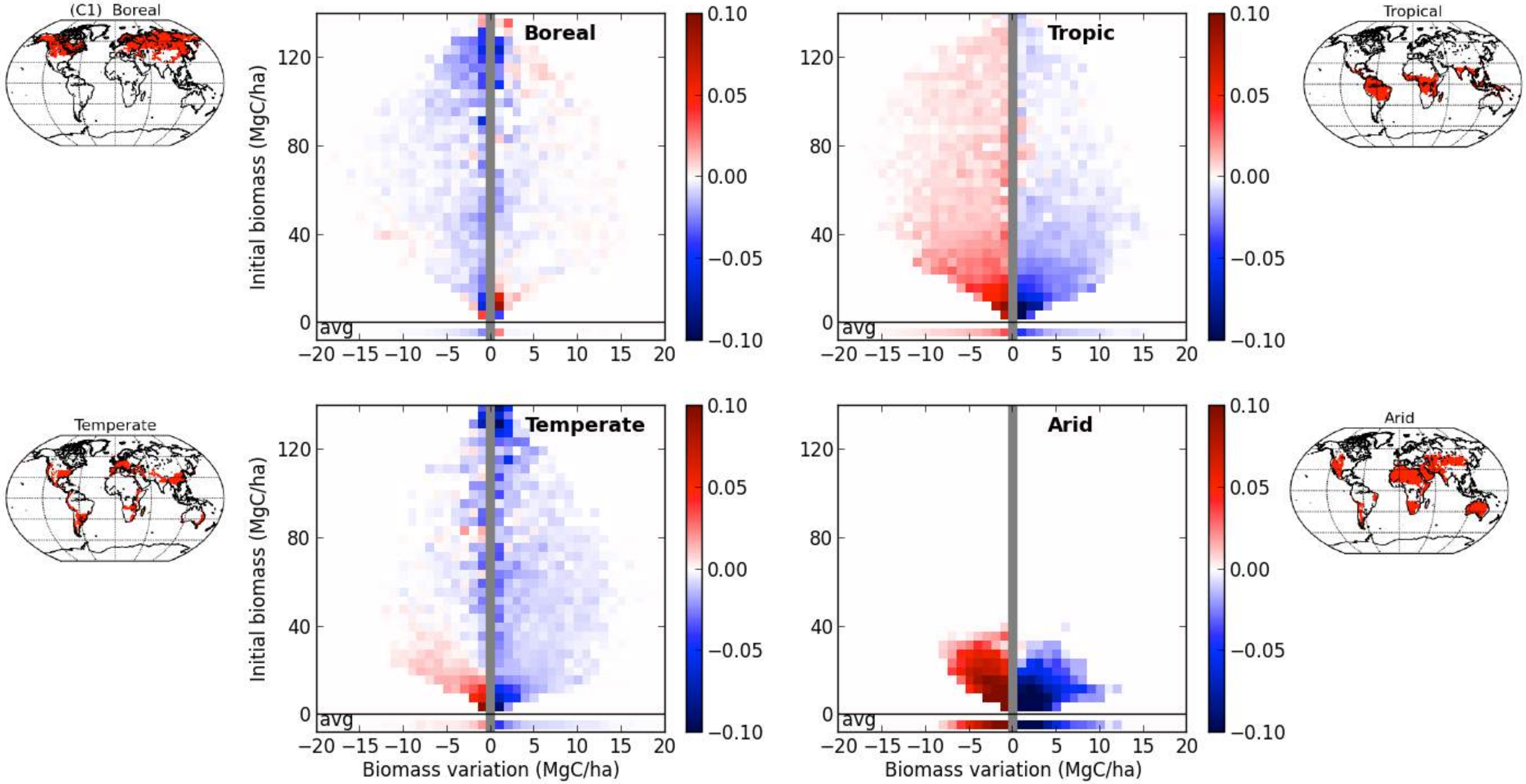
$$\Delta T - \Delta T_{clim} = \Delta T_{biomass}$$



The biophysical climate value of forest carbon

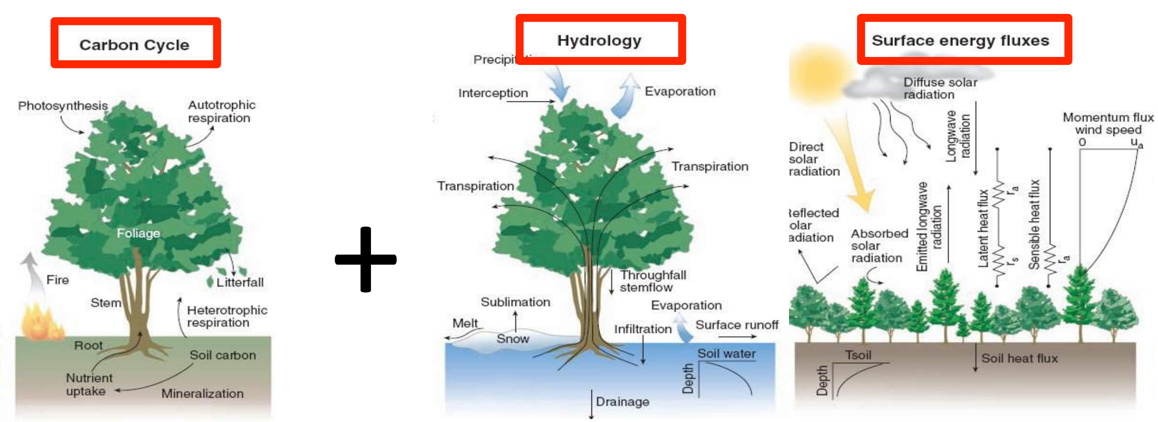
Low sensitivity in temperate and boreal zones

Strong sensitivity in arid/tropical zones



How to integrate the biogeochemical and biophysical climate value of forest carbon?

Biogeochemical effects + Biophysical effects = Net climate value of forest carbon

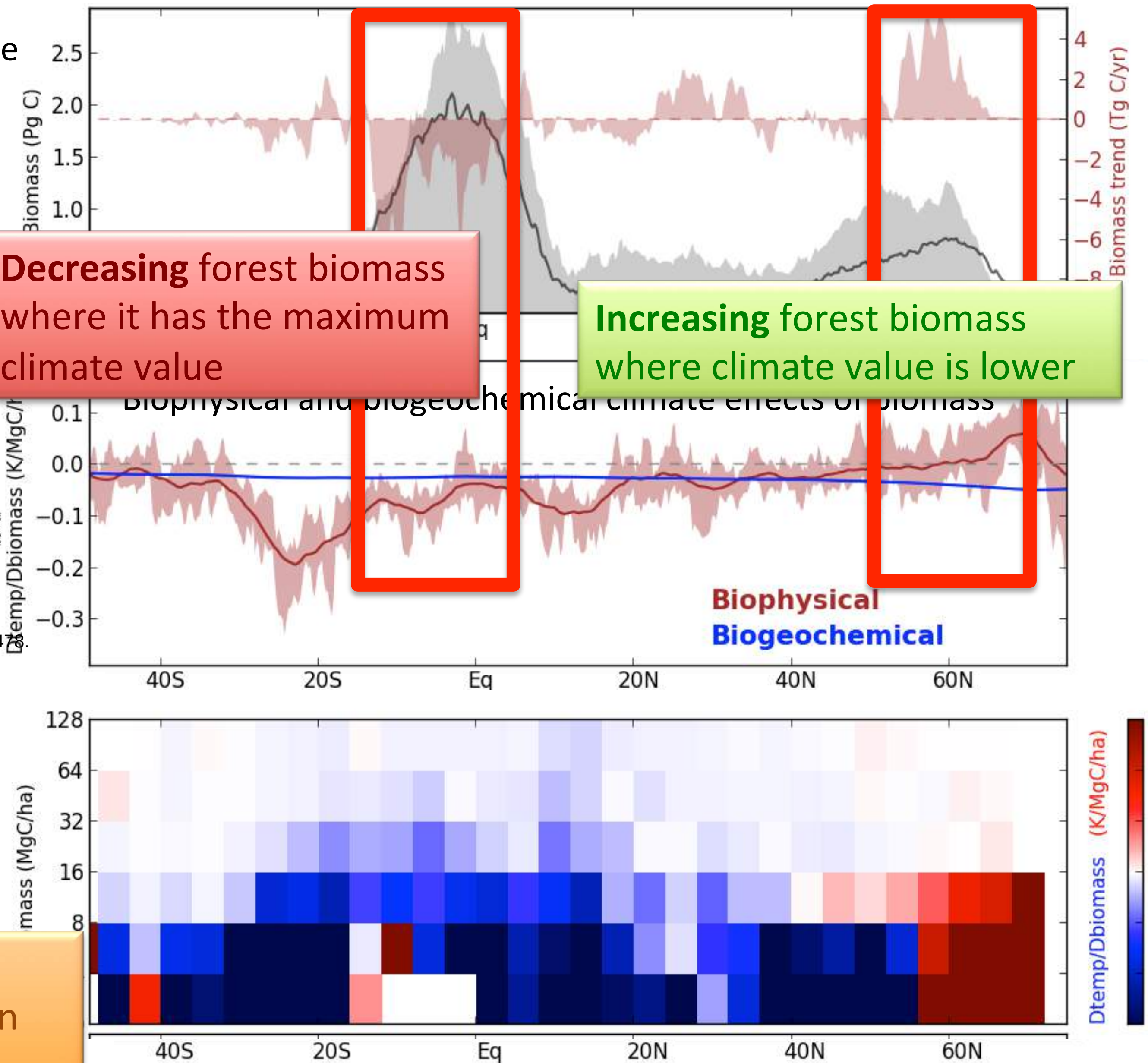


= ?

Bonan G.B. Science 2008, 320:1444-1449

What is the climate value of forest carbon?

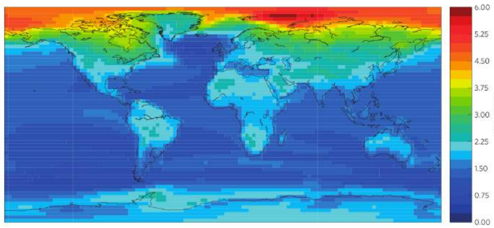
- Biomass from microwave
- Biomass FAO-FRA
- Biomass trends



Decreasing forest biomass where it has the maximum climate value

Increasing forest biomass where climate value is lower

Regional climate response to carbon emission/removals



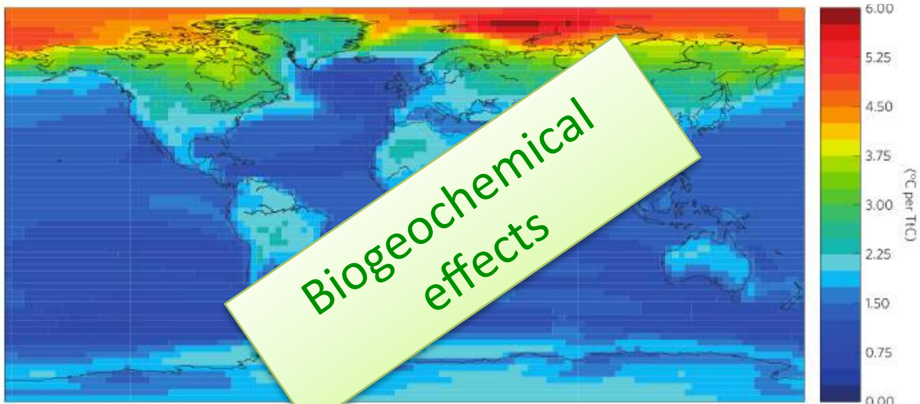
Leduc, M., et al. 2016. Nat. Clim. Chang. 6, 474–478.

Temperature sensitivity to biomass variation

For the climate a ton of carbon is more valuable in young/sparse forests

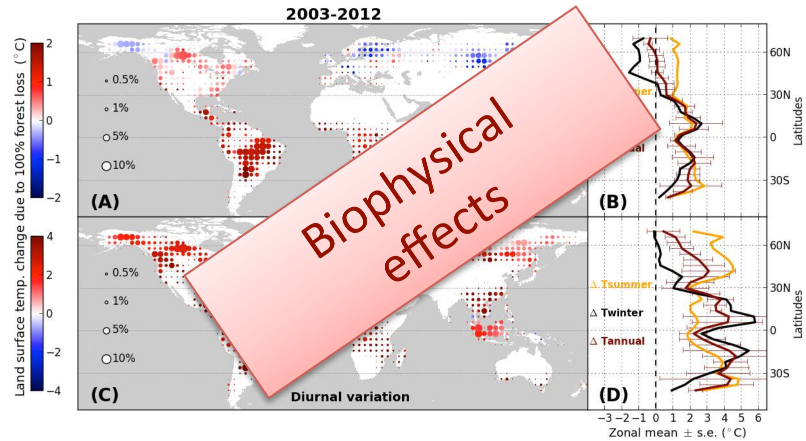
Local climate sensitivities to CO_2 emissions/removals

Regional climate response to carbon emission/removals



Leduc, M., et al. 2016. Nat. Clim. Chang. 6, 474–478.

Biophysical local climate response to variations in forest biomass



Implications for land-based climate policies and forestry

- Biogeochemical cooling is more important at northern latitudes
- Biophysical cooling on the contrary is more relevant in Tropical/Arid regions (additional incentives to reduce tropical deforestation, REDD+)

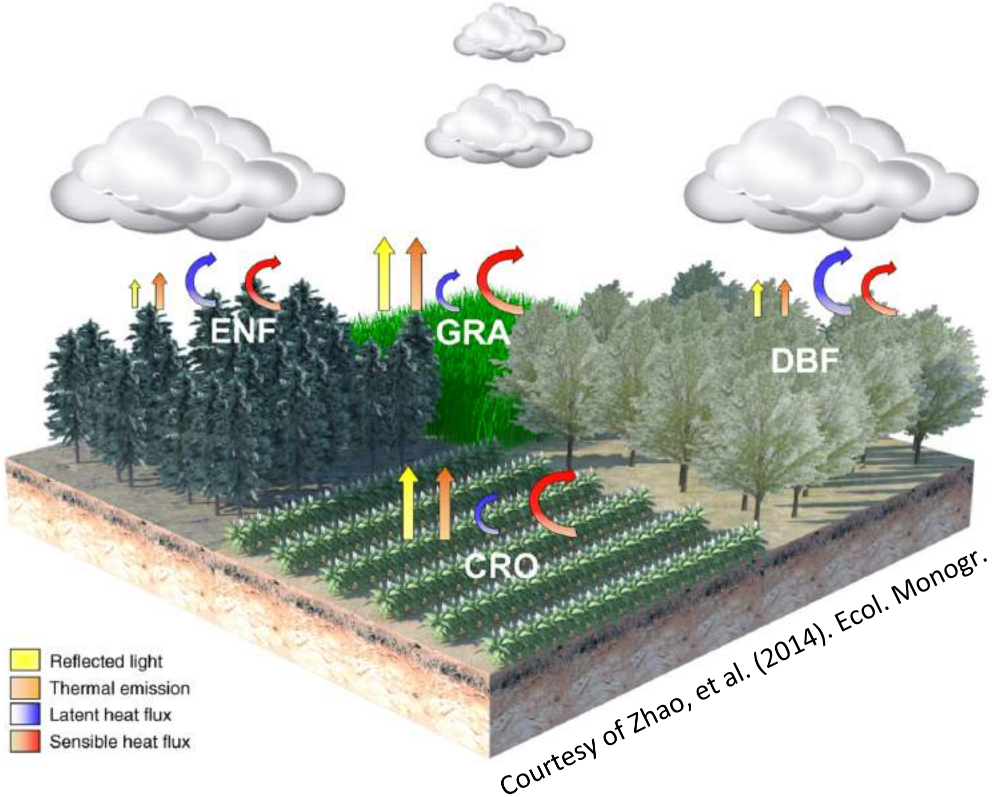
Not all the forest carbon has the same value for the climate!

Forests in the climate system

Alessandro Cescatti

Ramdane Alkama
Gregory Duveiller

Joint Research Centre
European Commission

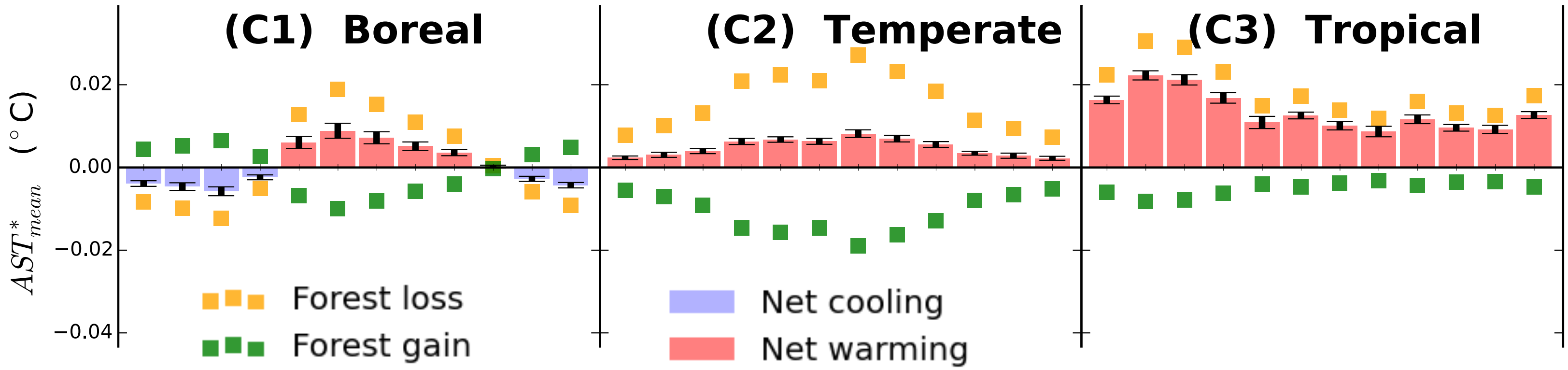


Environment, Sustainable Agriculture and Forest Management
Padova 26/04/2016

Concluding remarks

- Forests play a key role in the climate system thanks to biogeochemical and biophysical processes. To date only the first are accounted in climate treaties.
- Biophysical climate impacts of afforestation/deforestation change in sign and magnitude in the different World regions.
- The climate value of forest biomass is therefore not equal everywhere!
- Biophysical cooling from forest cover increase the climate value of forest carbon in Tropical/Arid region. This is reinforcing the local value of forest conservation.
- On the contrary northern countries benefit more for the biogeochemical cooling of the forest sink, due to the the larger climate sensitivity to CO_2
- The development of land-based mitigation policies based on forests have to go beyond the C budget and consider the net climate value of forest biomass.

The global biophysical climate signal of recent changes in forest cover



Alkama and Cescatti (2016) Science.

REFERENCES AND NOTES

1. S. Luyssaert *et al.*, *Glob. Change Biol.* **16**, 1429–1450 (2010).
2. B. Schlamadinger, G. Marland, *Biomass Bioenergy* **10**, 275–300 (1996).
3. T. W. Hudiburg, B. E. Law, C. Wirth, S. Luyssaert, *Nat. Clim. Change* **1**, 419–423 (2011).
4. UN, *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (1998); http://unfccc.int/kyoto_protocol/items/2830.php.
5. B. Amiro *et al.*, *Agric. For. Meteorol.* **136**, 237–251 (2006).
6. J.-Y. Juang, G. Katul, M. Siqueira, P. Stoy, K. Novick, *Geophys. Res. Lett.* **34**, L21408 (2007).
7. E. Rotenberg, D. Yakir, *Science* **327**, 451–454 (2010).
8. S. Luyssaert *et al.*, *Nat. Clim. Change* **4**, 389–393 (2014).
9. R. A. Pielke Sr. *et al.*, *Philos. Trans. A Math. Phys. Eng. Sci.* **360**, 1705–1719 (2002).
10. R. A. Pielke *et al.*, *WIREs Clim. Change* **2**, 828 (2011).
11. A. J. Pitman *et al.*, *Geophys. Res. Lett.* **36**, L14814 (2009).
12. J. Pongratz, T. Raddatz, C. H. Reick, M. Esch, M. Claussen, *Geophys. Res. Lett.* **36**, GB3018 (2009).
13. R. Mahmood *et al.*, *Int. J. Climatol.* **34**, 929–953 (2014).
14. M. J. McGrath *et al.*, *Biogeosciences* **12**, 4291–4316 (2015).
15. Materials and methods are available as supplementary materials on *Science* Online.
16. K. Naudts *et al.*, *Geosci. Model Dev.* **8**, 2035–2065 (2015).
17. P. Meyfroidt, E. F. Lambin, *Annu. Rev. Environ. Resour.* **36**, 343–371 (2011).
18. M. Bürgi, A. Schuler, *For. Ecol. Manage.* **176**, 173–183 (2003).
19. E. P. Farrell *et al.*, *For. Ecol. Manage.* **132**, 5–20 (2000).
20. K. Klein Goldewijk, A. Beusen, P. Janssen, *Holocene* **20**, 565–573 (2010).
21. U. Gimmi, M. Bürgi, M. Stuber, *Ecosystems* **11**, 113–124 (2008).
22. X. Lee *et al.*, *Nature* **479**, 384–387 (2011).
23. Y. Li *et al.*, *Nat. Commun.* **6**, 6603 (2015).

CLIMATE CHANGE

Biophysical climate impacts of recent changes in global forest cover

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Changes in forest cover affect the local climate by modulating the land-atmosphere fluxes of energy and water. The magnitude of this biophysical effect is still debated in the scientific community and currently ignored in climate treaties. Here we present an observation-driven assessment of the climate impacts of recent forest losses and gains, based on Earth observations of global forest cover and land surface temperatures. Our results show that forest losses amplify the diurnal temperature variation and increase the mean and maximum air temperature, with the largest signal in arid zones, followed by temperate, tropical, and boreal zones. In the decade 2003–2012, variations of forest cover generated a mean biophysical warming on land corresponding to about 18% of the global biogeochemical signal due to CO_2 emission from land-use change.

Forests play a relevant role in the climate system by absorbing approximately one-fourth of anthropogenic CO_2 emissions (*1*), storing large carbon pools in tree biomass and forest soils (*2*), and modulating the land-atmosphere exchange of energy and water vapor (*3*). Given the important role of forests in the global carbon cycle, climate treaties account for land-based mitigation options such as afforesta-

ing that spatial differences in surface temperature between areas with contrasting forest cover have been interpreted as the climate signal of hypothetical deforestation/afforestation. The substitution of space for time produces unbiased results only if forests are randomly distributed in the landscape. Conversely, the systematic location of forests in less favorable areas (such as steeper or colder slopes, shallow soils, etc.) may produce