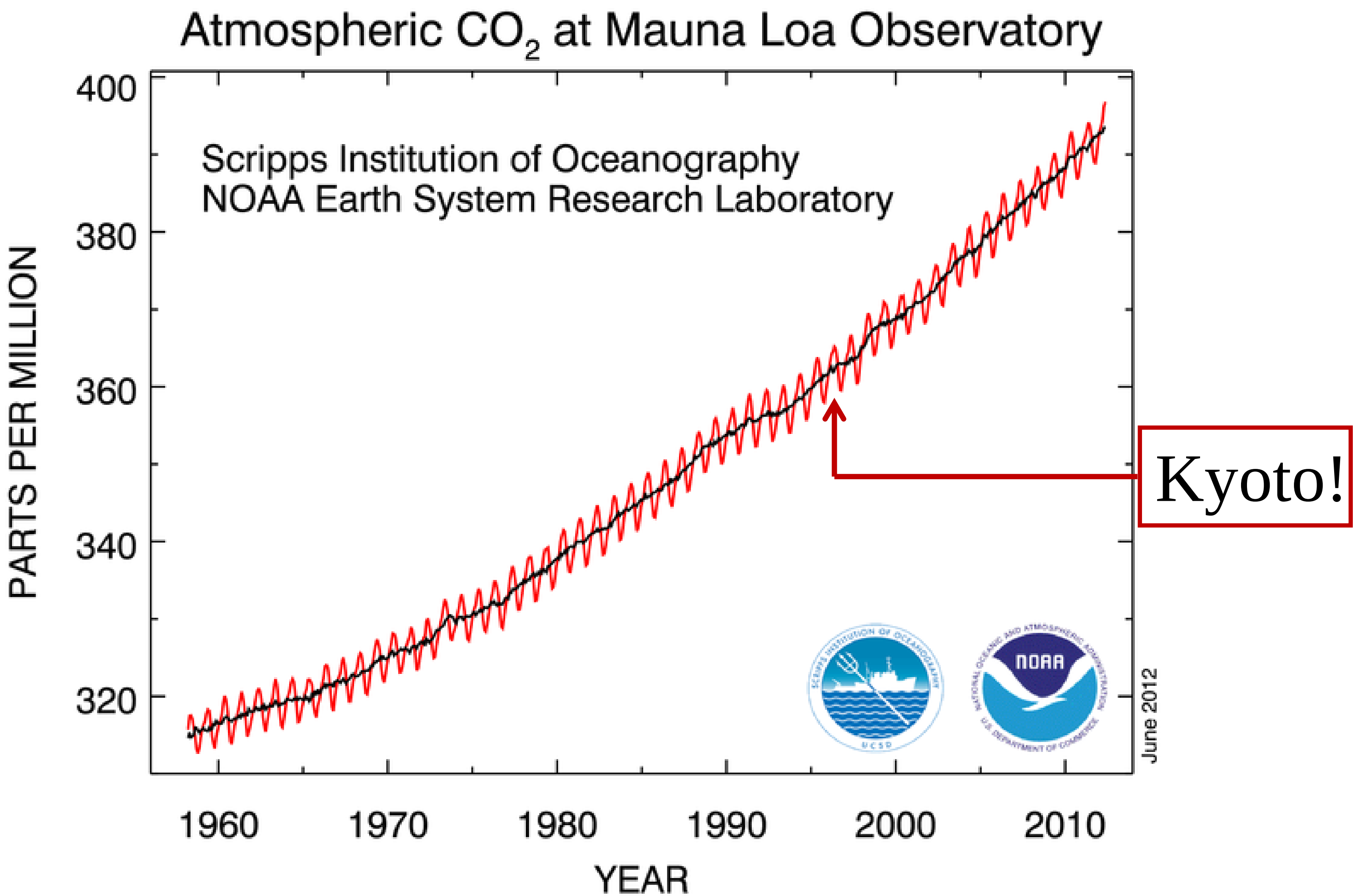
The role of CO_2 in the atmosphere - sources and sinks

Anders Lindroth

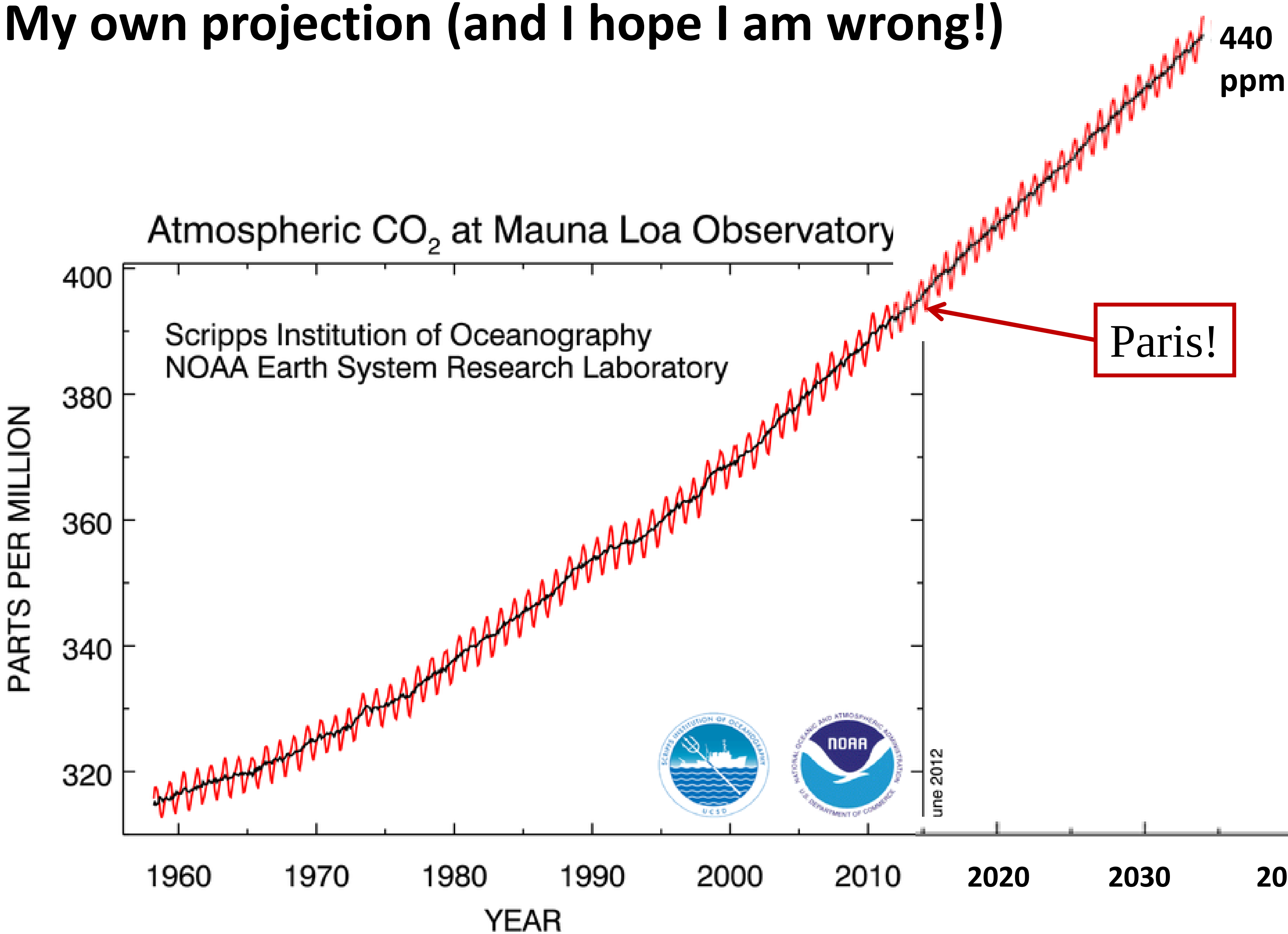
Lund University
Department of Physical Geography and Ecosystem Science
Lund, Sweden
Anders.lindroth@nateko.lu.se
www.nateko.lu.se
www.lucci.lu.se
www.icos-sweden.se

The global picture



From Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)

My own projection (and I hope I am wrong!)



Modified after Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)

Outline

- The global context
- Definition of net carbon exchange in terrestrial ecosystems (forests)
- Uncertainties in the future carbon balance
- Doing the right thing

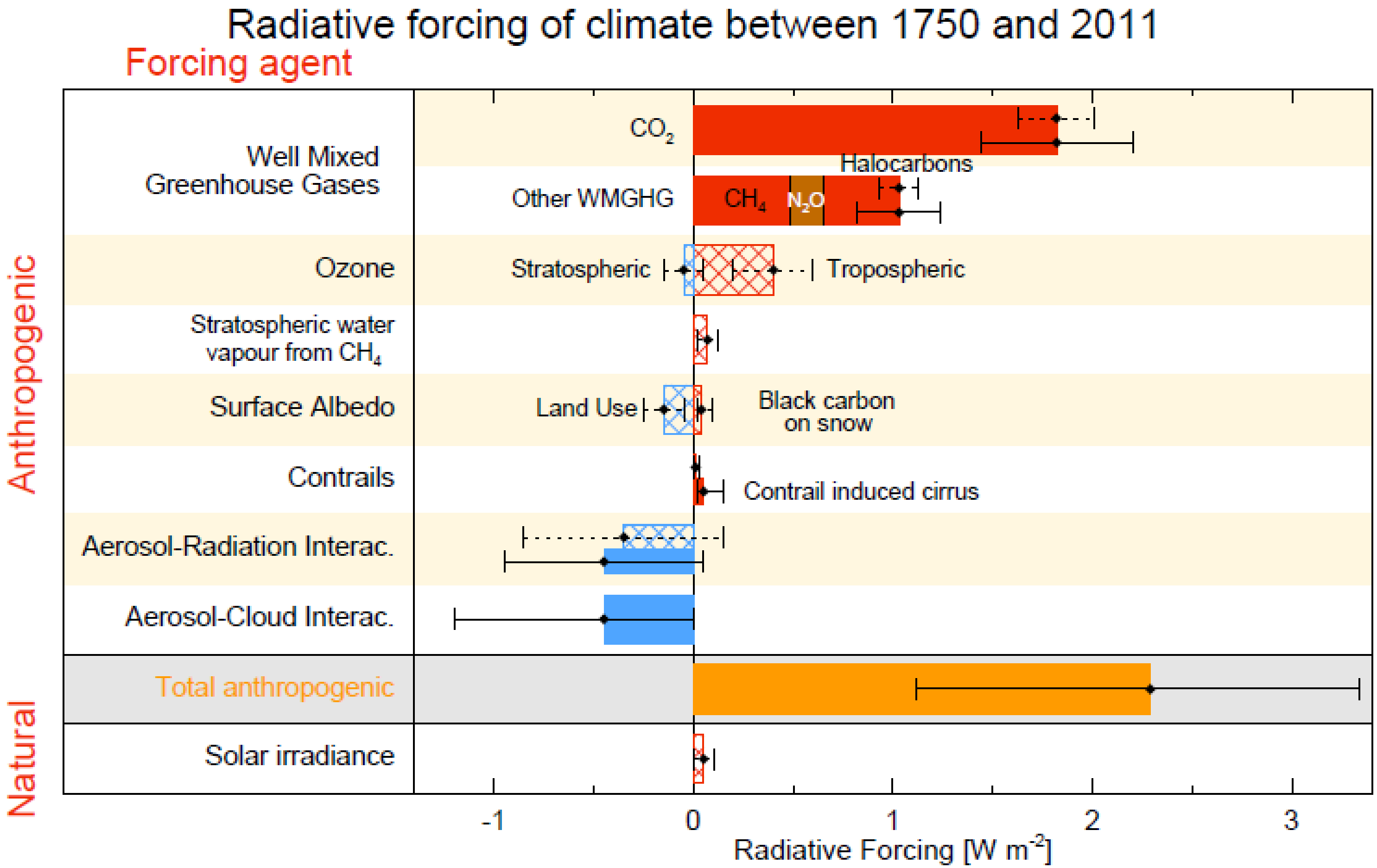
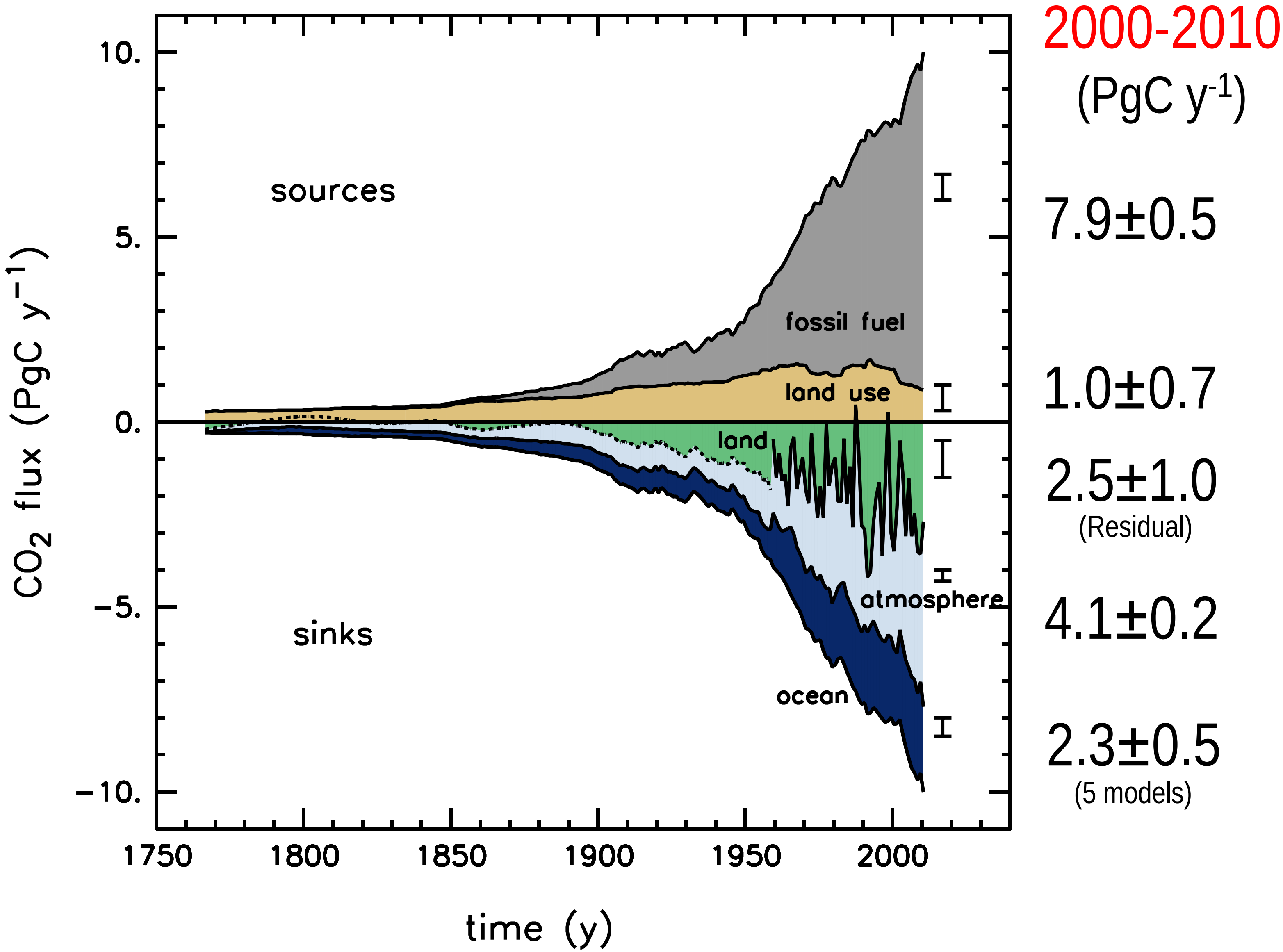


Figure 8.15: Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5–95% confidence range) are given for RF (dotted lines) and ERF (solid lines).

The global carbon balance



Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

Fate of Anthropogenic CO_2 Emissions (2010)

9.1±0.5 PgC y^{-1}

+

0.9±0.7 PgC y^{-1}

5.0±0.2 PgC y^{-1}

50%

2.6±1.0 PgC y^{-1}

26%

Calculated as the residual
of all other flux components

24%

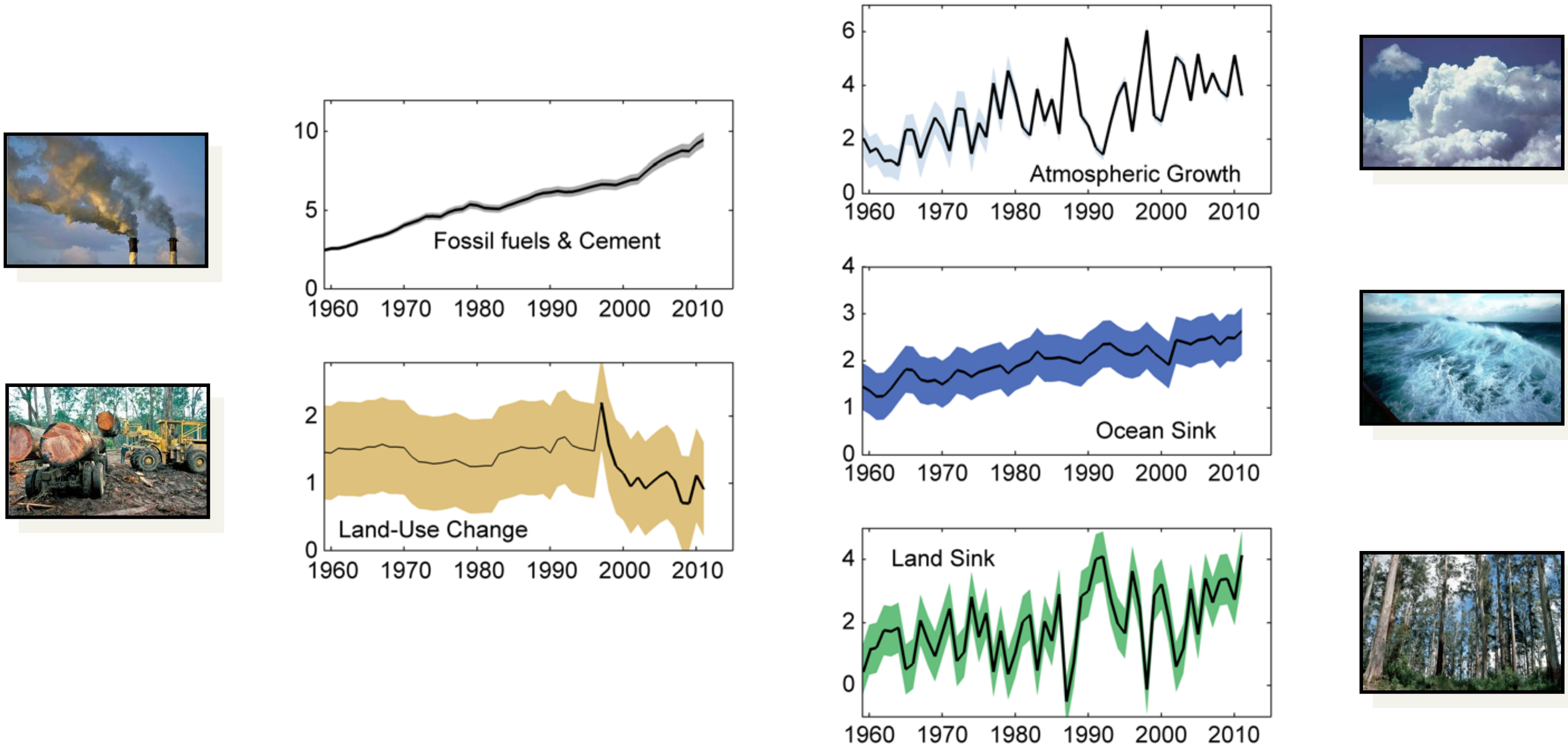
2.4±0.5 PgC y^{-1}

Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

Changes in the Global Carbon Budget over Time

The sinks have continued to grow with increasing emissions
It is uncertain how efficient the sinks will be in the future



Source: Le Quéré et al. 2012; Global Carbon Project 2012

A Large and Persistent Carbon Sink in the World's Forests

Yude Pan,[1*] Richard A. Birdsey,[1] Jingyun Fang,[2,3] Richard Houghton,[4] Pekka E. Kauppi,[5] Werner A. Kurz,[6] Oliver L. Phillips,[7] Anatoly Shvidenko,[8] Simon L. Lewis,[7] Josep G. Canadell,[9] Philippe Ciais,[10] Robert B. Jackson,[11] Stephen W. Pacala,[12] A. David McGuire,[13] Shilong Piao,[2] Aapo Rautiainen,[5] Stephen Sitch,[7] Daniel Hayes[14]

The terrestrial carbon sink has been large in recent decades, but its size and location remain uncertain. Using forest inventory data and long-term ecosystem carbon studies, we estimate a total forest sink of 2.4 ± 0.4 petagrams of carbon per year (Pg C year^{-1}) globally for 1990 to 2007. We also estimate a source of 1.3 ± 0.7 Pg C year^{-1} from tropical land-use change, consisting of a gross tropical deforestation emission of 2.9 ± 0.5 Pg C year^{-1} partially compensated by a carbon sink in tropical forest regrowth of 1.6 ± 0.5 Pg C year^{-1}. Together, the fluxes comprise a net global forest sink of 1.1 ± 0.8 Pg C year^{-1}, with tropical estimates having the largest uncertainties. Our total forest sink estimate is equivalent in magnitude to the terrestrial sink deduced from fossil fuel emissions and land-use change sources minus ocean and atmospheric sinks.

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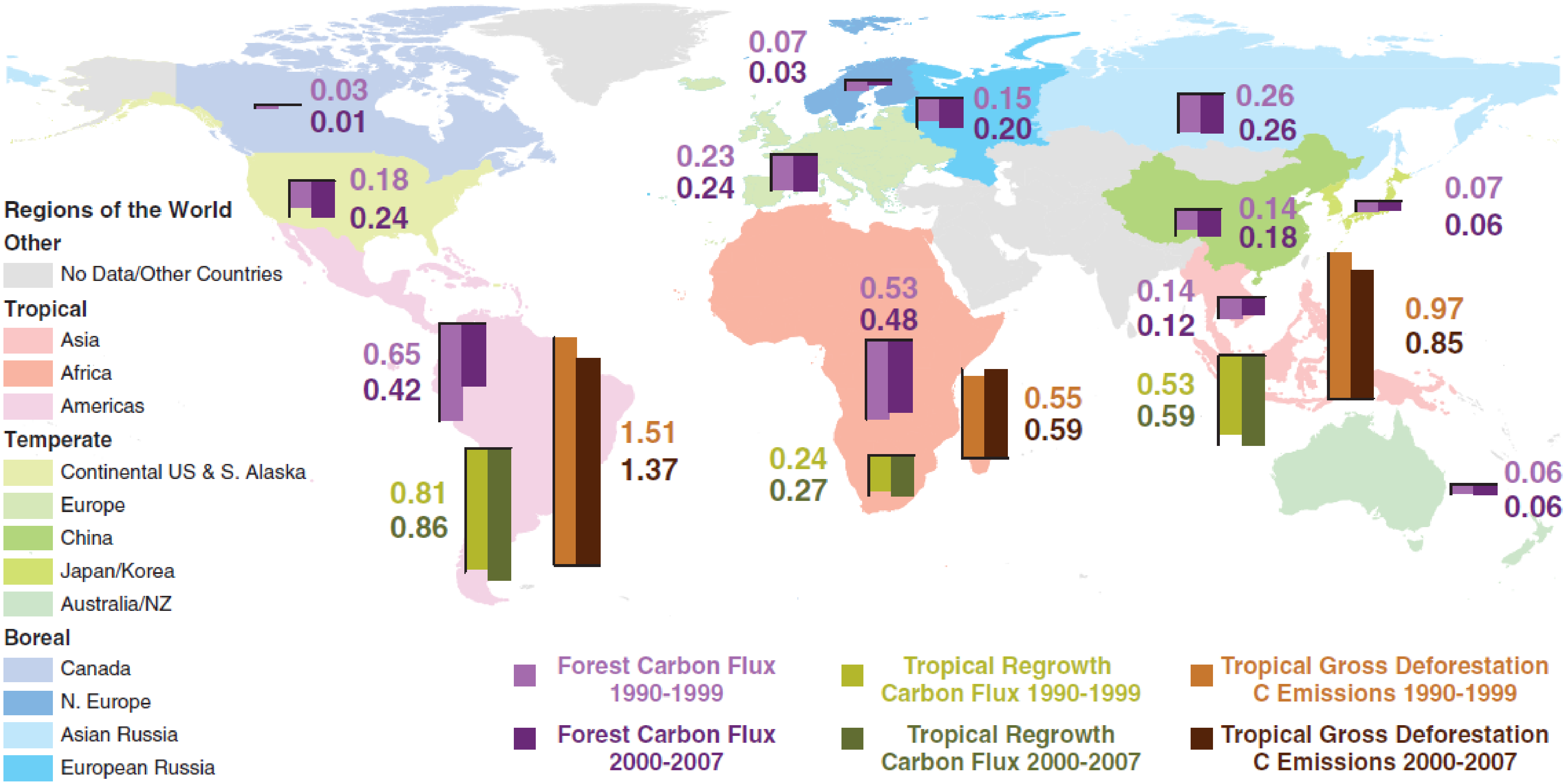

Fig. 1. Carbon sinks and sources (Pg C $year^{-1}$) in the world's forests. Colored bars in the down-facing direction represent C sinks, whereas bars in the upward-facing direction represent C sources. Light and dark purple, global established forests (boreal, temperate, and intact tropical forests); light and dark green, tropical regrowth forests after anthropogenic disturbances; and light and dark brown, tropical gross deforestation emissions.

Total forest sink = 2.4 ± 0.4 Pg C yr^{-1}
of which 20% in boreal forests

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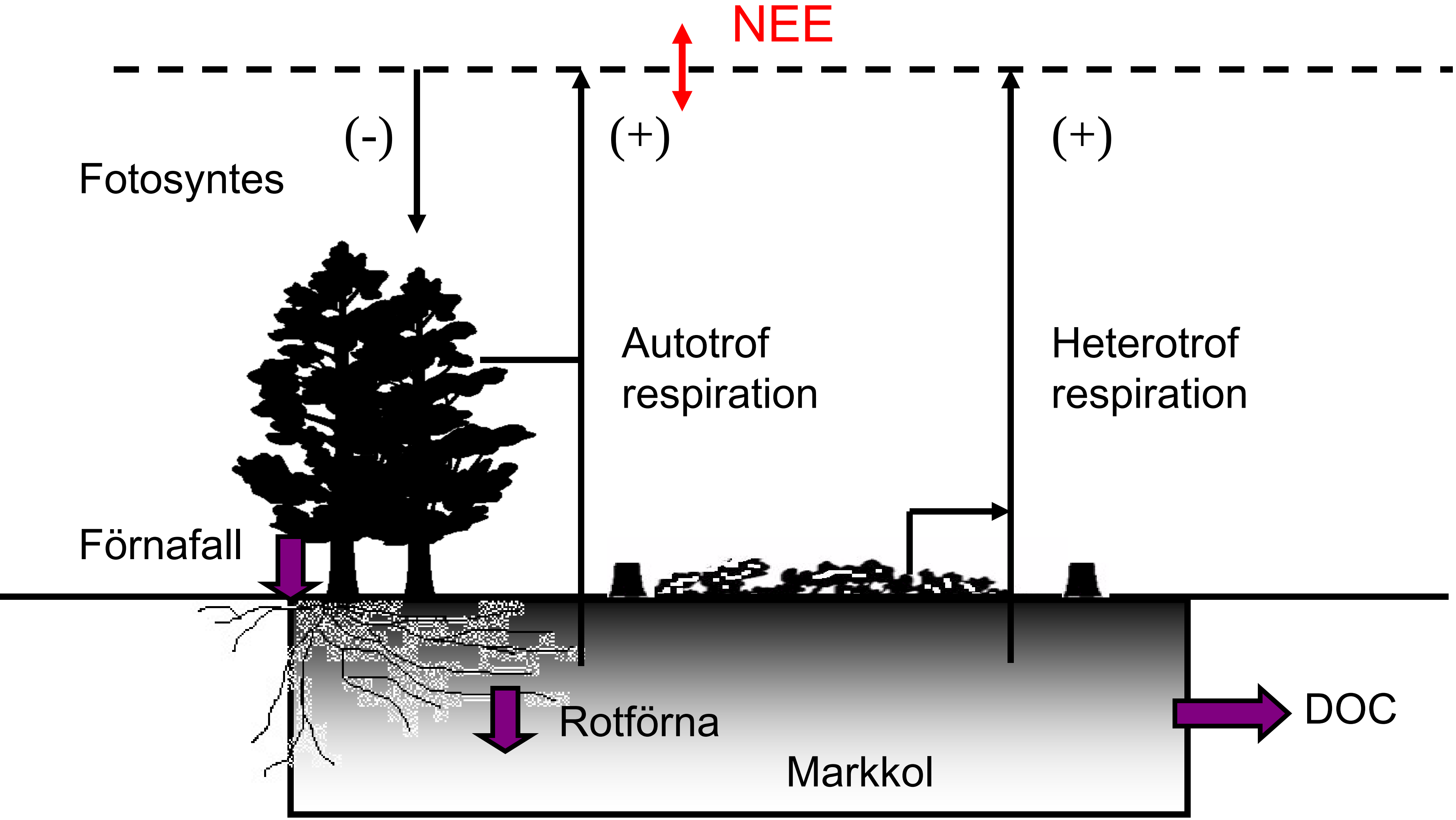
C-fluxes in forests

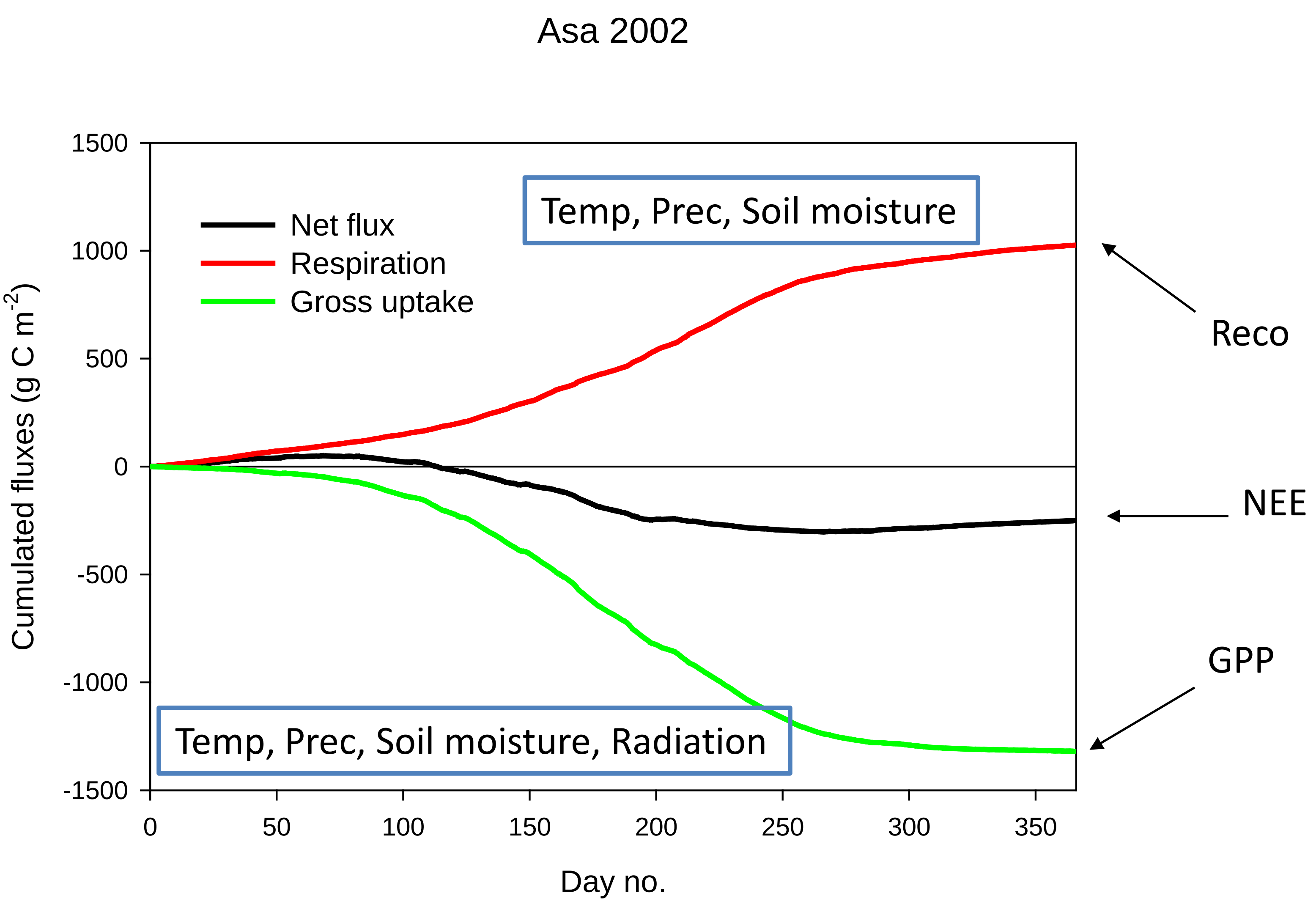


= partikelflöde

= gasflöde

NEE = Net exchange of CO_2= Photosynthesis + Respiration

Example of an annual C-balance of a 30-year old pine stand



Anders Lindroth, Lunds universitet

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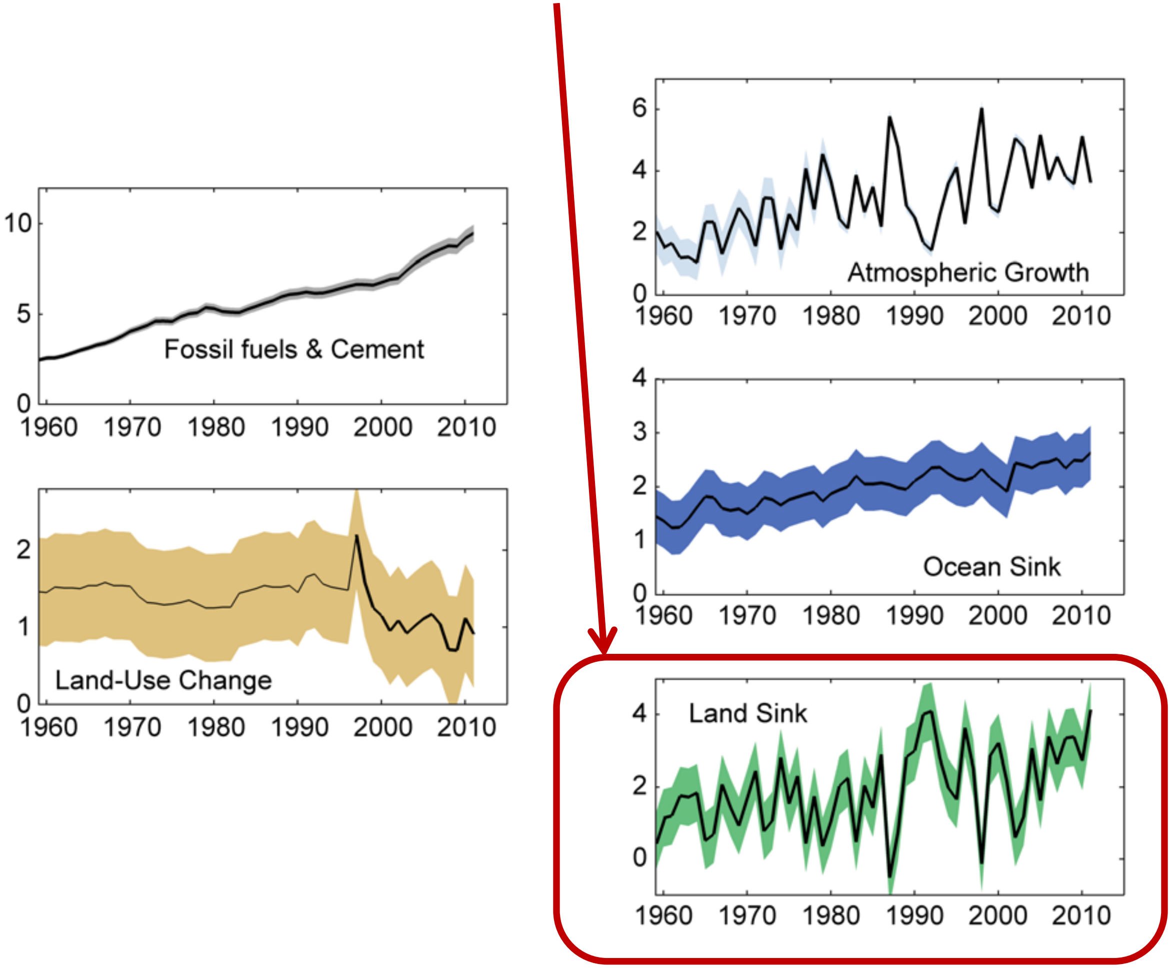
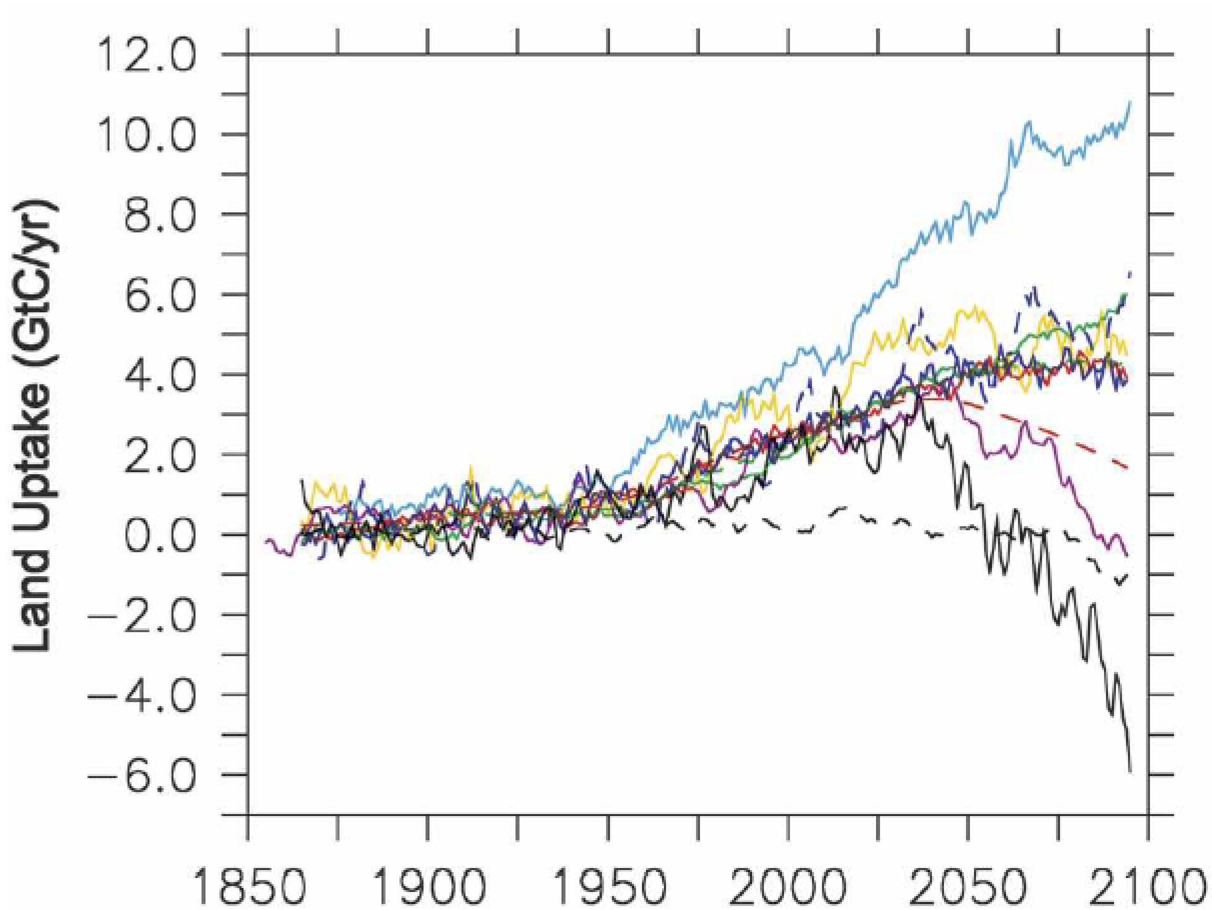
Question: How will the sink in the terrestrial ecosystems change in the future?



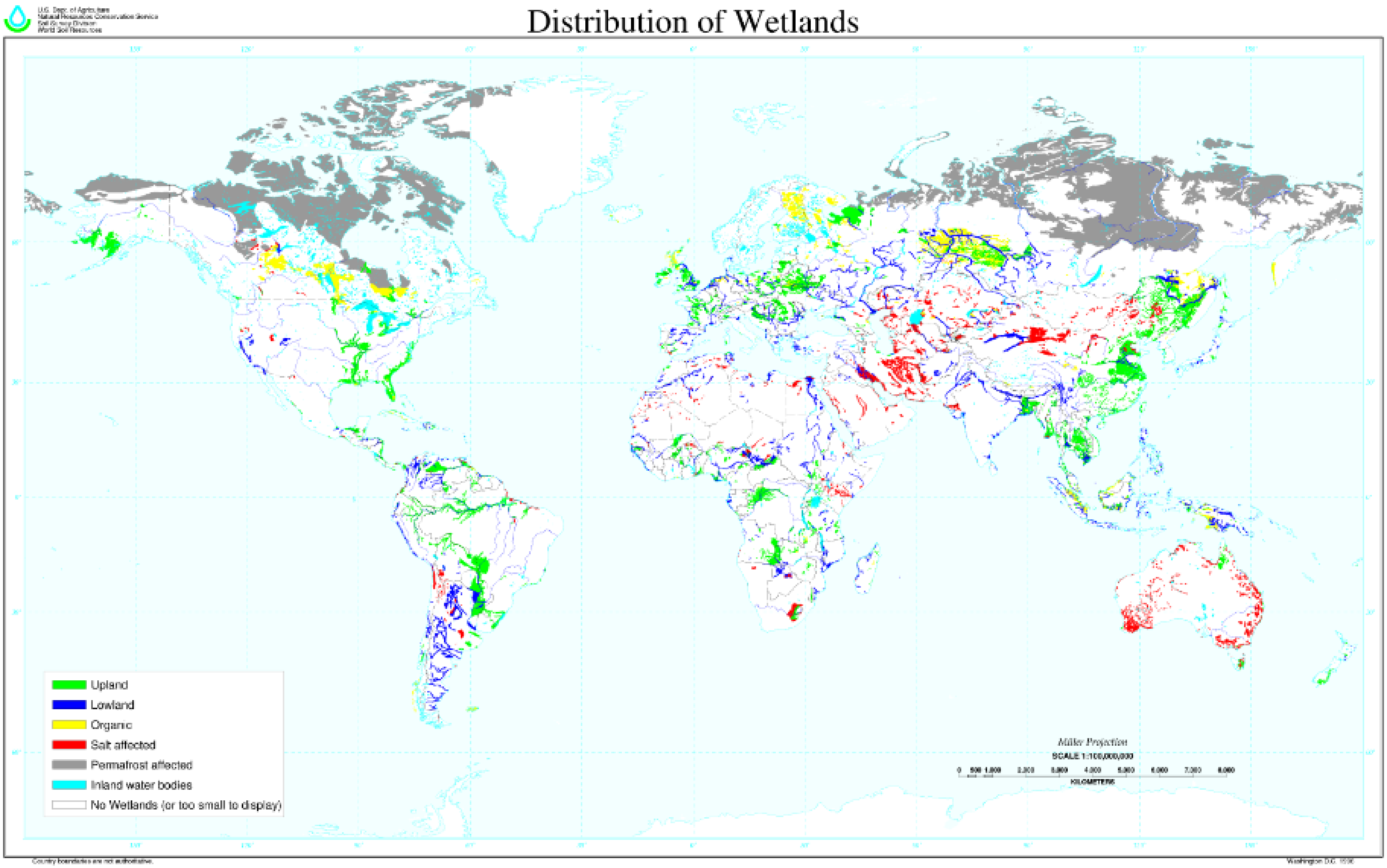
Source: Le Quéré et al. 2012; Global Carbon Project 2012

Climate–Carbon Cycle Feedback Analysis: Results from the C⁴MIP Model Intercomparison



Source: Friedlingstein et al., 2006

Question: What will happen with the permafrost C pool in the future?



Collapsing edge of a peatland

Photo: Seppälä

Table 1

Estimates of carbon stocks in the northern cryosphere region[a]

Reservoir	Size of carbon stock ($Pg = 10^{15}$ g)
Northern cryosphere land	
Soil	1400–1850 Pg C
Vegetation	60–70 Pg C
Northern cryosphere ocean	
Dissolved inorganic carbon	310 Pg C
Dissolved organic carbon	9 Pg C
Surface sediments	9 Pg C
Methane hydrates	
Beneath northern cryosphere land	2–65 Pg CH_4 (2–49 Pg C)
Beneath northern cryosphere ocean	30–170 Pg CH_4 (23–128 Pg C)
Total	1813–2425 Pg C

Atmosphere ~ 750 Pg

[a] Based on estimates in Ref. [1••].

(From McGuire et al., 2010)

CARBON STORAGE

A permafrost carbon bomb?

The fate of permafrost soil carbon following thaw depends on hydrology.

Claire C. Treat and Steve Frolking

Lurking beneath Arctic tundra and boreal forest, there is a potential climate-disrupting carbon (C) store in the frozen soil. There is more than twice the amount of atmospheric C in northern permafrost soils[1], which are predicted to warm substantially by 2100[2]. In these regions, the mean annual air temperature is generally below freezing, which has resulted in permafrost formation — where the ground/soil remains frozen throughout the year, except for a thin (typically <1 m) seasonally thawing surface soil, the active layer. Incorporation of organic matter into the permafrost soil limits decomposition of readily available organic

news & views

LETTERS
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nature climate change

Long-term CO_2 production following permafrost thaw

Bo Elberling[1,2]*, Anders Michelsen[1,3], Christina Schädel[4], Edward A. G. Schuur[4], Hanne H. Christiansen[1,2], Louise Berg[1], Mikkel P. Tamstorf[5] and Charlotte Sigsgaard[1]

Thawing permafrost represents a poorly understood feedback mechanism of climate change in the Arctic, but with a potential impact owing to stored carbon being mobilized[1–5]. We have quantified the long-term loss of carbon (C) from thawing permafrost in Northeast Greenland from 1996 to 2008 by combining repeated sediment sampling to assess changes in C stock and >12 years of CO_2 production in incubated permafrost samples. Field observations show that the active-layer thickness has increased by >1 cm yr^{-1} but thawing has not resulted in a detectable decline in C stocks. Laboratory mineralization rates at 5 °C resulted in a C loss between 9 and 75%, depending on drainage, highlighting the potential of fast mobilization of permafrost C under aerobic conditions, but also that C at near-saturated conditions may remain largely immobilized over decades. This is confirmed by a three-pool C dynamics model that projects a potential C loss between 13 and 77% for 50 years of incubation at 5 °C.

The Northern Hemisphere permafrost region contains approx-

repeated in 2008 and 2012. In 2008, two permafrost cores were obtained down to at least 2 m depth at the same sites by drilling. Two Circumpolar Active Layer Monitoring Network (CALM) grids were established in 1996 in the two landforms studied here[5,7]. Since then, thaw progression has been recorded based on regular probing throughout the summers.

Top permafrost samples ($n = 3$ per site) collected in 1996 at a depth of about 80–90 cm on the heath site and 60–70 cm on the wet grassland site were kept cold (<7 °C) and transported back to the laboratory for long-term incubation at 5 ± 1.5 °C. Each intact permafrost sample, consisting of 100–200 g soil, was incubated in glass jars with the top covered with Parafilm M with more than ten (<1 mm) holes to allow atmospheric conditions during incubation, but to limit evaporation. Subsamples from the wet grassland site were drained before incubation using a sand bath and leaving the samples to drain freely at 5 °C for 48 h to mimic natural drainage following thawing.

Subsamples of 2–3 g from each of the replicate intact permafrost

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The C sink in Swedish forests by inventory method

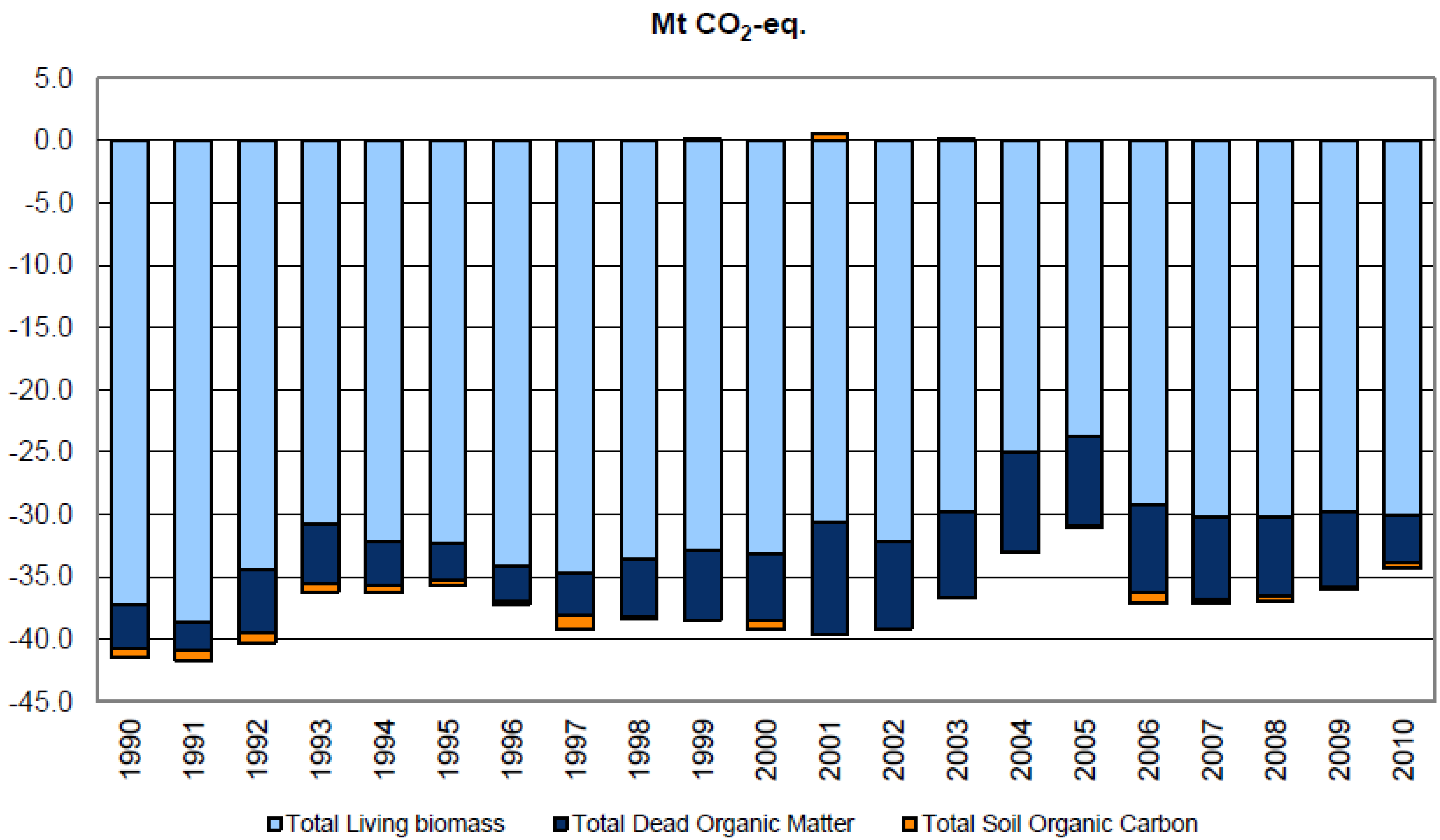
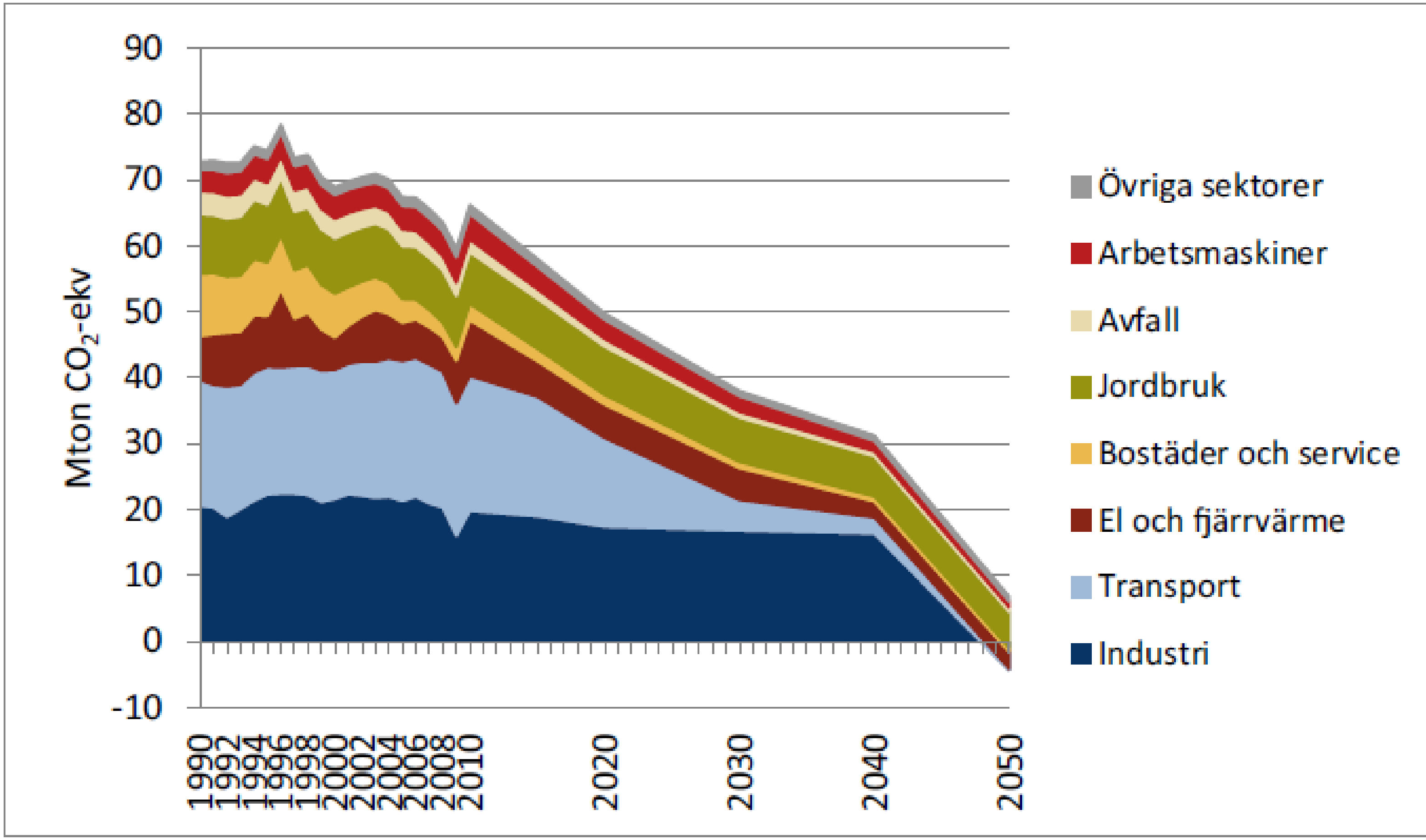


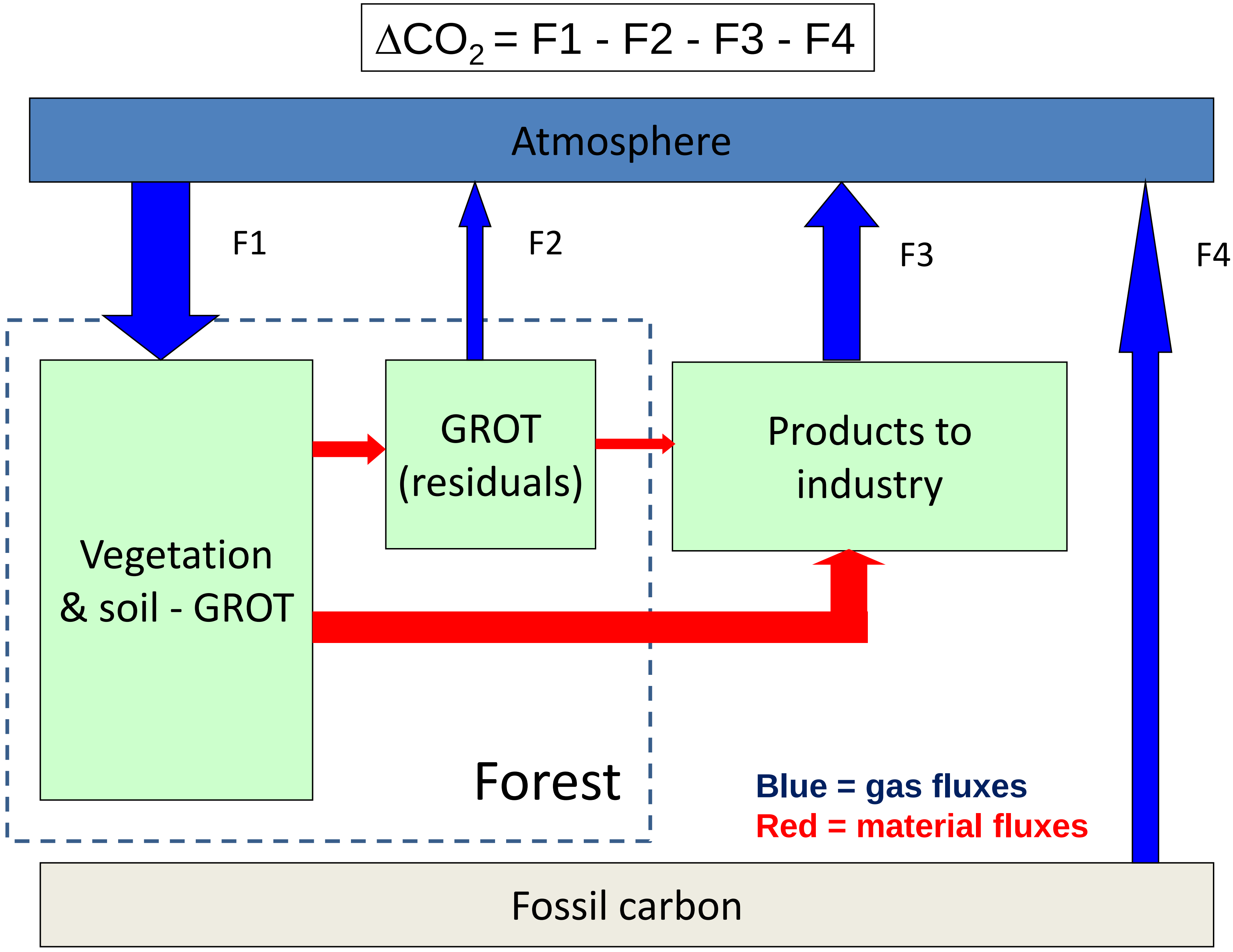
Figure 2.20 Emissions (+) and removals (-) of carbon dioxide from different carbon pools.

The Swedish roadmap towards zero net emissions 2015

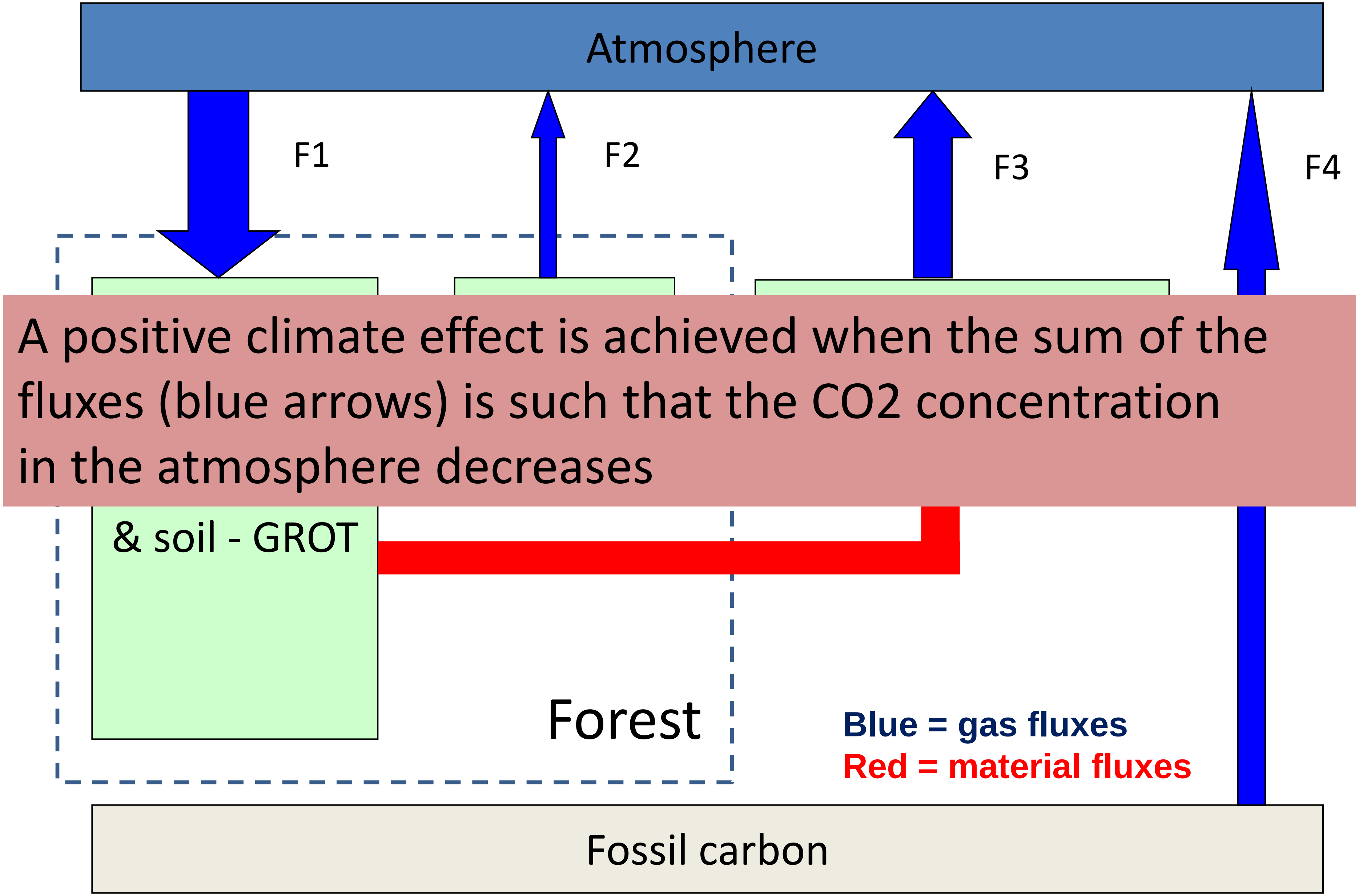


Figur 1. Målscenario Teknikåtgärder och CCS på fossila och biogena utsläpp från industrin. Teknik och transportsnålt samhälle för transportsektorn.

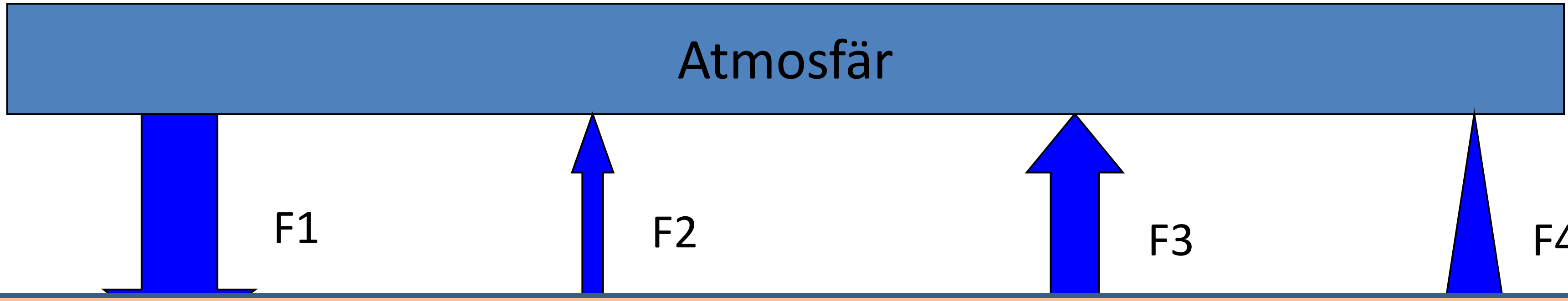
NATURVÅRDSVERKET RAPPORT 6537
Underlag till en färdplan för ett Sverige utan klimatutsläpp 2050


$\Delta CO_2 = F1 - F2 - F3 - F4$
Atmosphere
F1
F2
F3
F4
GROT
(residuals)
Products to
industry
Vegetation
& soil - GROT
Forest
Blue = gas fluxes
Red = material fluxes
Fossil carbon

$$\Delta CO_2 = F1 - F2 - F3 - F4$$

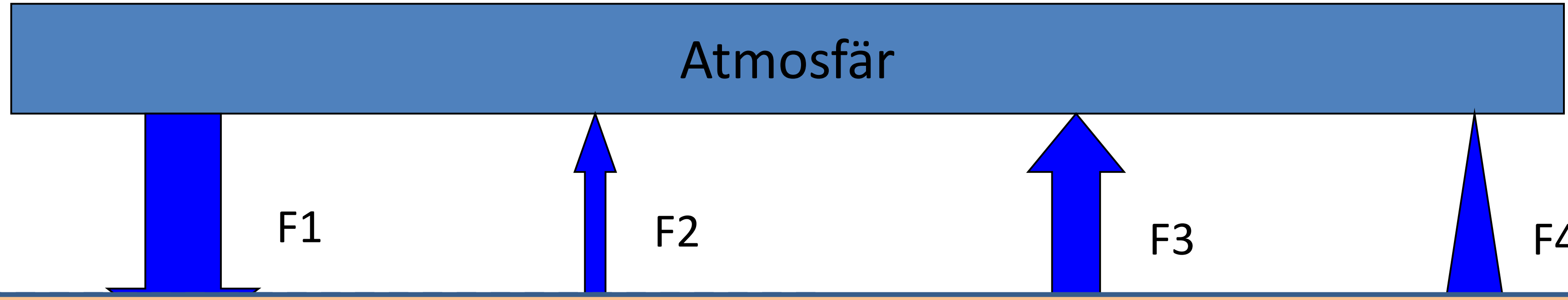


Suppose now that we wish to use the forest to obtain a reduction of the CO_2-emissions to 2020 – how to do?



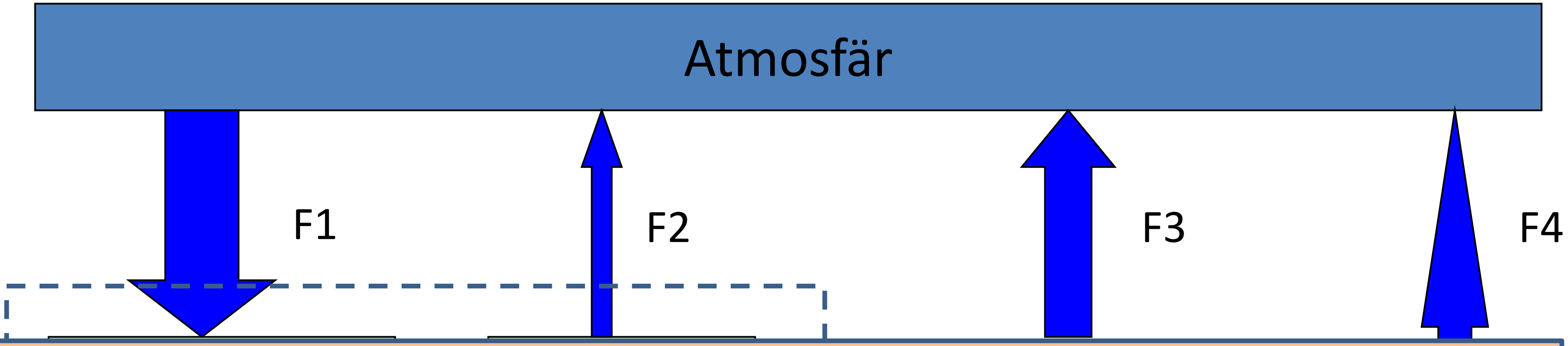
Scenario 1 – we increase the cuttings by 10% (20 000 ha/yr) and substitute fossil fuels with biomass. The effect will be:

1. The net uptake in the forest will decrease by ca 12 M tonnes of CO_2 because 8 M tonnes of emissions from clearcuts and 4 M tonnes 'lost' uptake in the forest that was harvested (F1 decreases)
2. Emissions to the atmosphere from the combustion of the biomass will be approximately the same as the one that would have been emitted from the fossil fuels
   (F3 increases as much as F4 decreases)
3. The total effect – a strong **increase of CO_2 in the atmosphere**!



Scenario 2 – we **decrease** the cuttings by 10% (20 000 ha/yr) and substitute biomass with fossil fuels(!). The effect will be:

1. The net uptake in the forest will increase by ca 12 M tonnes of CO_2 because 8 M tonnes of less emissions from clearcuts and 4 M tonnes additional uptake in the forest that was not harvested (F1 increases)
2. Emissions to the atmosphere from the combustion of the fossil fuel will be approximately the same as the one that would have been emitted from the biomass (F3 decreases as much as F4 increases)
3. The total effect – a strong decrease **of CO_2-conc. in the atmosphere**!



<u>The scenario 2-paradox</u>

Please notice that this does not mean that I advocate increased use of fossil fuels!

OF COURSE shall we do everything we can to reduce our dependence on fossil fuels BUT we must take notice so that our suggested actions will have the anticipated effect.

Take home messages:

1. The forests constitute an important sink in the global and regional C-budget
2. There are large uncertainties in the evolution of the future C-sink
3. Permafrost thawing is another risk with positive climate feedback
4. Understanding the whole forest-climate-'industry' system is critical for making the right mitigation decision