Climate Change Implications of Shifting Land Use Between Forest and Permanent Pasture.

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Forest ⟶ pasture ⟶ forest

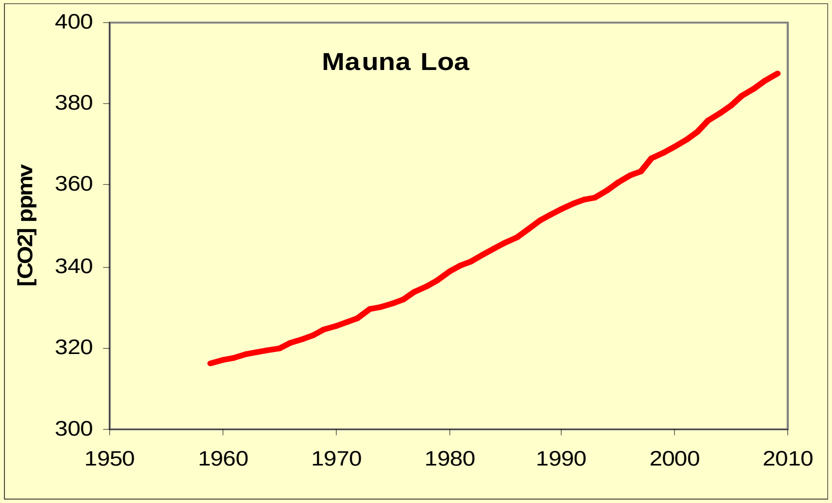
CO_2 with full carbon cycle

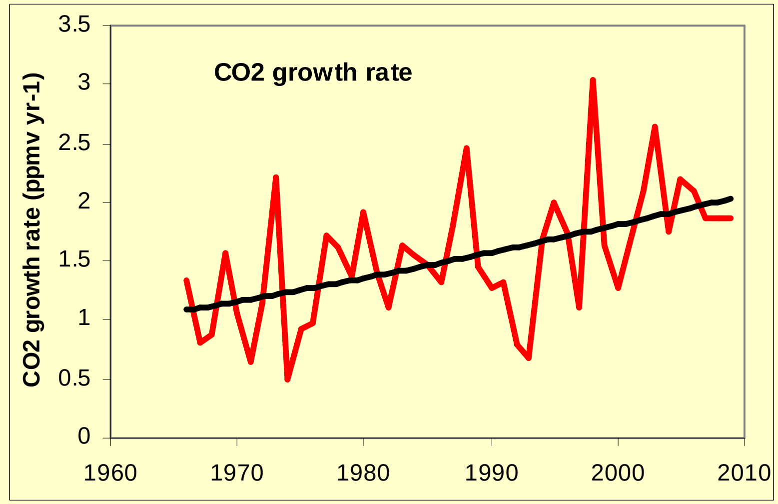
Nitrous oxide (long-lived gas)

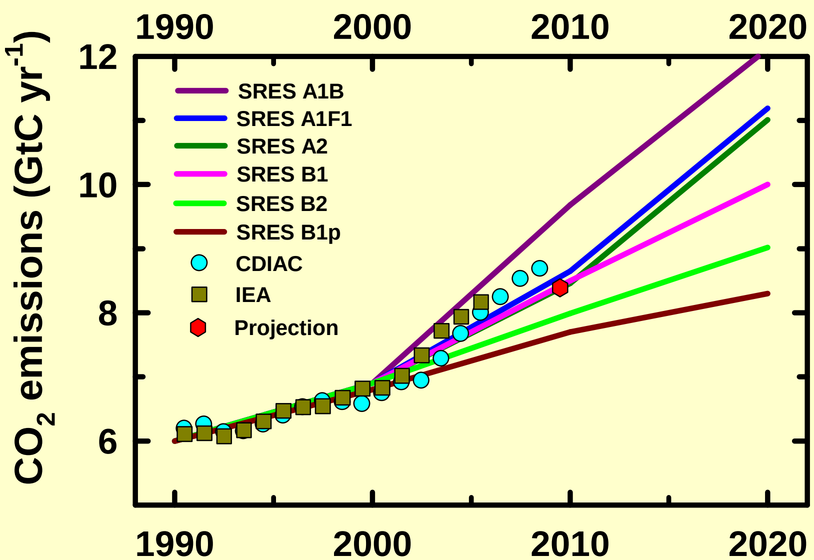
Methane (short-lived gas)

Albedo (surface reflectance)

CO_2 emissions are rising fast



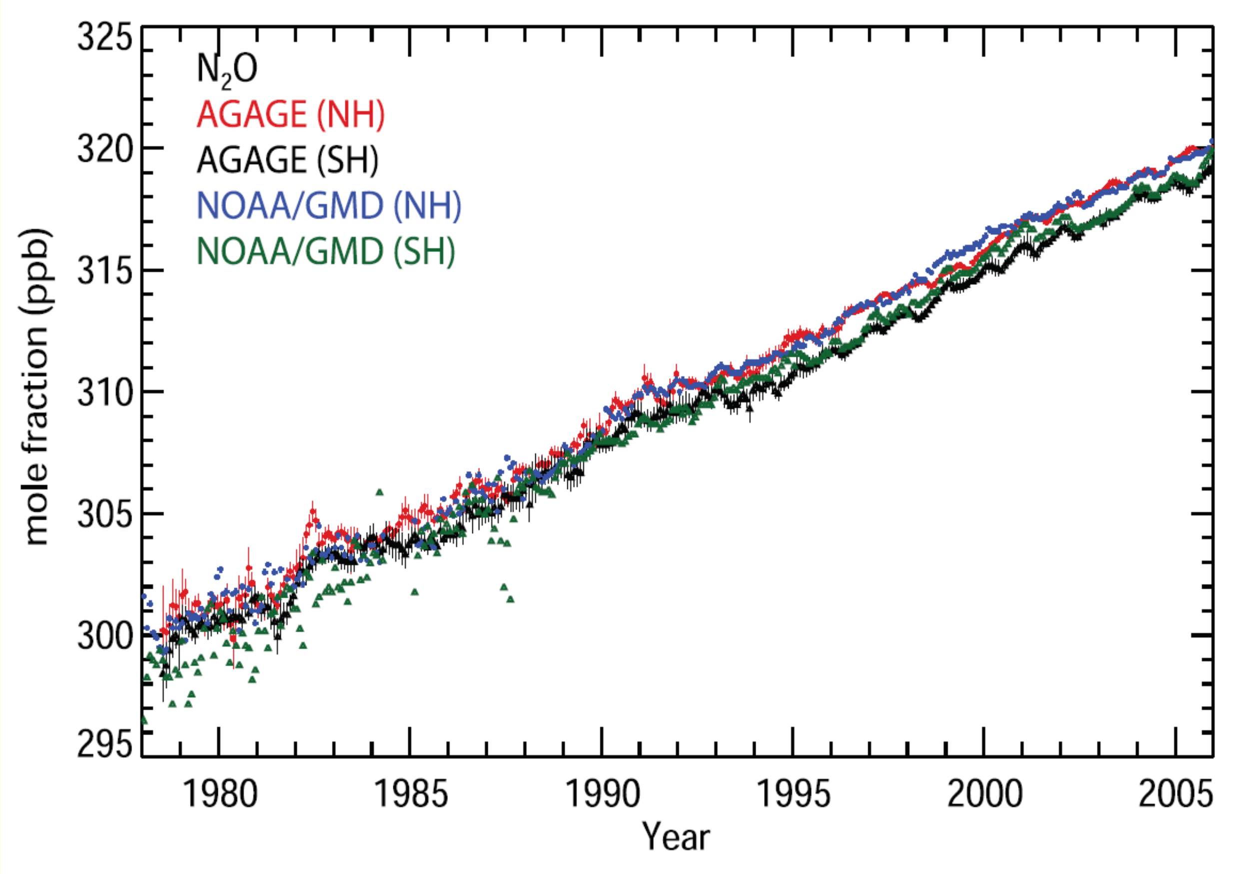




Key points:
CO_2 concentrations are rising rapidly, with annual growth rate now being about 2 ppmv yr^{-1}. The atmospheric increase is driven primarily by the large emissions from the burning of fossil fuels. Observed emissions are at the upper range of IPCC scenarios.

Raupach et al. (2007); Steffen (2009); NOAA (2009); IMF (2009)

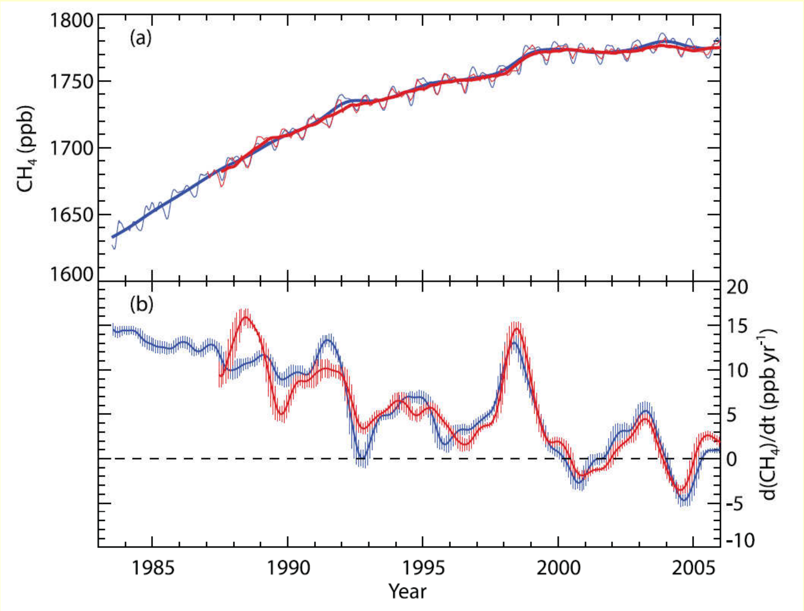
Nitrous oxide



Key points:
N_2O concentrations have been going up steadily for at least the past 25 years. While concentrations are low, they are nonetheless important because N_2O has powerful radiative absorptive properties.

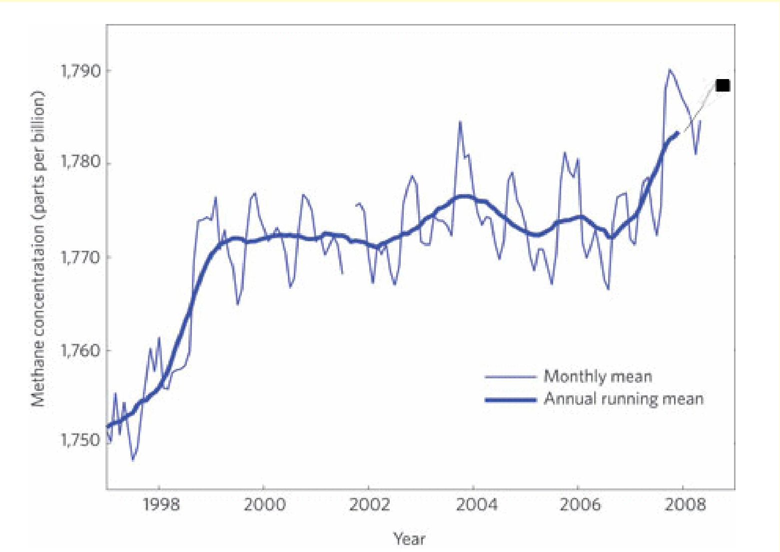
IPCC (2007)

Methane



IPCC (2007)

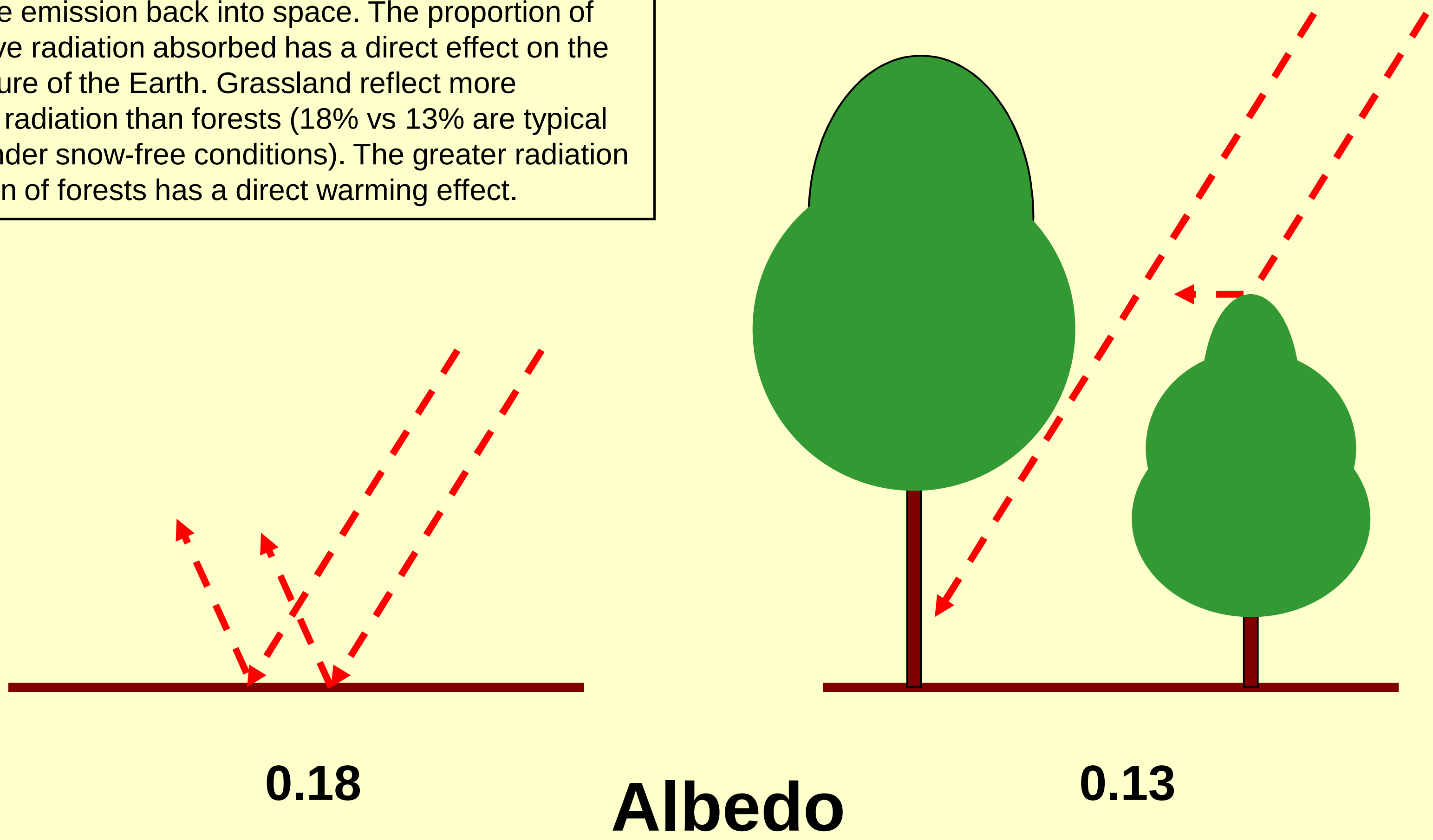
Key points:
Methane concentrations have more than doubled since pre-industrial times, but appear to have stabilised since about 2000. The most recent measurements suggest, however, that its atmospheric concentration has started to increase again.



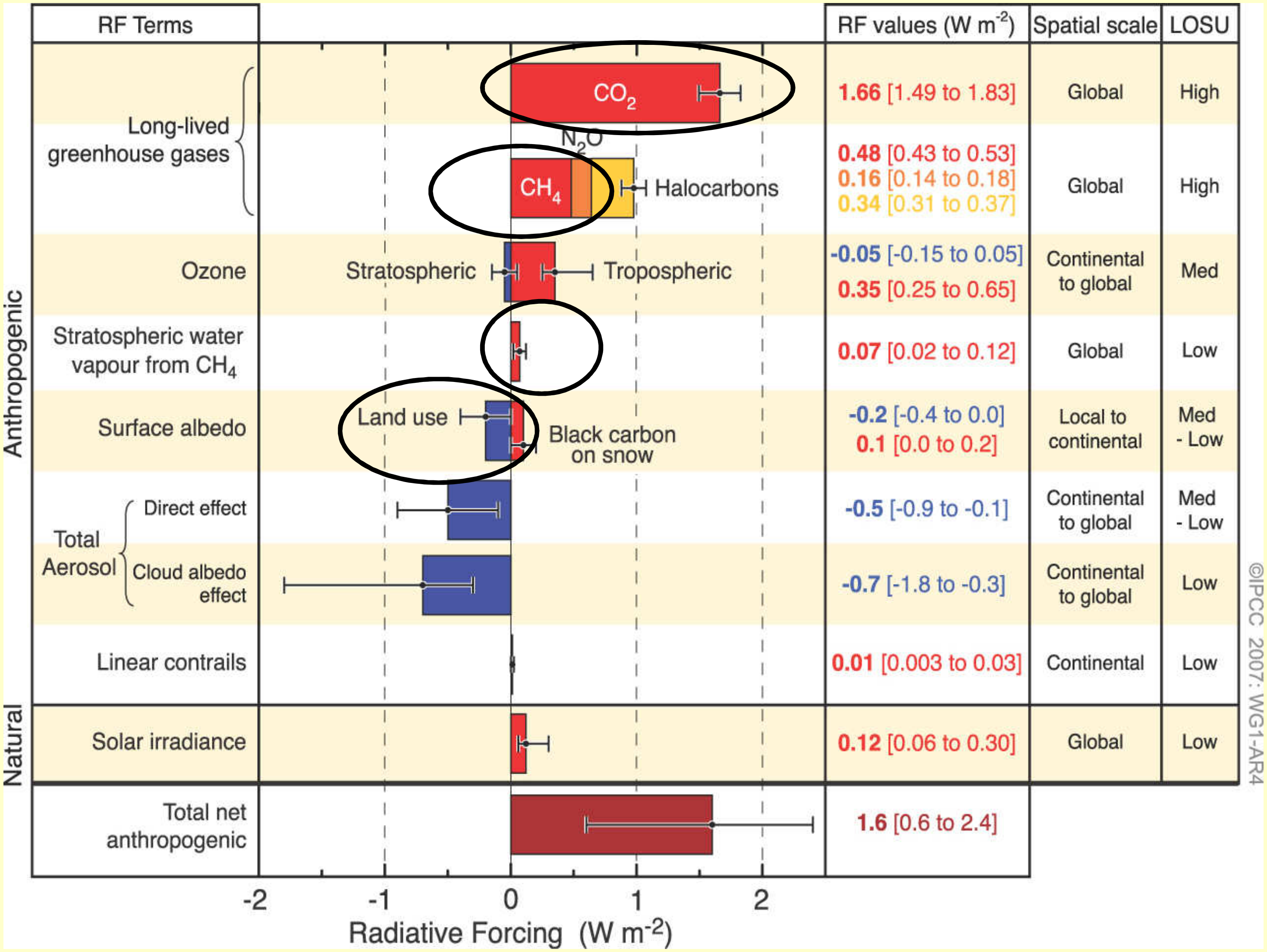
NOAA (2009)

Forests absorb more radiation than pastures

Key points:
The Earth receives basically all of its energy as short-wave radiation from the sun which must be balanced by long-wave emission back into space. The proportion of short-wave radiation absorbed has a direct effect on the temperature of the Earth. Grassland reflect more incoming radiation than forests (18% vs 13% are typical values under snow-free conditions). The greater radiation absorption of forests has a direct warming effect.



Betts (2000)

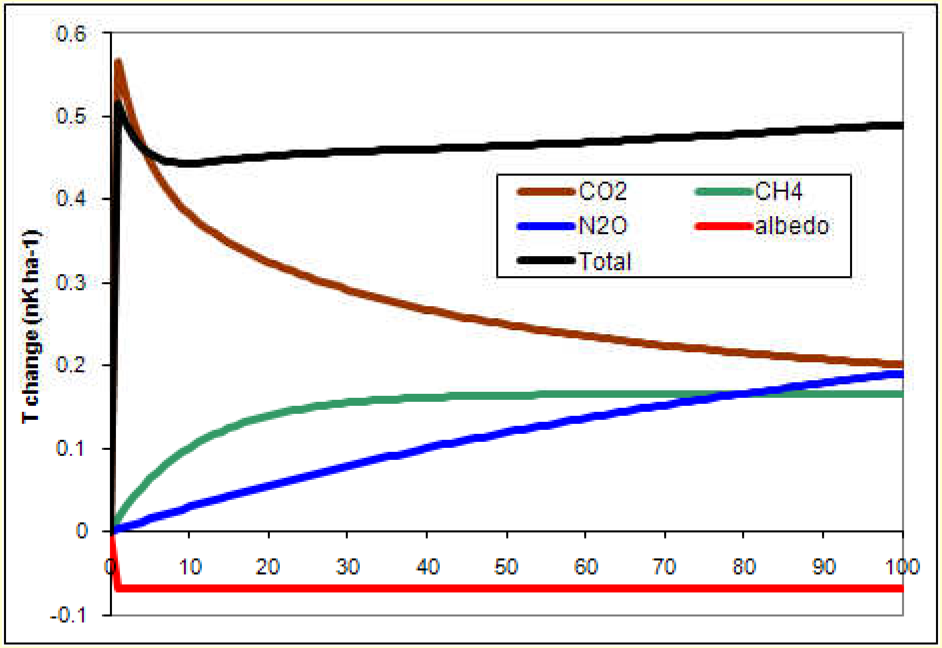


Key points:
This graph shows the contribution to observed radiative forcing changes by all radiative forcing agents. The radiative forcing agents affected by land-use change are circled.

IPCC (2007)

Deforestation

Dairying



Methane: 240 $kgCH_4\ ha^{-1}\ yr^{-1}$
Nitrous oxide: 10 kgN_2O (N) $ha^{-1}\ yr^{-1}$
Forest: 200 tC ha-1
Albedo: 0.13 and 0.18 (forest, pasture)

CH_4 and N_2O emission factors from Saggar (pers. comm.)

Key points:
The graph shows the contribution to global warming for 1 ha converted from forest to dairying.
Albedo changes at the time of land-use change and makes an on-going cooling contribution.
N_2O adds year after year to make a cumulative warming contribution.
CH_4 adds to warming for some years, but then an equilibrium is reached with new added CH_4 balancing the loss of methane emitted in earlier years.
CO_2 makes a one-off large contribution when the original forest is cut. Some of that atmospheric CO_2 is taken up by the oceans to lower the warming effect of the originally emitted CO_2 over later years.

Deforestation

Dairying

Integrals over 100 years

CO_2	27.5 (51%)
CH_4	14.9 (28%)
N_2O	11.2 (21%)
Albedo	-6.8 (-13%)
Total	**46.7**

Key points:
This shows the integrated effect of warming effect in individual years integrated over 100 years. CO_2 contributes about half of total warming and CH_4 and N_2O about a quarter each. Albedo changes offset the warming effect by about 10-20%. These relativities are strongly affected by the magnitude of respective emissions of the different greenhouse gases. The numbers here are based on New Zealand numbers for dairying, which have high emissions of methane and nitrous oxide. It is also based on large numbers for carbon loss which are based on the emission when a mature *Pinus radiata* stand is felled.

Methane: 240 kgCH_4 ha^{-1} yr^{-1}
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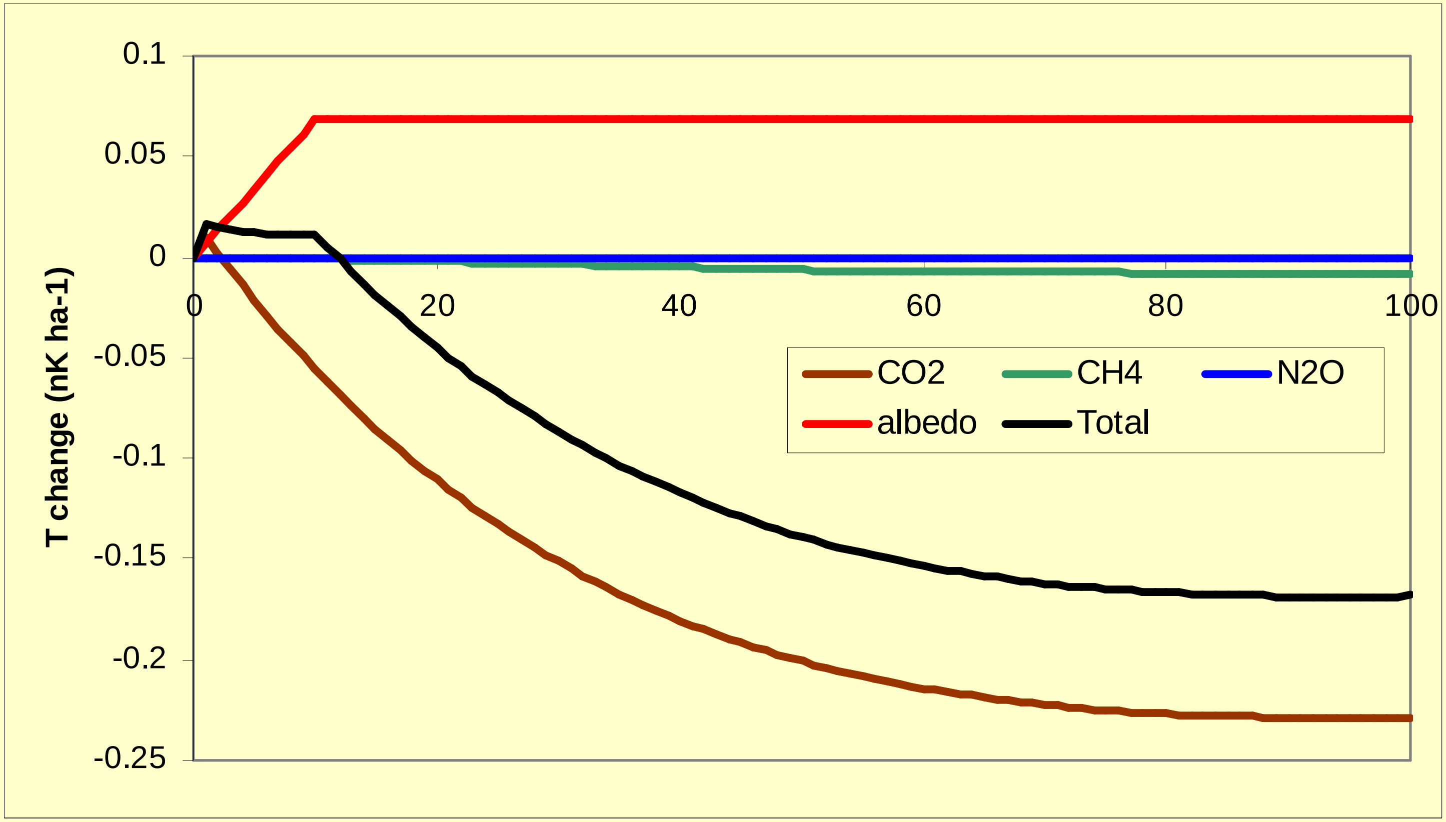
Reforesting dairy pasture



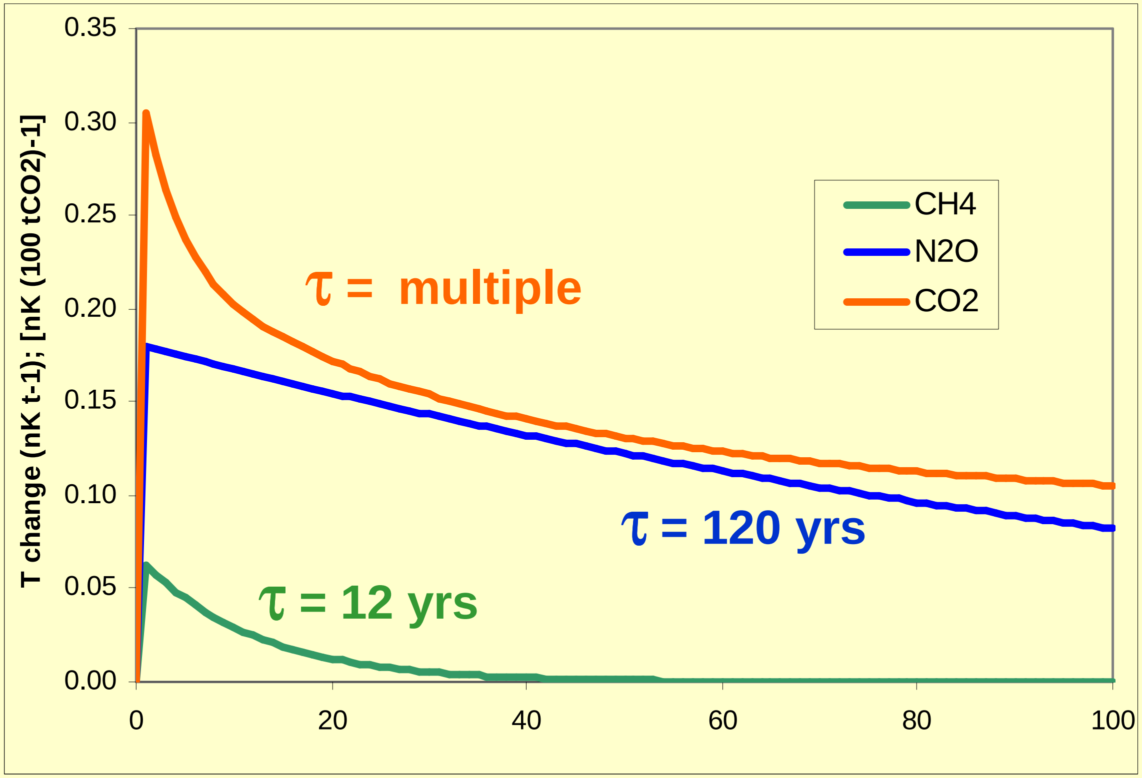
Key points:
Upon reforestation, methane and nitrous oxide emissions cease, and there may be a slightly enhanced rate of methane oxidation, instead. The relative importance of CO_2 and albedo changes are thus the only radiative agents that play an actual role after reforestation. CO_2 accumulation takes time with the on-going but relatively slow growth of forests so that albedo changes can offset the cooling effect for some years.

Reforesting dairy pasture

	Actual	with credit
CO_2	-17.2	-17.2 (-31%)
CH_4	-0.5	-18.8 (-34%)
N_2O	0	-19.6 (-35%)
Albedo	6.5	6.5 (12%)
Total	-11.2	-49.1

Key points:
For an integration over 100 years, one can do the calculations based on only the observed emissions or include a credit for avoided emissions (of methane and nitrous oxide). If avoided emissions are included as well, it greatly increases the calculated benefit of reforestation, and the benefit is about equally due to CO_2, CH_4 and N_2O, with albedo changes negating the benefit by 10-15%.

A closer look at time



Key points:
The different greenhouse gases have quite different atmospheric lifetimes. The atmospheric lifetimes of methane and nitrous oxide are usually described with first-order decay kinetics of 12 and 120 years, respectively, and CO_2 is described with multiple decay constants for different fractions of emitted CO_2. These different turn-over times affect their respective climatic impacts.

Which aspect of climate change impacts us most?

Instantaneous climatic conditions?

- Heat damage
- Severe weather
- Tropical diseases (e.g. malaria)
- Food production

Rate of climate change?

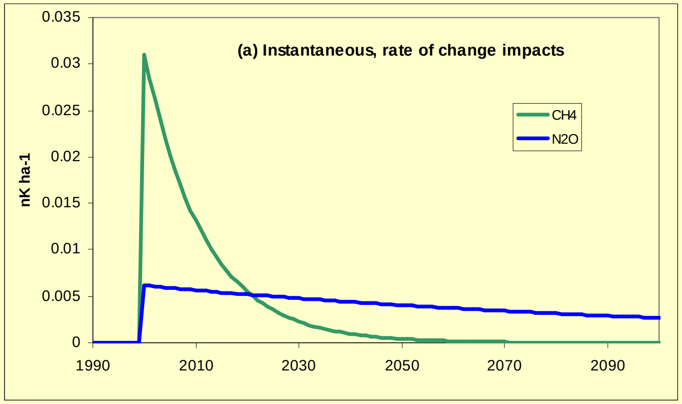
- Ecological mal-adaptation
- Socio-economic institutions

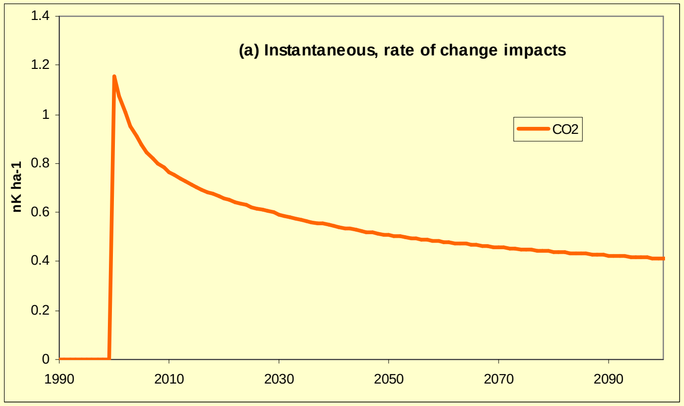
Cumulative climate change?

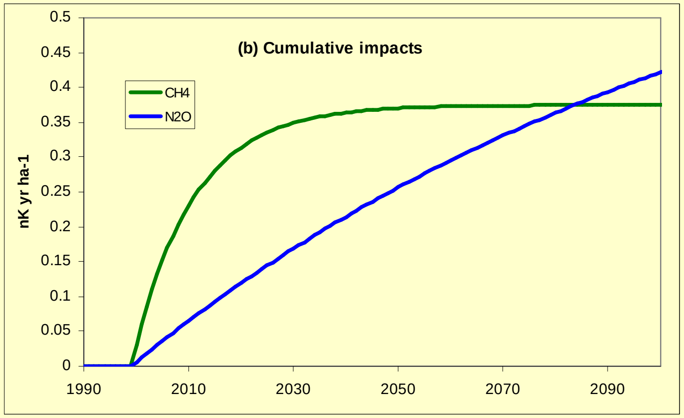
- Sea level rise

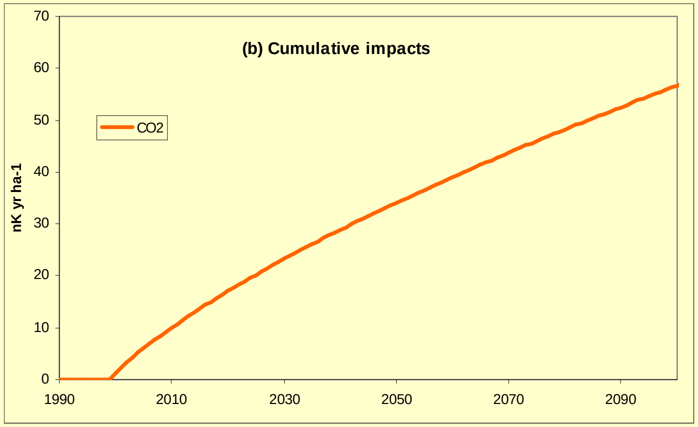
Key points:
These different climatic impacts require very different quantifications. Instantaneous climate impacts are quantified directly as a function of temperature itself. Rate of change impacts are quantified as a function of temperature divided by the time over which a temperature increase has occurred.
Cumulative temperature impacts are quantified through summing the temperature increases over the number of years over which they occur.

A detailed look at impacts (from 1 year's worth of emission)









Key points:
The top graphs give the instantaneous and rate of change impact due to a single one-off emission of a unit of greenhouse gas. It shows that N_2O and CO_2 emitted in 2000 still have a substantial warming impact in 2100 whereas all methane emitted in 2000 will have been oxidised well before 2100.

Key points:
The bottom graphs show that in terms of cumulative temperature impacts, a unit of gas emitted of all three gases will add to the cumulative impact experienced in 2100. In the case of CO_2 and N_2O, the cumulative impact will further continue to increase beyond 2100.
Traditional greenhouse warming potentials are calculated with an approach similar to that used to calculate cumulative temperature impacts.

Greenhouse warming potentials (relative to CO_2, 100 year horizon)

Current	Adjusted
$CH_4 = 25$	$CH_4 \approx 9$
$N_2O = 298$	$N_2O \approx 298$

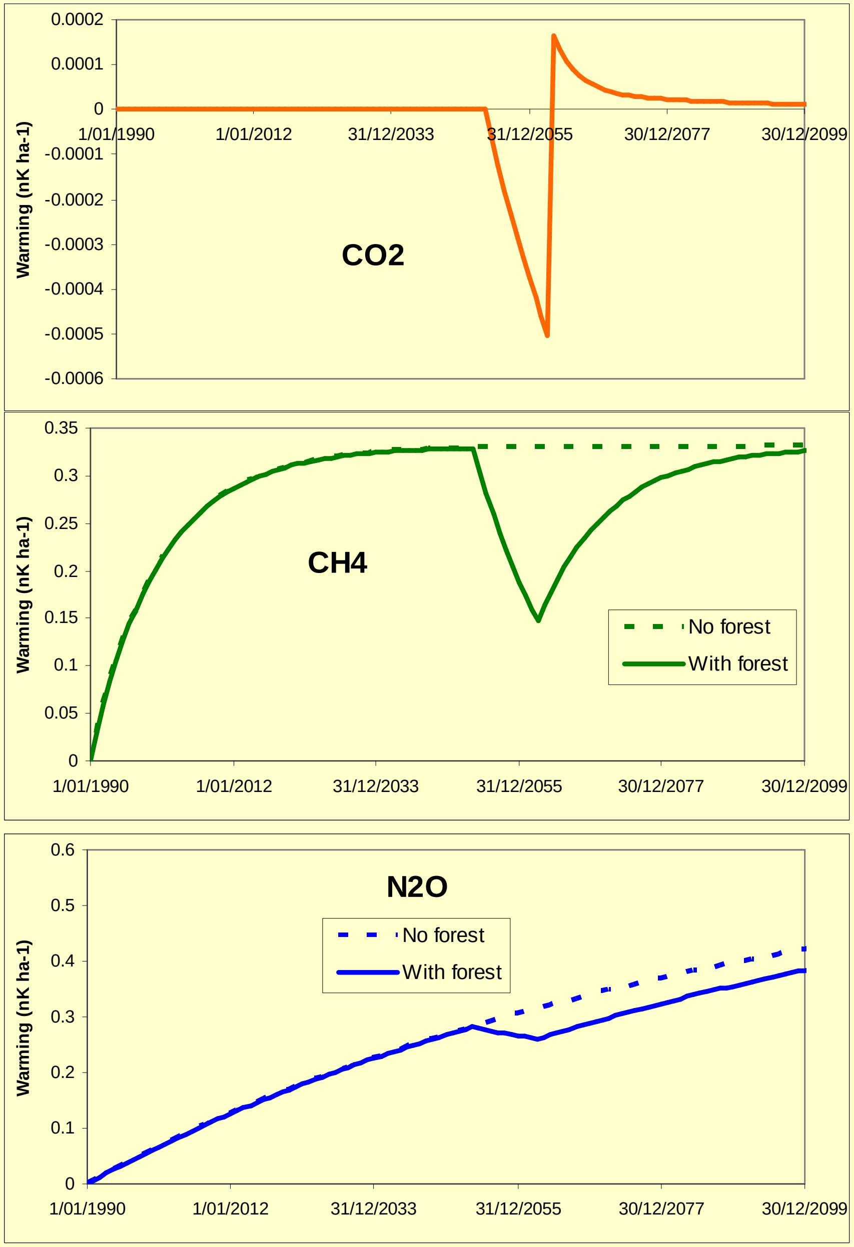
Key points:

If one

a) defines the mitigation goal to minimise the most severe climatic impacts expected to be experienced by the end of this century; and
b) gives each of the three kinds of the climatic impacts (defined above) equal weight, then
c) that would not make much difference for the quantification of N_2O relative to CO_2; but
d) it would greatly reduce the calculated (impact-weighted) warming potential of methane from 25 to about 9.

This would have significant implications for the relative importance attached to the emission of different greenhouse gases and the urgency in controlling their respective emissions. It would mean that short-term emission controls should focus primarily on the long-lived gases N_2O and CO_2, whereas emission control of methane can be given somewhat lower priority in the near term.

An example: The effect of short-term plantations



10-year plantations on pasture, cease CH_4 and N_2O emissions for 10 years; wood growth for 10 years, then harvested with immediate release of CO_2.

Key points:

This assesses the mitigation effect of planting a forest in 2050, cutting it after 10 years and thereafter immediately releasing the temporarily stored carbon.

Atmospheric CO_2 goes down while the forest is storing carbon, but after re-release of the carbon in the forest, atmospheric CO_2 is higher than it would have been without temporary storage. Hence, atmospheric CO_2 and temperature in 2100 will be higher than without the 10-year plantation.

Methane goes down while the land is under forest, but the gains are lost over the following decades. By 2100, there is only a very small benefit remaining.

The N_2O concentration falls while land is under forest, and the gain is maintained to 2100 and beyond.

Conclusions

- CO_2, CH_4, N_2O are of comparable significance under LUC
- Albedo changes are opposite in their effect to that of greenhouse gases by (≈10-20%)
- Impact assessment should quantify impacts in detail, esp. cumulative vs instantaneous
- The importance of methane is over-rated.

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