Model intercomparison of idealized global deforestation experiments

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CRESCENDO

AIMES
analysis, integration, and modeling of the earth system

An idealized global deforestation experiment

Geosci. Model Dev., 9, 2973–2998, 2016
www.geosci-model-dev.net/9/2973/2016/
doi:10.5194/gmd-9-2973-2016

Geoscientific Model Development

The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: rationale and experimental design

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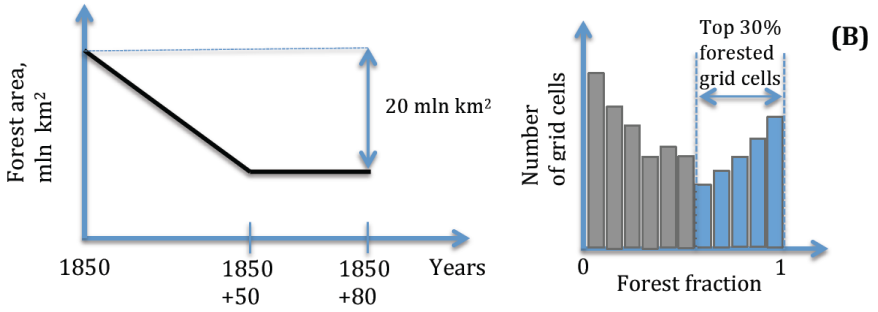
2.2.1 Global deforestation (*deforest-glob*, GCM, Tier 1, 80 years)

Description: Idealized deforestation experiment in which 20 million km^2 of forest area (covered by trees) is converted to natural grassland over a period of 50 years with a linear rate of 400 000 km^2 $year^{-1}$, followed by 30 years of constant forest cover (Fig. 2a). This simulation should

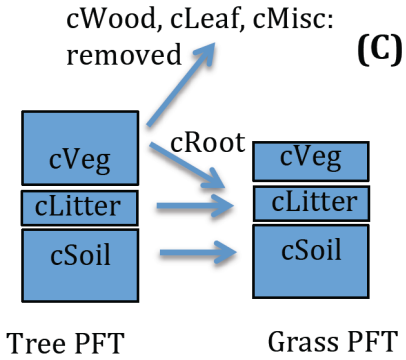
Experimental set up:

- Branching off PI-control; coupled land-atmosphere-ocean; CO_2 and land-use fixed in 1850
- **20 million km² of forest linearly removed over 50 years** (historically: ~10 mio km²)
- Only from 30% most forested grid cells (→ same pattern across models)
- Replacement by natural grass land; removal of above-ground carbon
- Dynamic vegetation switched off
- At least 30 years of stabilization → ≥ 80 yrs



Novelty

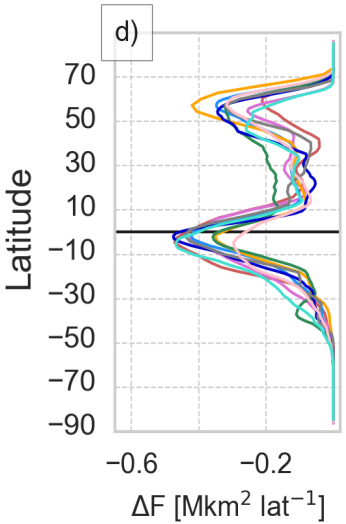
- Straightforward implementation
  → comparability of models
- Robust detection: strong deforestation signal (> historical or RCP)
  → Similar to 1%/yr CO_2 experiments
- Transient simulations
  → signal over time
- Biogeophysical and carbon cycle effects in one run

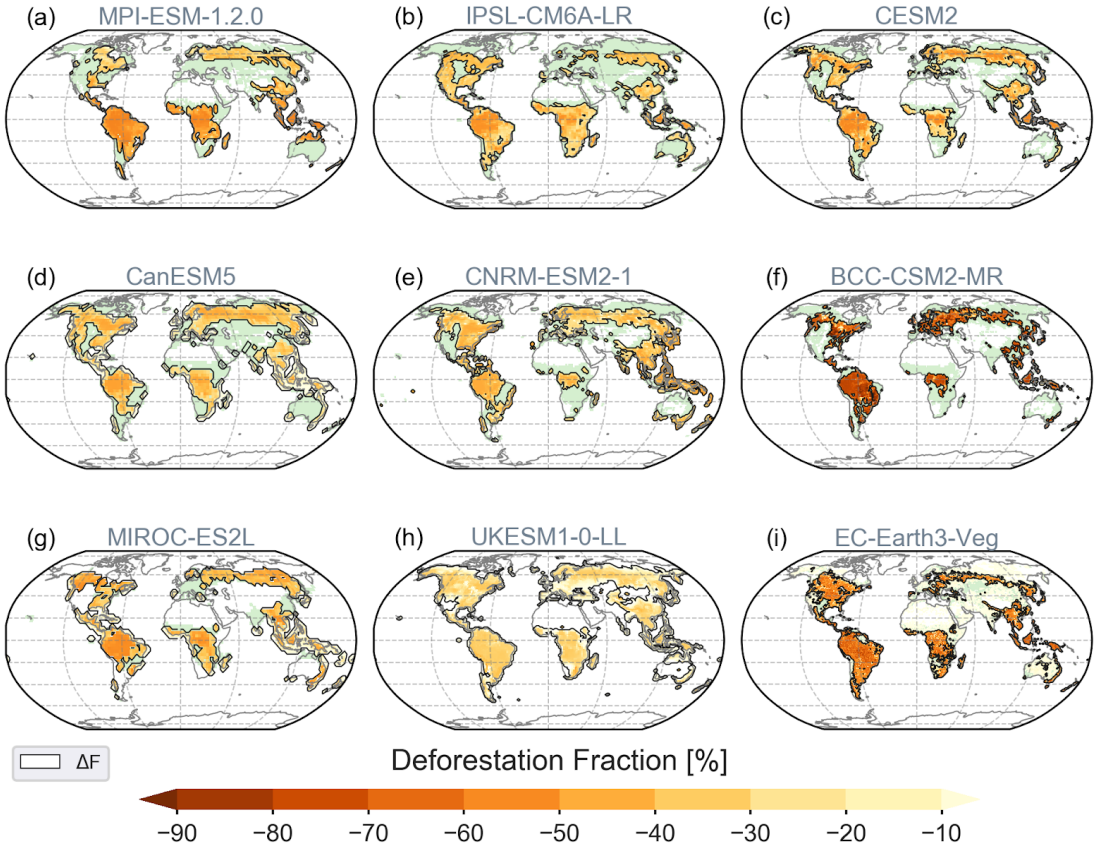


Model	MPI-ESM1.2-LR	IPSL-CM6A-LR	CESM2	BCC-CSM2-MR	CNRM-ESM2-1	CanESM5	MIROC-ES2L	EC-Earth3-Veg	UKESM1-0-LL
years	150	80	80	80	80	90	150	80	80
realizations	7	3	3	1	1	1	1	1	1

Deforested fraction

Predominantly tropical deforestation; second peak in boreal region





Initial forest area: 36 - 66 10^6 km^2

Model	Initial forest cover [Mkm^2]
MPI	48.15
IPSL	56.25
CESM	46.98*
CNRM	66.39*
BCC	35.96*
CanESM	56.48
UKESM	45.53
EC-Earth	37.75
MIROC	40.86
Model mean	48.26

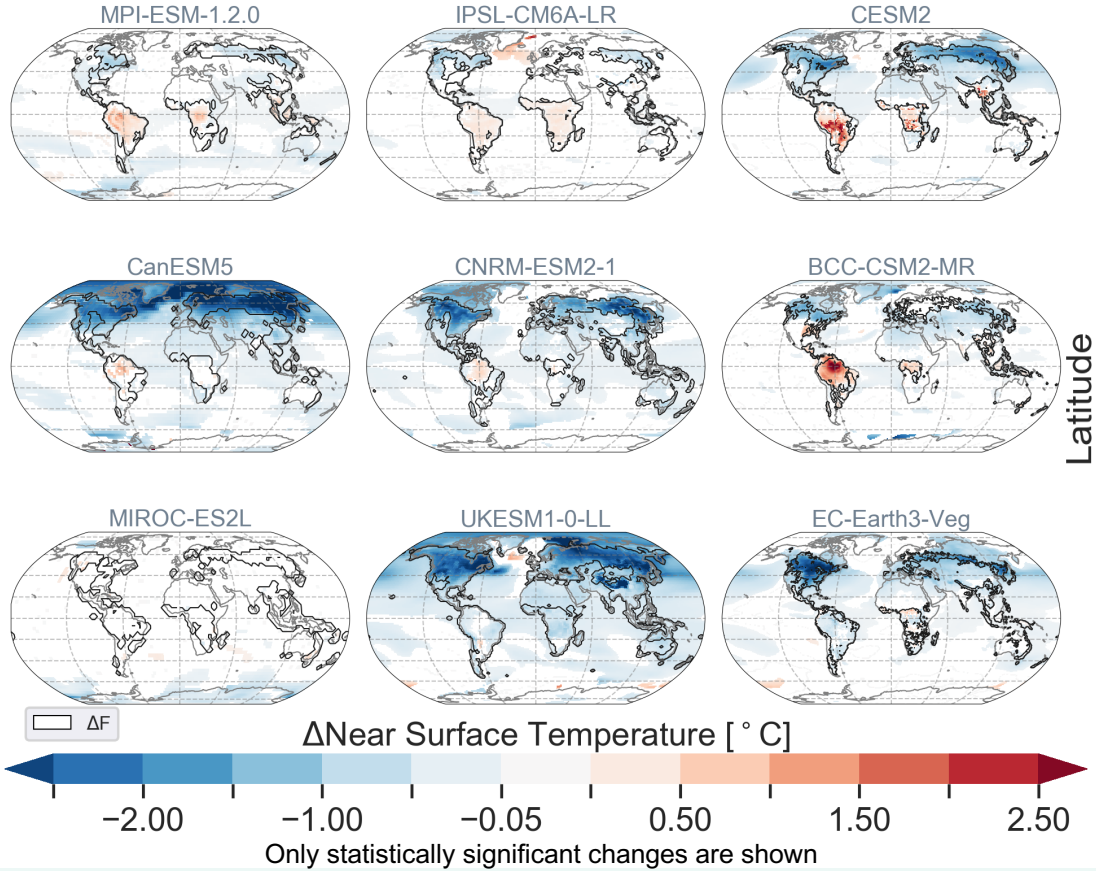
Temperature response to deforestation (last 30 years)

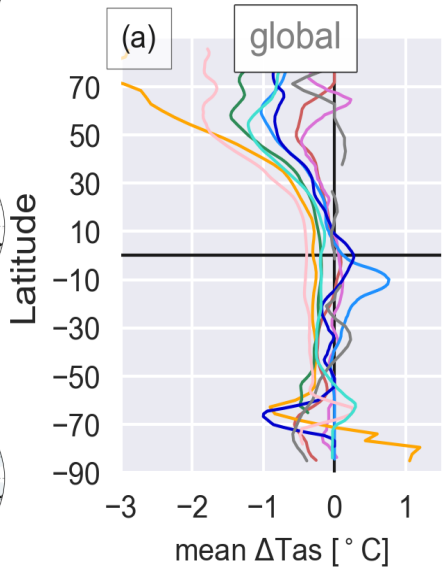
Generally, no surprises:

- Extratropical cooling due to albedo increase
- Tropical warming due to a reduction in evapo-transpiraion

Unexpected:

- cooling in UKESM and EC-Earth, also over land in tropics





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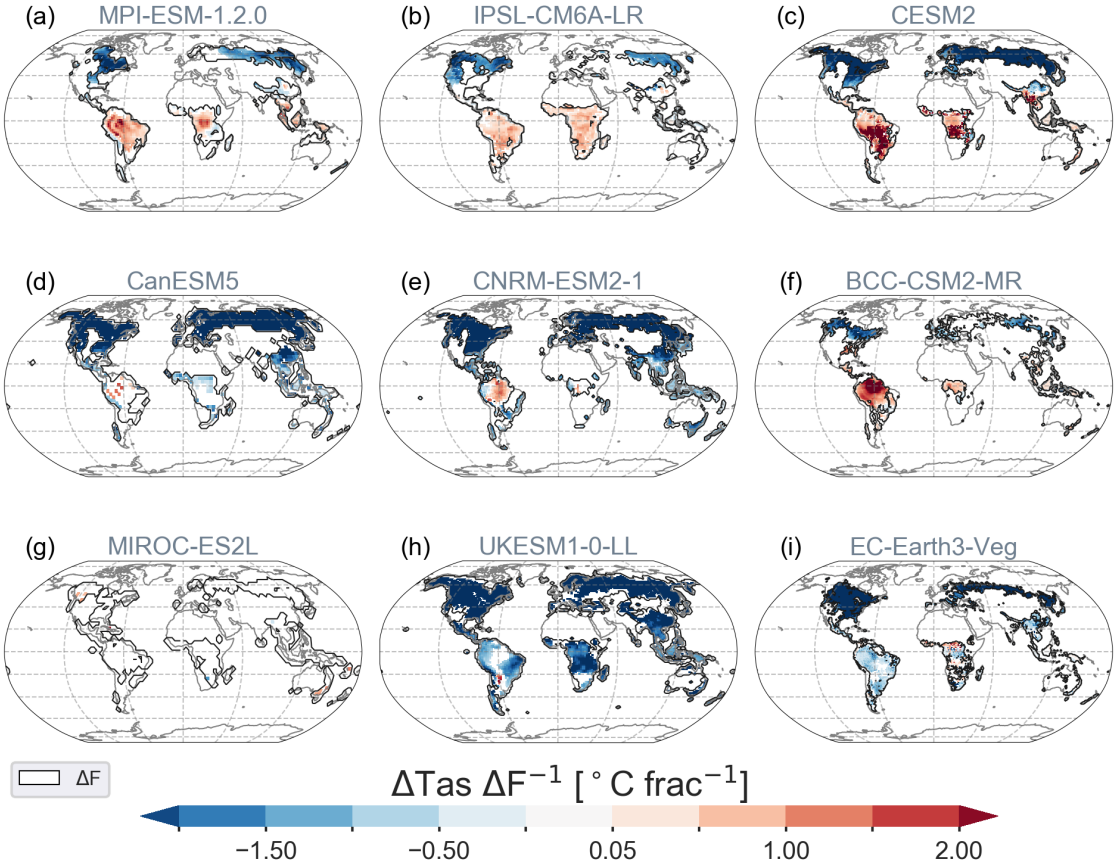
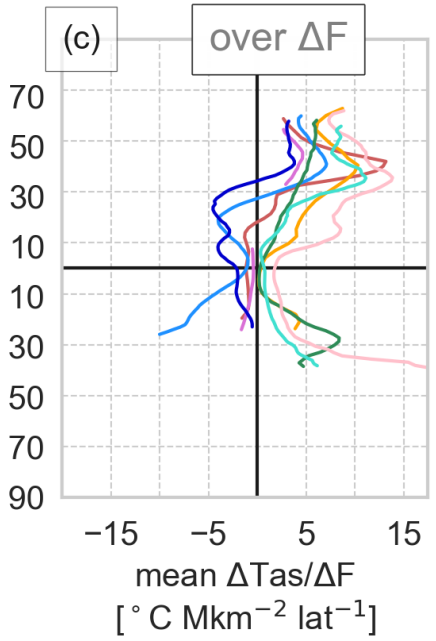
Temperature sensitivity to deforestation: ΔT/ΔF

Changes in Tas per unit of tree fraction (ΔT/ΔF): if universal, could be used for any landuse change scenario

A complication: Mixed local and non-local effects

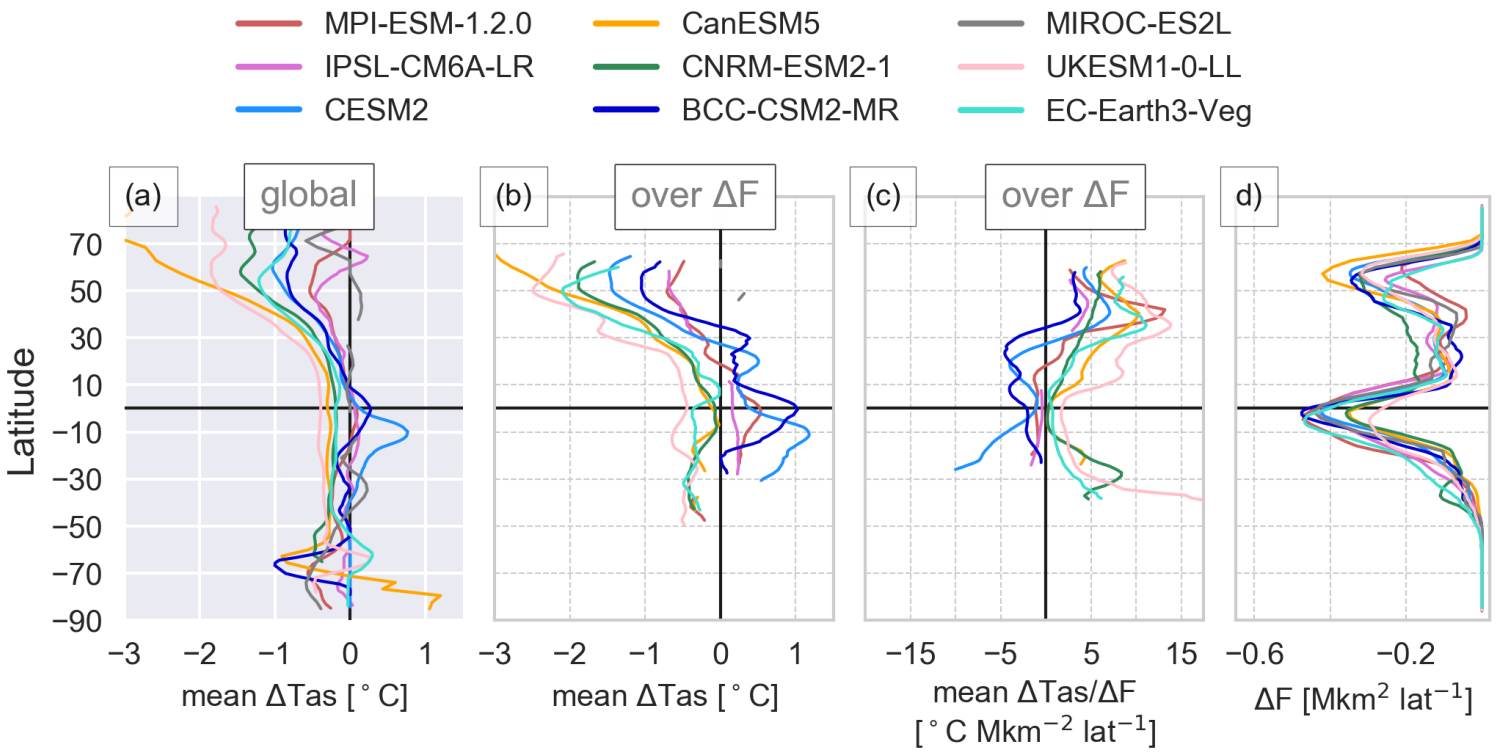




Zonal changes in temperature & zero latitude

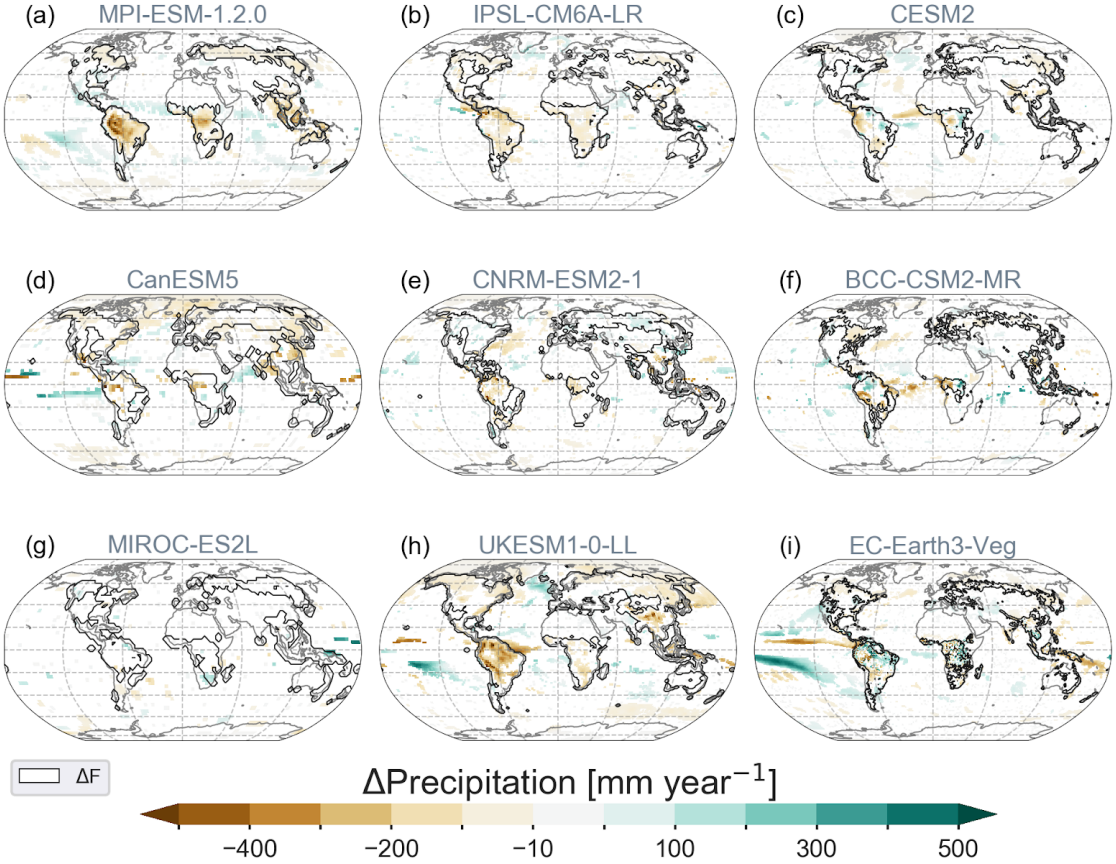
Model	Zero lat
MPI	17.7°N
IPSL	11.4°N
CESM	26.9°N
BCC	34.2°N

Zero Latitude: Latitude of ΔT sign changes in Northern Hermisphere



Precipitation response to deforestation

Reduction of hydrological cycle in tropics: transpiration of grasses < forests in tropics (exc. BCC and EC-Earth)



Only statistically significant changes are shown

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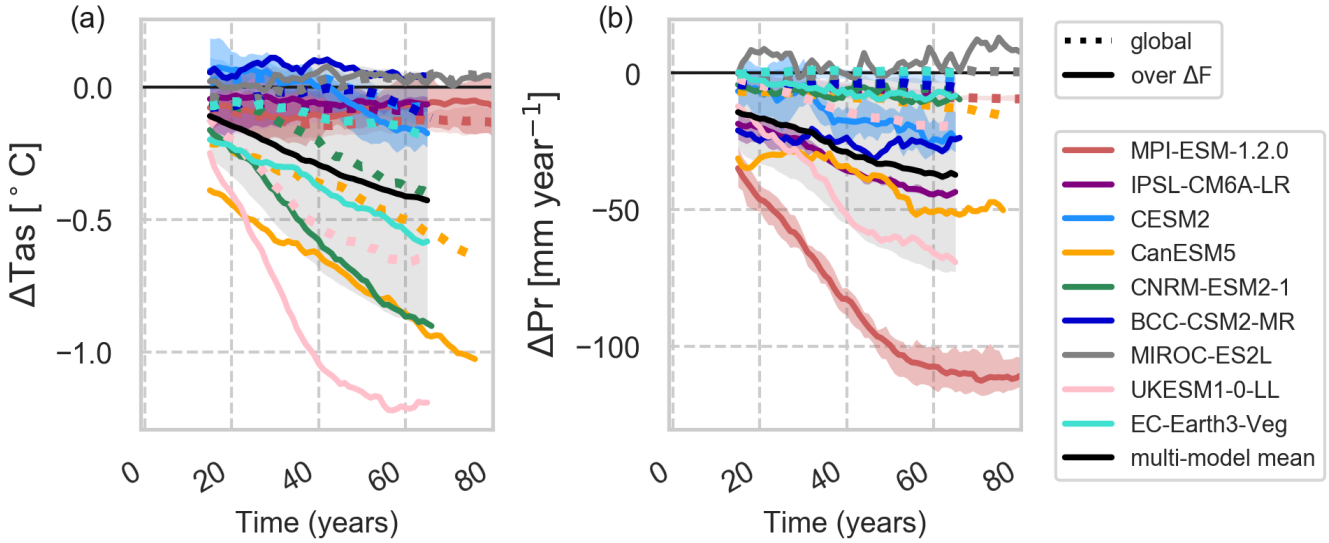
Biogeophysical effects in time (30-yr mov. average)



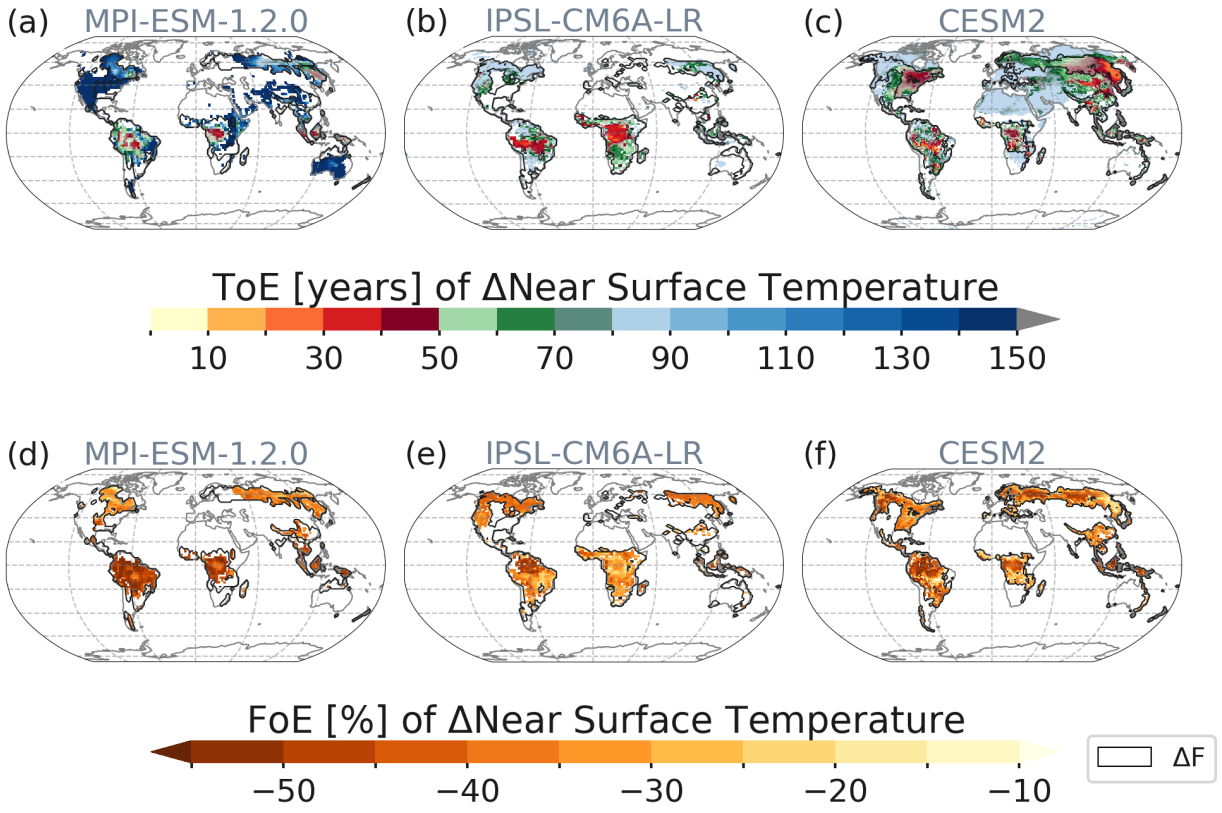
Different amplitude of cooling response, linear trend

When do changes emerge (ensemble mode)?

Time/fraction of emergence:
When is the signal > noise?

(mean of trends) > (1 σ of trends)

- "Time of emergence": within 50 years over the strongly deforested tropical regions
- The signal propagates from the centre of deforestation to the edges
- The "fraction of emergence" is more similar among the models than the "time of emergence"



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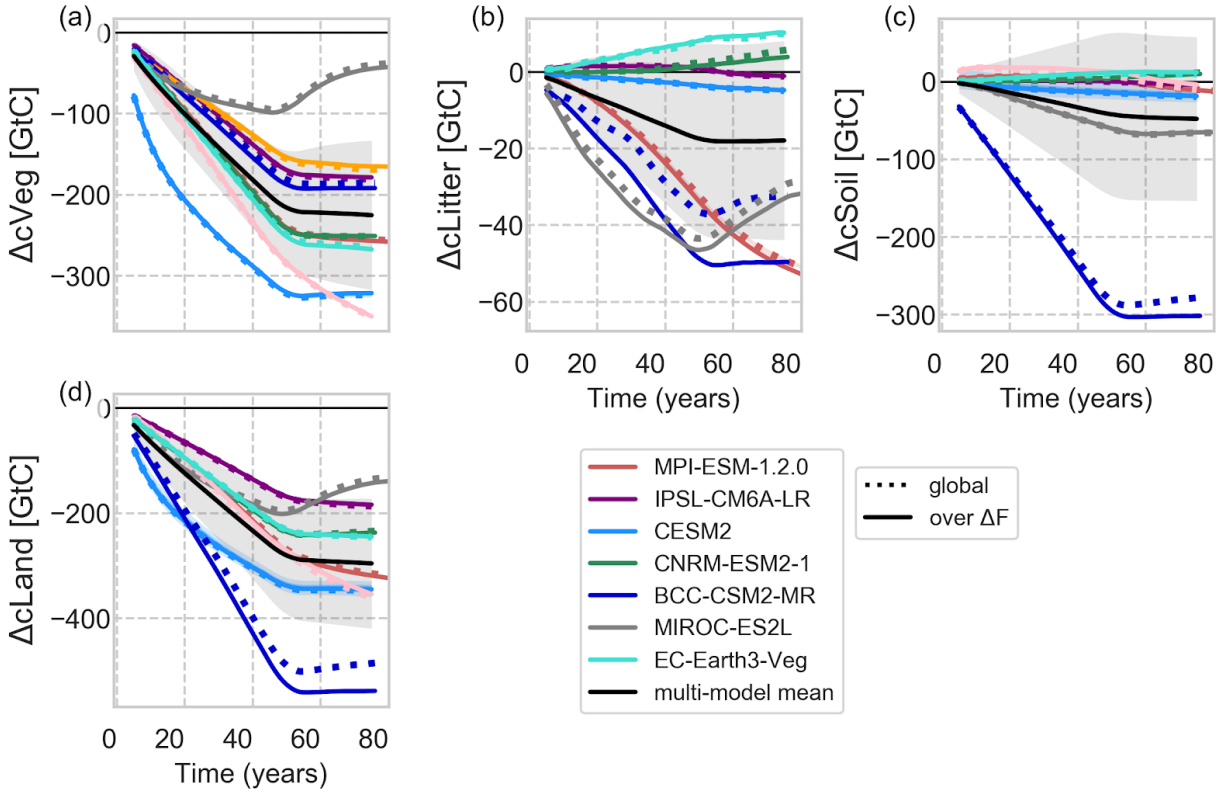
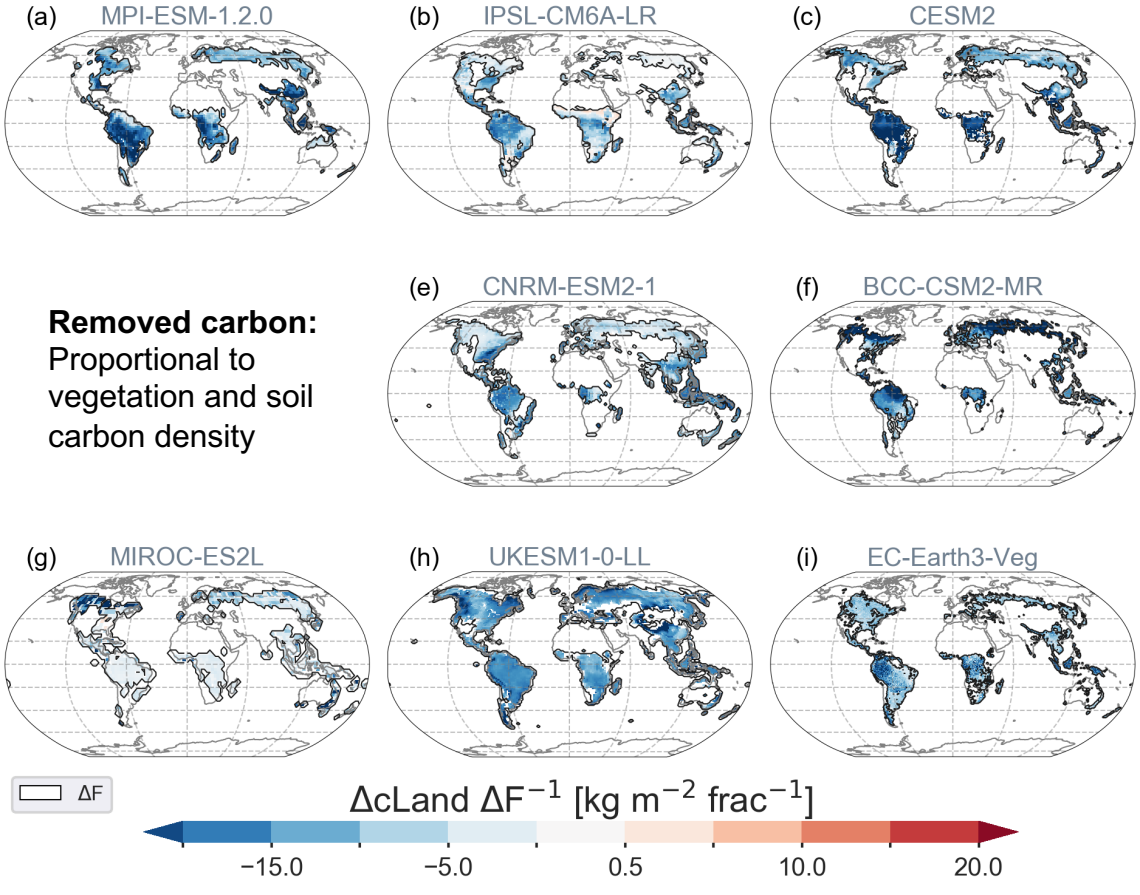
Carbon cycle response

- MPI: continued decline due to changed litter input
- IPSL: almost only governed by cVeg
- CESM: stabilization due to productive grasses
- CNRM: Soil C increase
- BCC: strongest C decrease
- multi-model mean of land carbon decrese: 274±113 PgC



Relative changes in carbon density



Removed carbon:
Proportional to vegetation and soil carbon density

Summary & Conclusions

- The pre-industrial forest area ranges between 36 and 66 million km^2 with multi-model mean of 48.3±9.9 million km^2, close to historical reconstructions
- Most of the deforested area is in tropics, with a second peak in the boreal region. The effect on global annual near-surface temperature ranges from no significant change to a cooling by 0.55°C, with multi-model mean of -0.22±0.21°C
- Four models simulate temperature increase over deforested land in tropics and a cooling over deforested boreal land. In these models, the latitude of changing the sign of temperature response ranges from 11 to 34°N, with a multi-model mean of 23°N
- For those models that provided several ensemble members (MPI, IPSL and CESM2), the near-surface temperature changes emerge within 50 years over the tropical regions of strongest deforestation. The signal propagates from the centre of deforestation to the edges, indicating the influence of non-local effects
- The biogeochemical effect of multi-model mean of land carbon reduction by 274±113 PgC calculated offline would be a warming by 0.52±0.22°C, suggesting that the net effect of deforestation is a warming
- Sensitivities such as $\Delta T/\Delta F$, $\Delta cLand/\Delta F$ in idealized runs could be compared with variable landuse scenarios in the CMIP6 runs, providing a basis for understanding “realistic” CMIP6 simulations