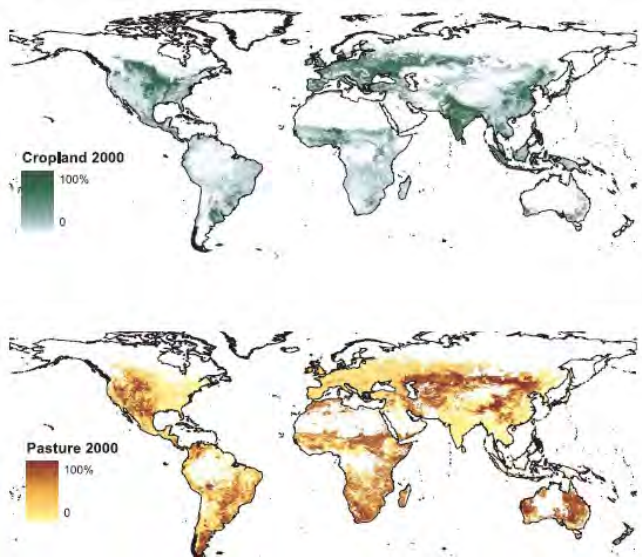
Land use radiative impact on global and regional climate

A.V. Eliseev

A.M. Obukhov Institute of Atmospheric Physics RAS

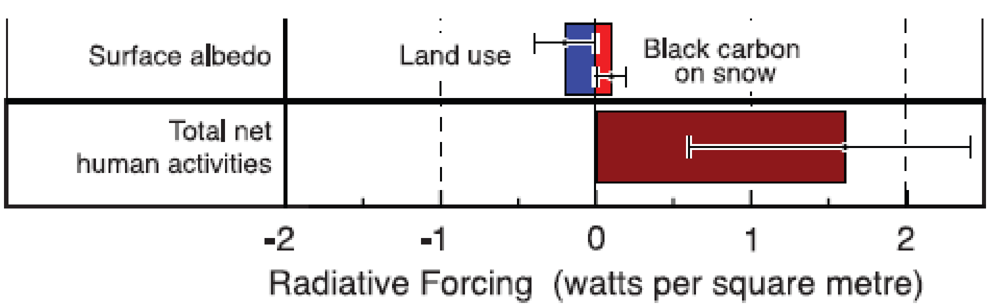
ENVIROMIS-2010

Motivation



adopted from [Ramankutty et al., 2008]

Around year 2000, about ⅓ of the ice-free land surface is covered by crops or pastures [Ramankutty et al., 2008]. Land cover transformations affect surface albedo (direct effect due to albedo differences between different vegetation types + snow masking effect), transpiration, surface roughness, etc.



adopted from IPCC AR4

According to IPCC AR4, land use leads to the shortwave radiative forcing -0.2±0.2 W/m^2 which, in general, not a negligibly small part of the total anthropogenic radiative forcing ~1.6 W/m^2 (from 0.6 W/m^2 to 2.4 W/m^2).

1. How large is the land use radiative impact on the historical climate change and to the climate changes projected for the 21st century?

Historical simulations:

- EMIC intercomparison [Brovkin et al., 2006]: cooling by 0.13-0.25 K;
- simulations with the same model (UVic ESCM) but under different set ups [Matthews et al., 2004]: cooling by 0.06-0.22 K;
- LUCID intercomparison: divergence even in the sign of the response [Pitman et al., 2009].

IAP RAS CM

Resolution: 4.5°*6°, L8 – atmosphere, L4 – ocean, L1 –land; Δt = 5 days

Atmosphere: 3D quasi-geostrophic large-scale dynamics. Synoptic-scale dynamics is parametrised as Gaussian ensembles. In any atmospheric layer, temperature depends linearly on height. Fully interactive hydrological cycle.

Ocean: Prognostic equation for sea surface temperature (SST). Geostrophic large-scale dynamics. Universal vertical profiles in any oceanic layer. Oceanic salinity is prescribed. Interactive, globally averaged oceanic carbon cycle.

Sea ice: Diagnostic, based on the local SST

Vegetation: Spatial distribution of ecozones is prescribed. Fully interactive, globally averaged terrestrial carbon cycle. Interactive CH_4 emissions from natural wetlands.

Turnaround time: ~ 6 sec per model year (Intel Core Quad 2.2 GHz)

Land surface albedo

Direct effect:
Surface albedo depends on vegetation type (natural/agricultural; for natural vegetation albedo is biome-dependent).

Snow masking:
Forested vegetation may partly mask snow. Degree of this masking in the model is controlled by parameter $0 \le k_{alb,snow} \le 1$:

$k_{alb,snow} = 0$ → $\alpha_s = \alpha_{trees}$ → perfect masking;

$k_{alb,snow} = 1$ → $\alpha_s = \alpha_{snow}$ → no masking.

Simulations

Duration: 1500-2100

SRES*yyy* (*yyy* = B1, A1B, A2):

- historical + Special Report on Emission Scenarios anthropogenic CO_2 and CH_4 emissions;
- historical + SRES atmospheric concentrations of N_2O, CFC-11, CFC-12 (BernCC), and tropospheric sulphates (MOZART 2.0);
- historical variations of stratospheric aerosol loading and total solar irradiance;

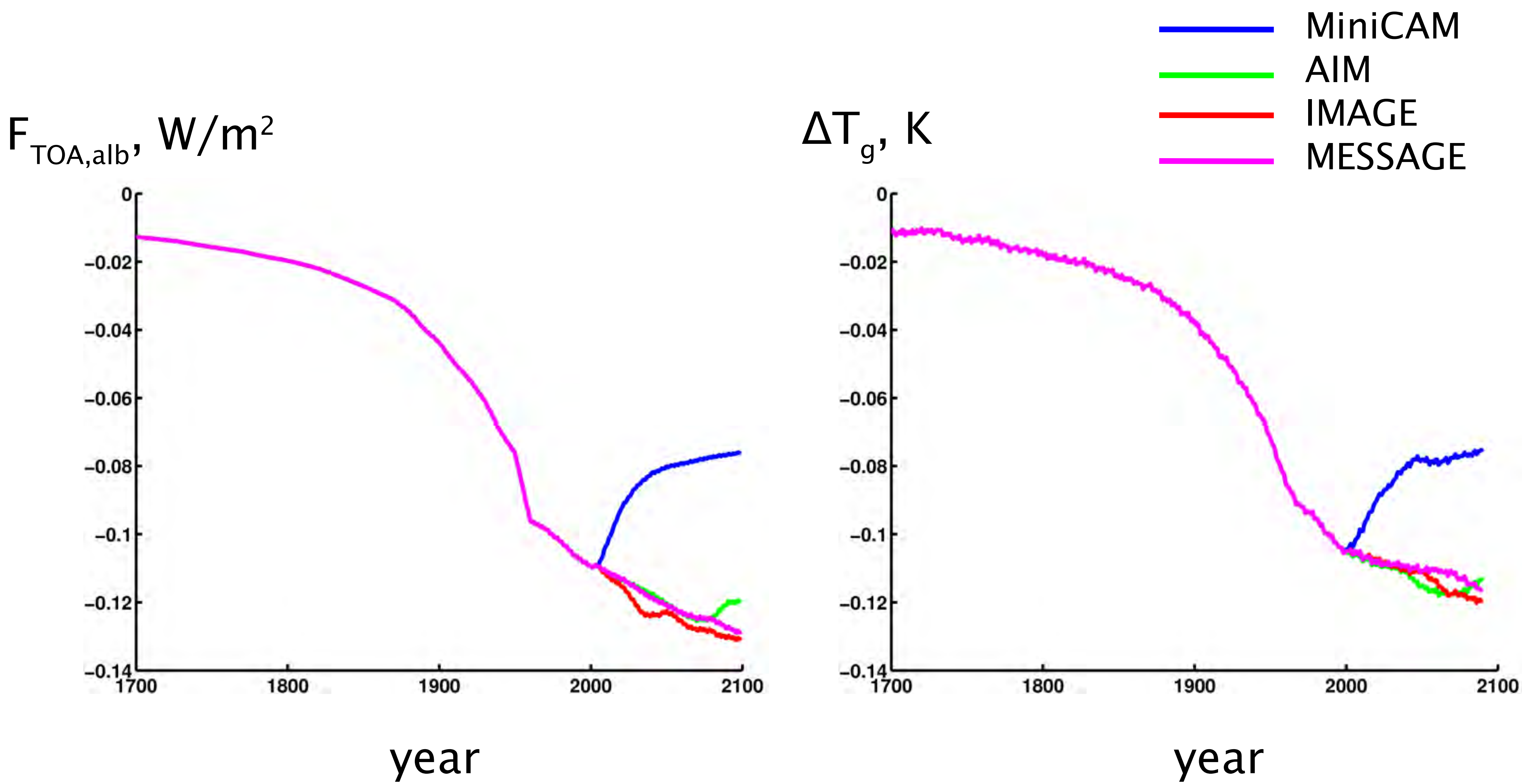
LUH*zzz* (*zzz* = MiniCAM, AIM, IMAGE, MESSAGE):

- historical (HYDE 3.1)+Land Use Harmonization extent of crops and pastures;

SRES*yyy* -LUH*zzz*: SRES*yyy* + LUH*zzz;*

For every simulation, 3 realisations are constructed with different initial conditions selected from the preanthropogenic simulation. Only ensemble means are studied.

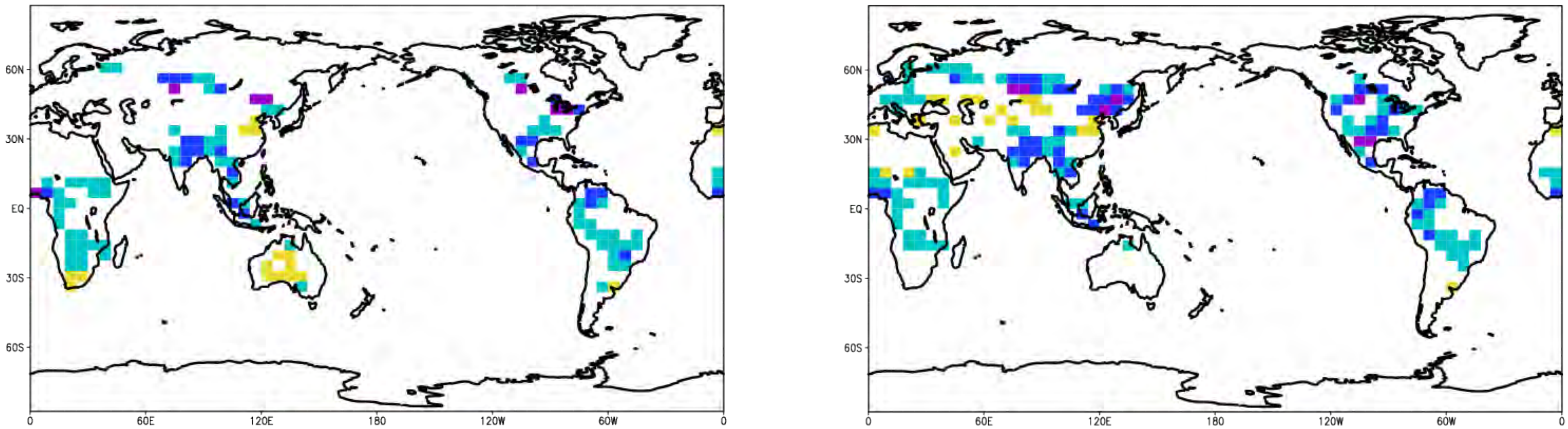
Top-of-the atmosphere instantaneous radiative forcing due to land use and climate response in LU-only simulations



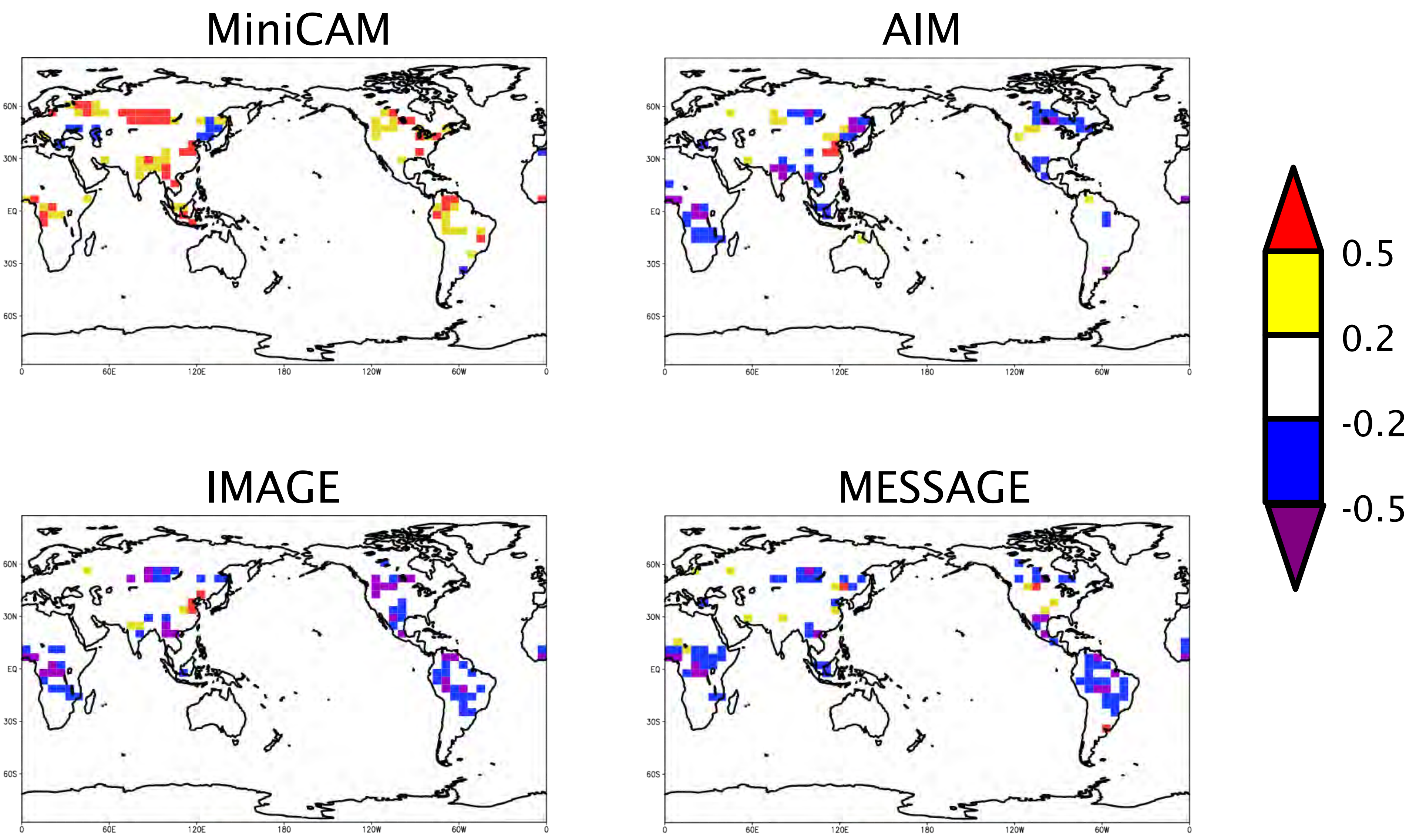
Top-of-the atmosphere instantaneous radiative forcing [W/m²] due to land use: 1990-2000 relative to preanthropogenic state

January

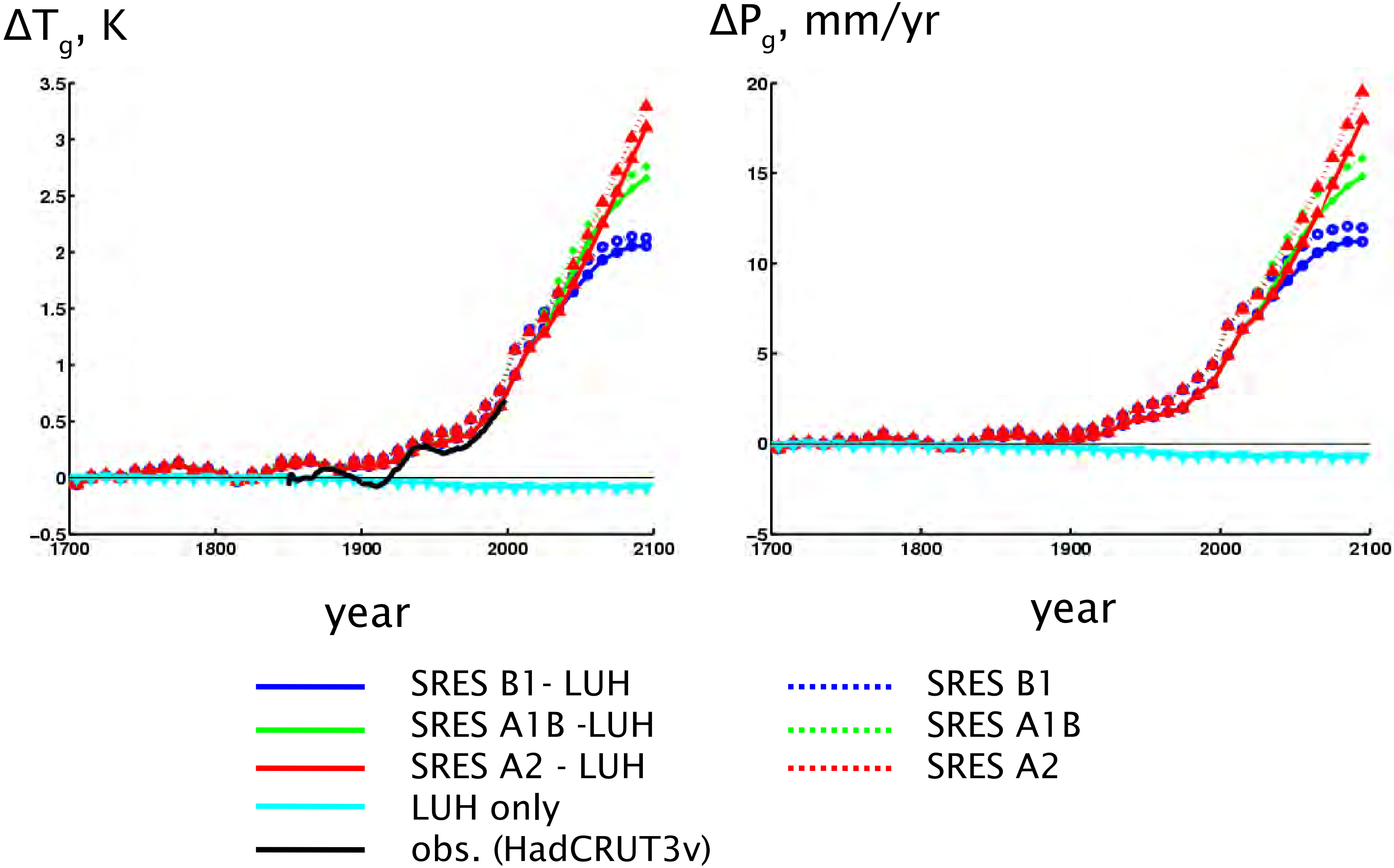
July



Top-of-the atmosphere instantaneous radiative forcing [W/m²] due to land use: 2090-2100 relative to 1990-2000, July

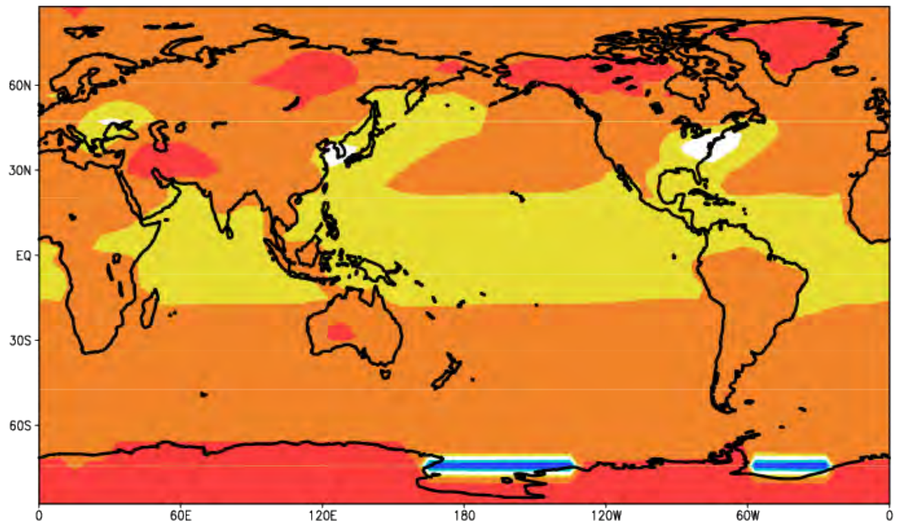


Global annual mean response averaged over all LUH scenarios

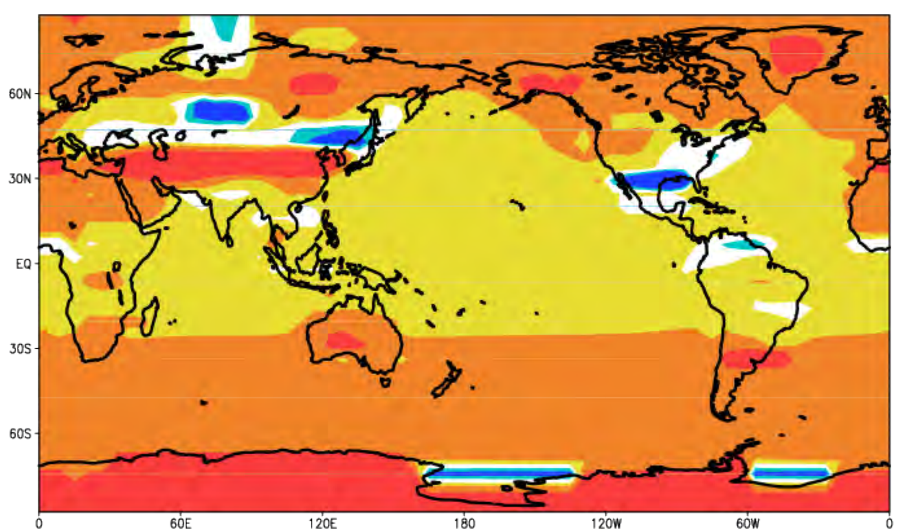


20th century surface air temperature change [K]

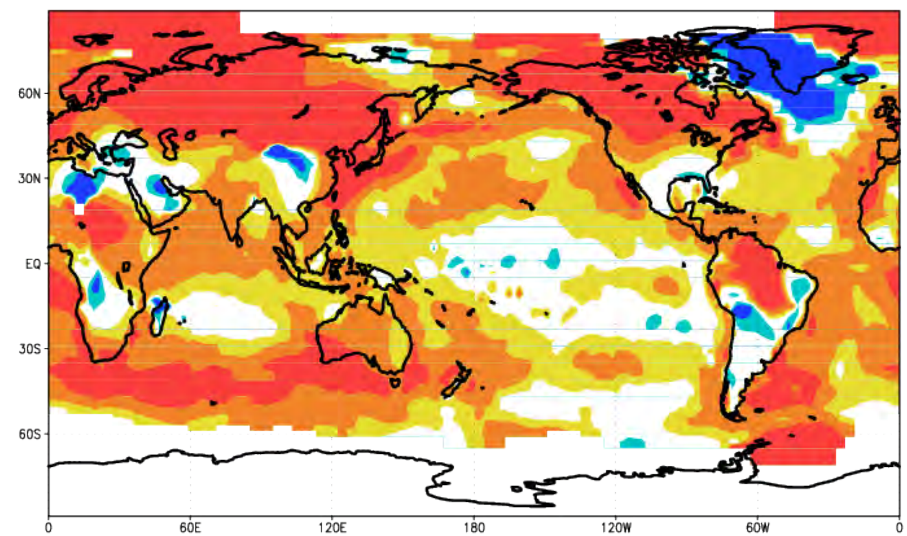
SRES

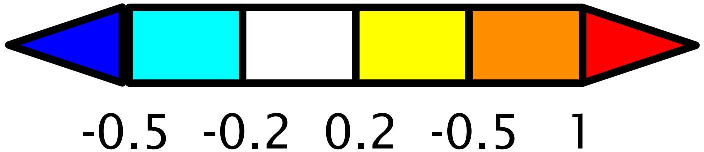


SRES-LUH



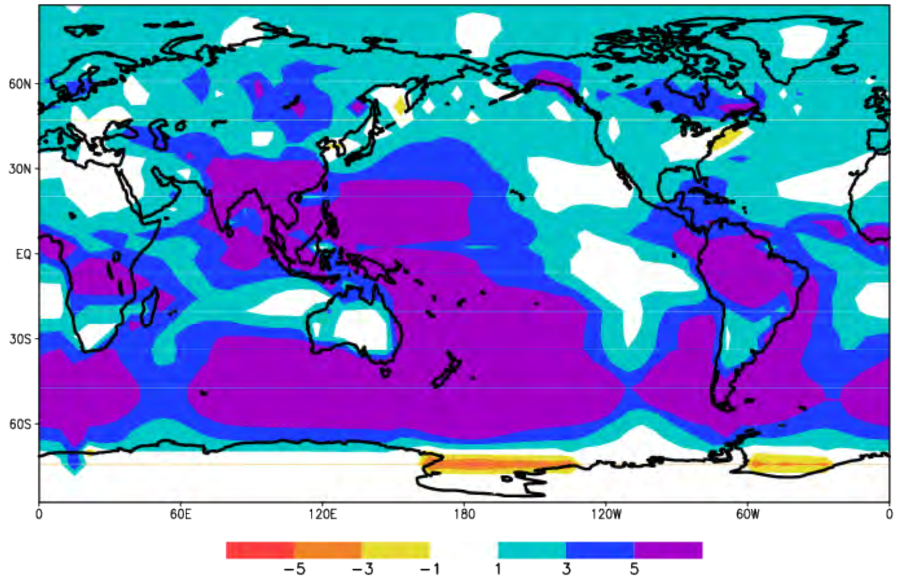
observed
(GISS analysis data)



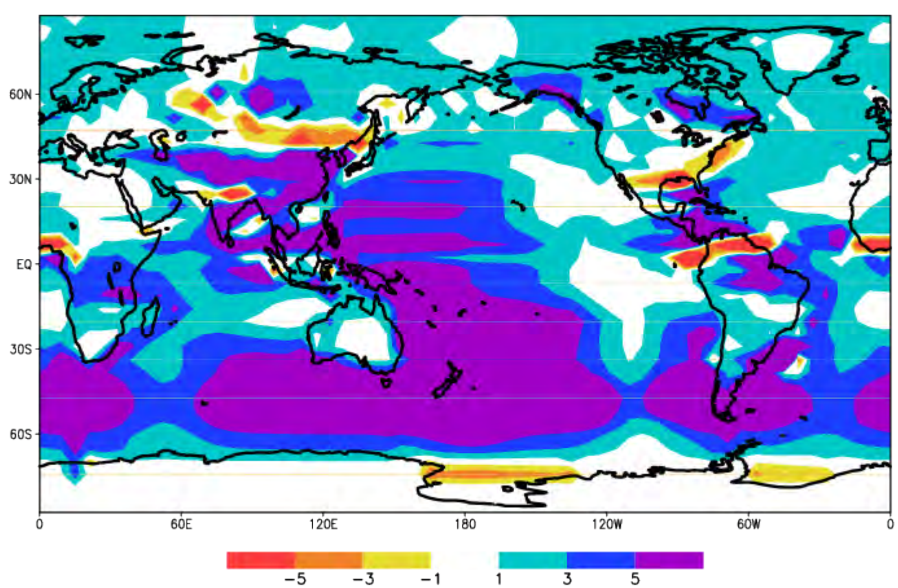


20th century annual precipitation change [cm]

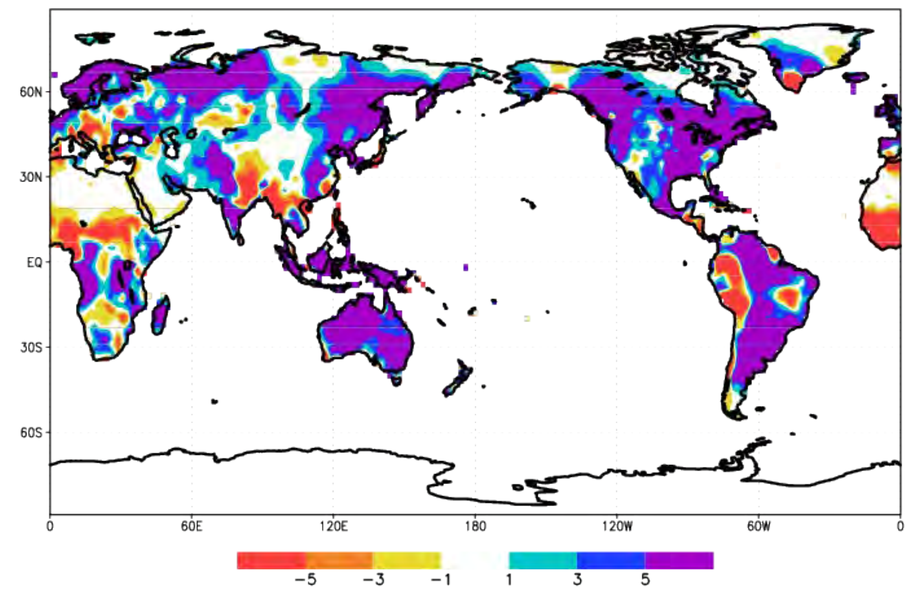
SRES

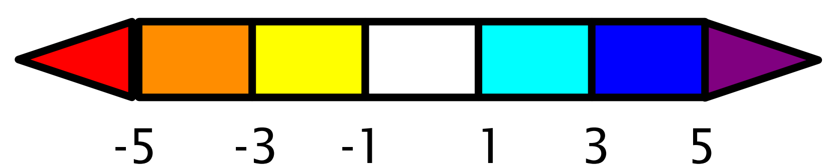


SRES-LUH

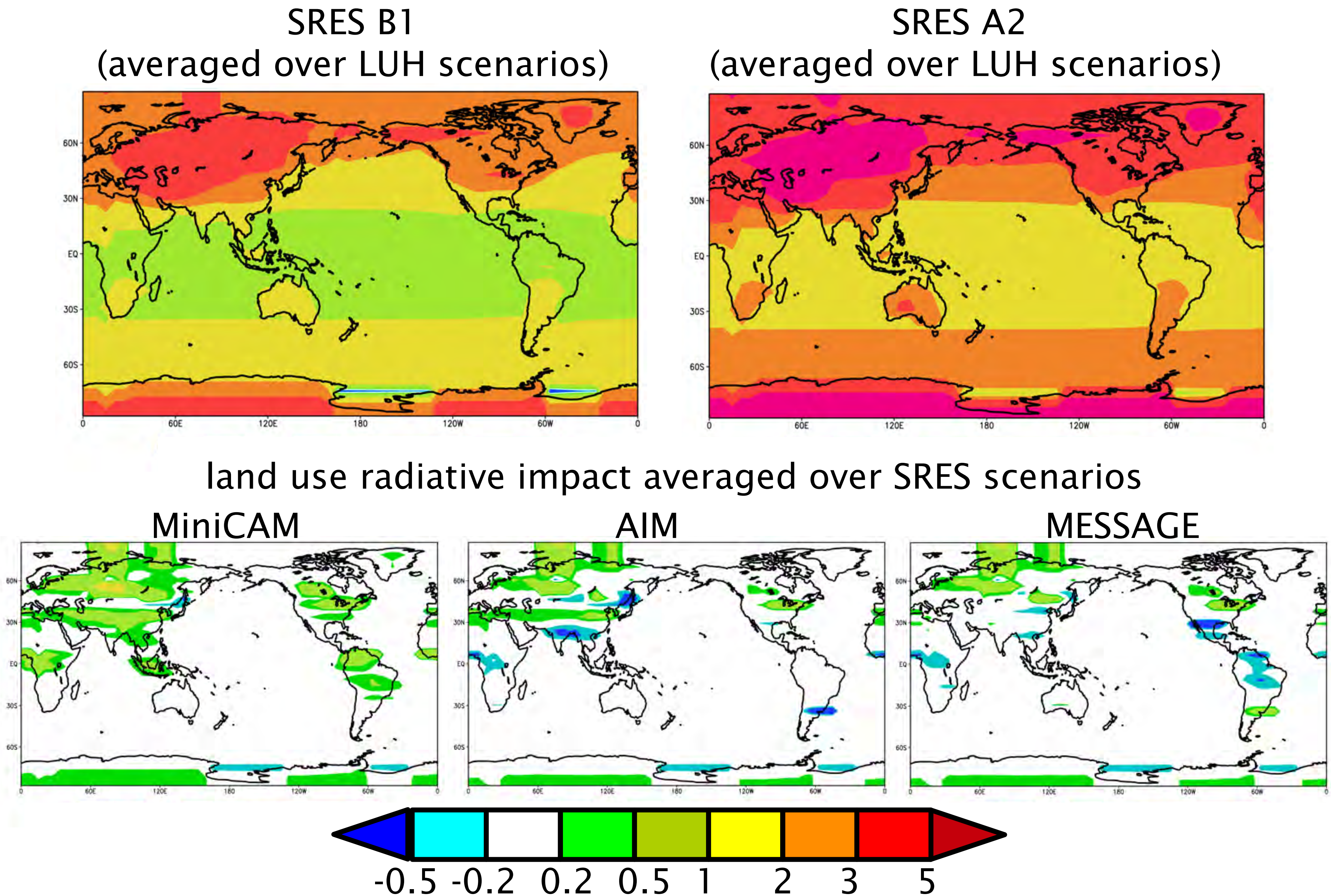


observed
(UEA CRU analysis data)





21st century surface air temperature change [K]



2. What is more important under realistic land use scenarios: direct change of albedo due to replacement of natural vegetation by crops/pastures or suppression of snow masking?

Ensemble numerical experiments with the IAP RAS CM

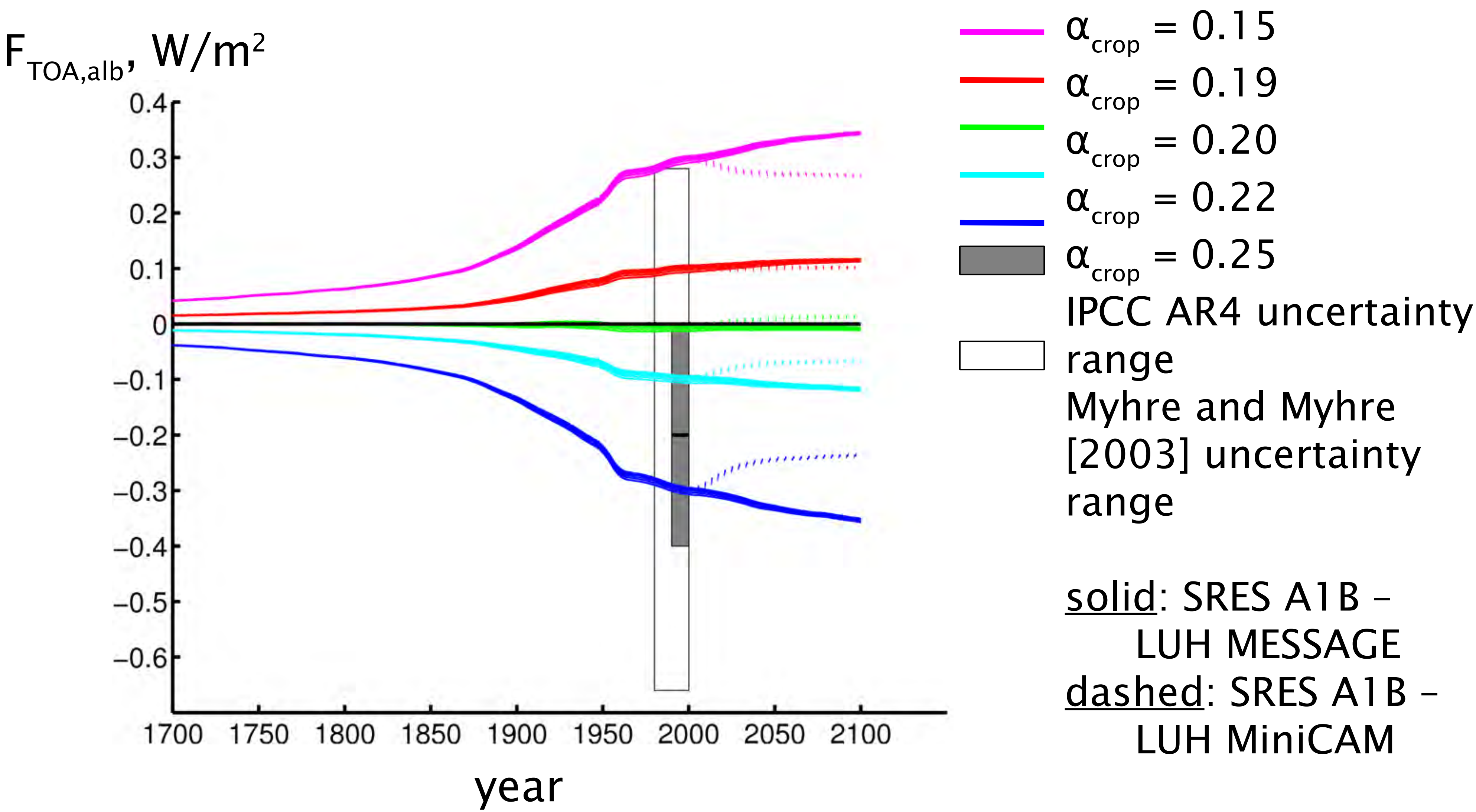
External forcing:

SRES A1B anthropogenic scenario;
land use scenarios LUH MiniCAM and MESSAGE.

Individual ensemble members are constructed by varying two governing parameters of the IAP RAS CM relevant for land use:

- crop albedo α_{crop} for the fully developed leaf area: from 0.15 to 0.25 (in the standard version of the IAP RAS CM $\alpha_s = 0.22$);
- parameter $k_{alb,snow}$ regulating intensity of snow masking: from 0 (no masking) to 1 (perfect masking; standard version of the IAP RAS CM)

Dependence of the top-of-the-atmosphere radiative forcing on the governing parameters of the IAP RAS CM

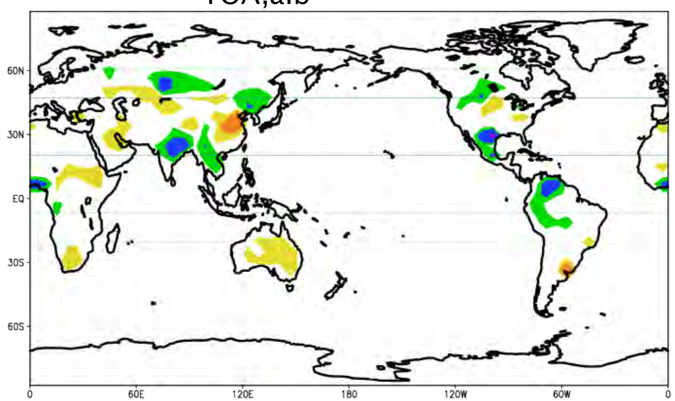


solid: SRES A1B – LUH MESSAGE

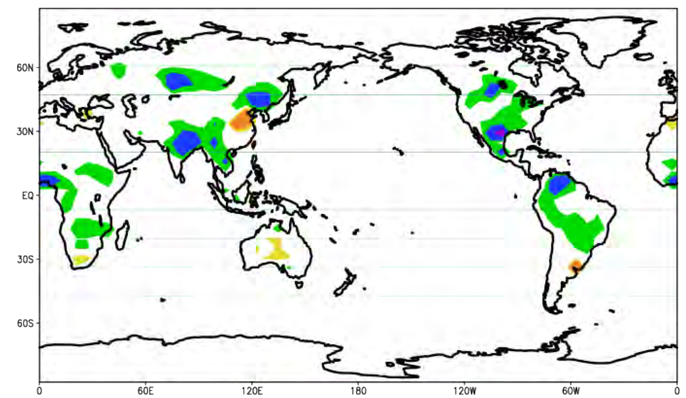
dashed: SRES A1B – LUH MiniCAM

Annual mean radiative forcing [W/m^2] due to land use

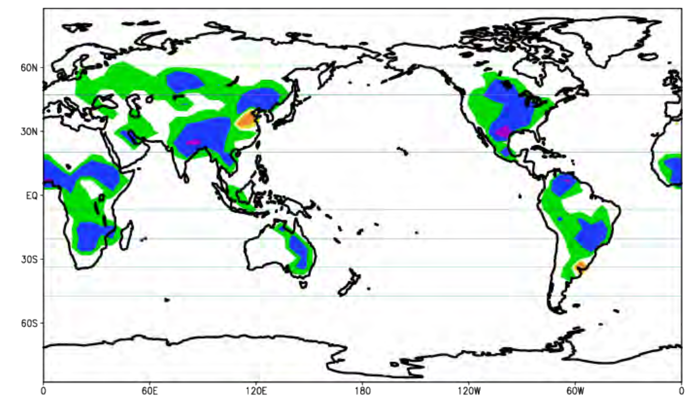
$\alpha_{crop} = 0.20$
$F_{TOA,alb}(2000) \approx 0$



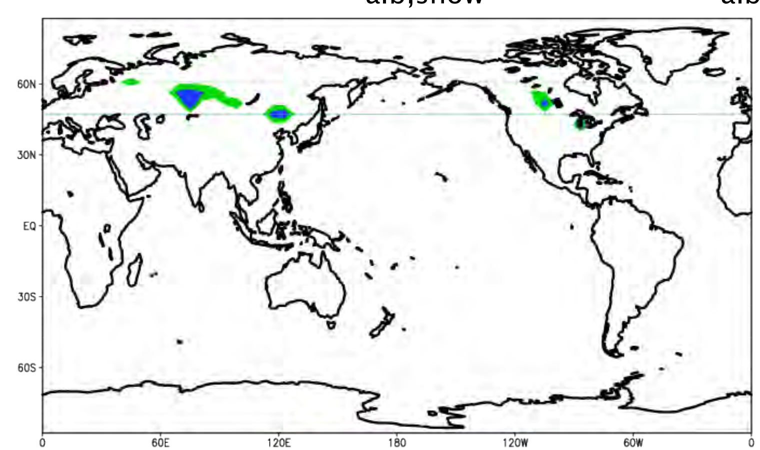
$\alpha_{crop} = 0.22$
$F_{TOA,alb,g}(2000) = -0.11\ W/m^2$

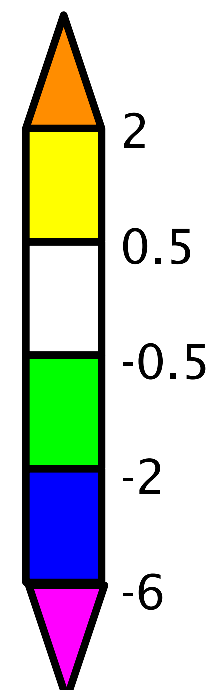


$\alpha_{crop} = 0.25$
$F_{TOA,alb,g}(2000) = -0.33\ W/m^2$



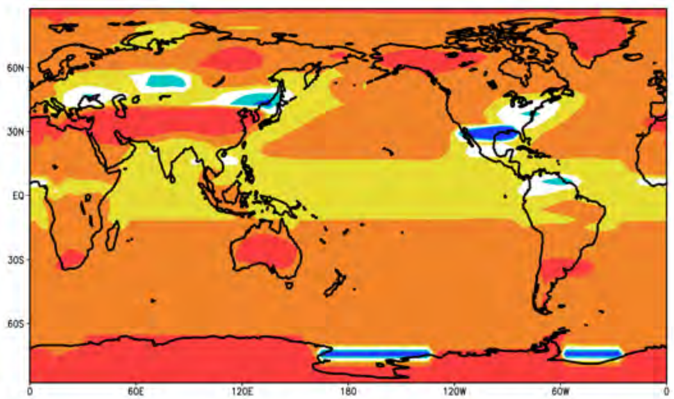
$\alpha_{crop} = 0.22$,
difference between $k_{alb,snow} = 1$ and $k_{alb,snow} = 0$



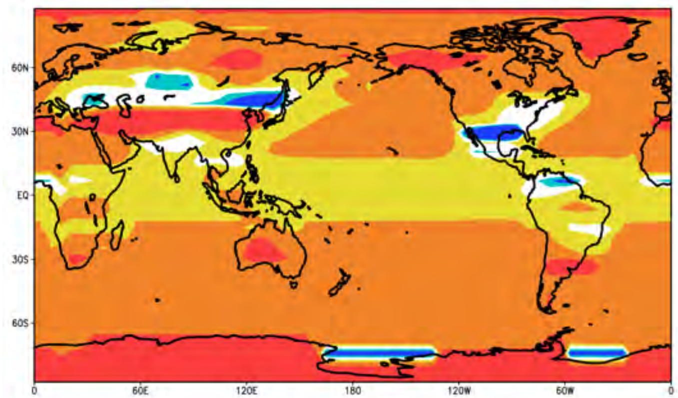


Annual mean surface air temperature trend during the 20th century [K/century]

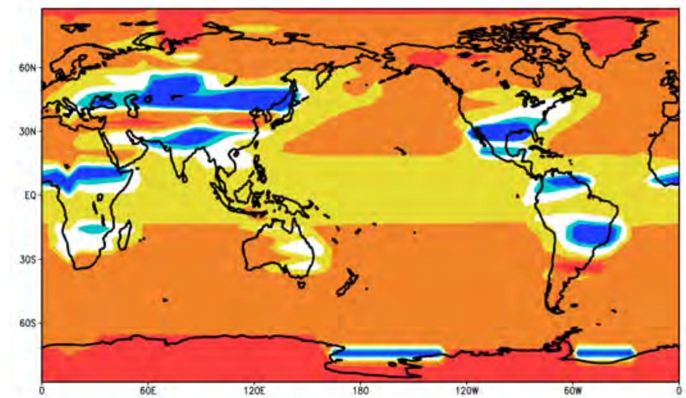
$\alpha_{crop} = 0.20$
global: 0.66 K/century



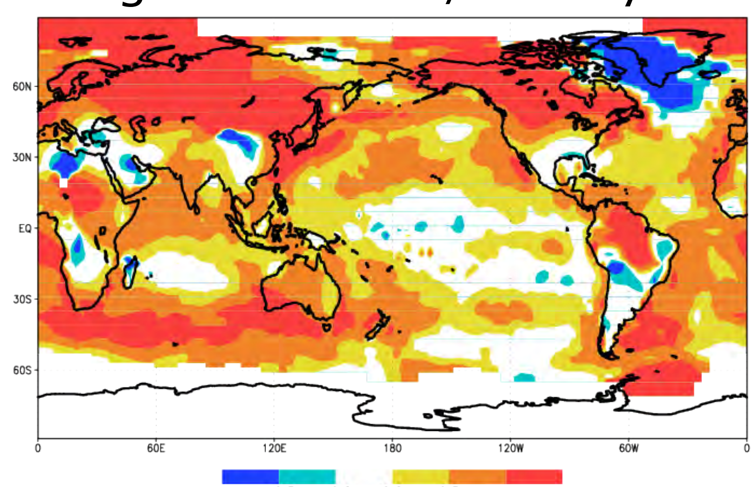
$\alpha_{crop} = 0.22$
global: 0.61 K/century

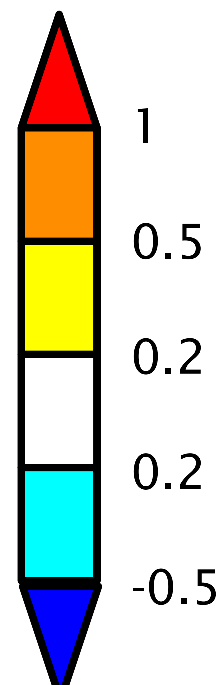


$\alpha_{crop} = 0.25$
global: 0.48 K/century

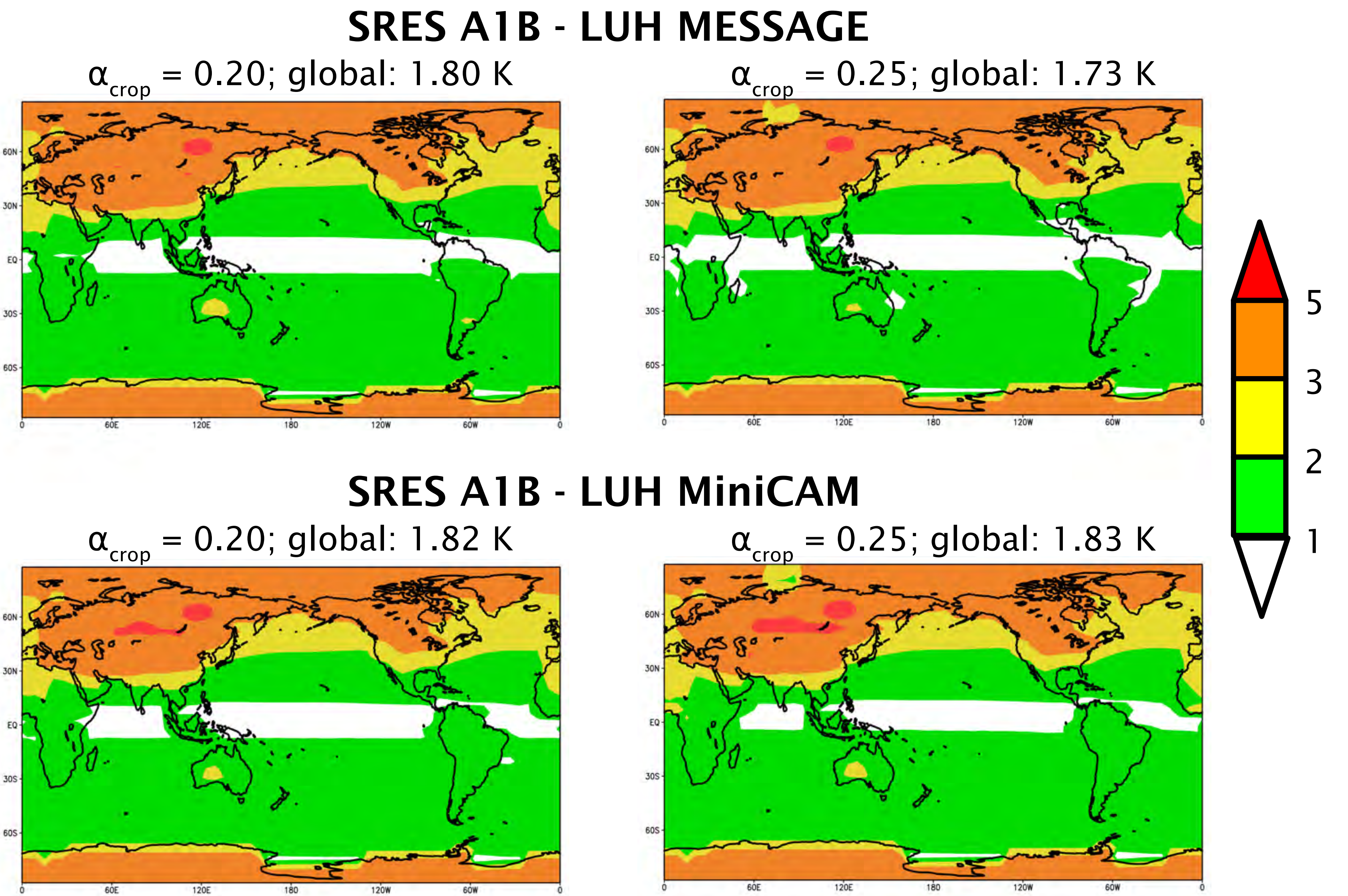


observed (GISS analysis)
global: 0.62 K/century





Annual mean surface air temperature change during the 21st century [K]



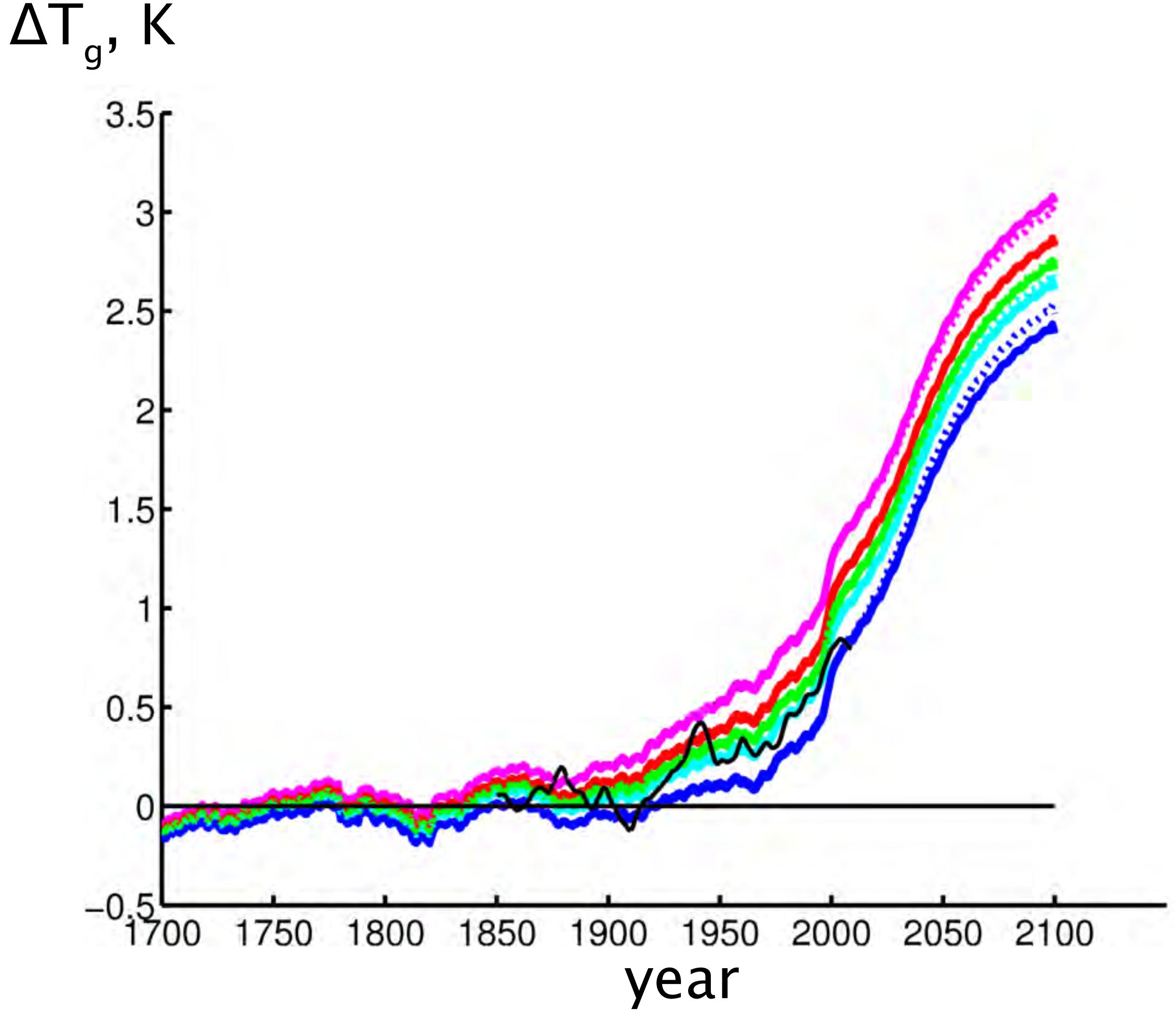
Conclusions

- Radiative impact of land use is important for the observed decrease of temperature and precipitation in regions of intensive contemporary extension of agriculture. Globally, albedo change due to land use may account for 0.03 K of cooling in the 18-19th centuries. In addition, land use slows down the 20th century warming by ~0.07 K.

- In the IAP RAS CM, vegetation affects albedo basically through different albedo values for different biomes. However, snow masking is important regionally.

- In the 21st century the radiative impact of land use activity under the LUH scenarios is, at least, smaller by one order of magnitude than the warming projected under the SRES anthropogenic scenarios. This is valid for broad range of variations of crops albedo and parameter of snow masking intensity.

Dependence of the global surface air temperature response on the governing parameters of the IAP RAS CM



α_{crop} = 0.15
α_{crop} = 0.19
α_{crop} = 0.20
α_{crop} = 0.22
α_{crop} = 0.25
obs. HadCRUT3v

solid: SRES A1B – LUH MESSAGE
dashed: SRES A1B – LUH MiniCAM

General structure of the IAP RAS CM