Uncertainty of climate and carbon cycle changes in the 21st century due to uncertainty in values of governing parameters for terrestrial biota: A Bayesian assessment

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Basic question:

How large the observational-constrained uncertainty in the 21st climate-carbon cycle projections could be due to uncertainty in values of governing parameters of terrestrial carbon cycle?

Note: This is not a complete assessment of uncertainty because model's parameters directly affecting equilibrium and transient climate sensitivity are not sampled.

IAP RAS CM

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

Atmosphere: 3D quasigeostrophic large-scale dynamics. Synoptic-scale dynamics is parameterised based on their representation as Gaussian ensembles. In any atmospheric layer, temperature depends linearly on height. Fully interactive hydrological cycle.

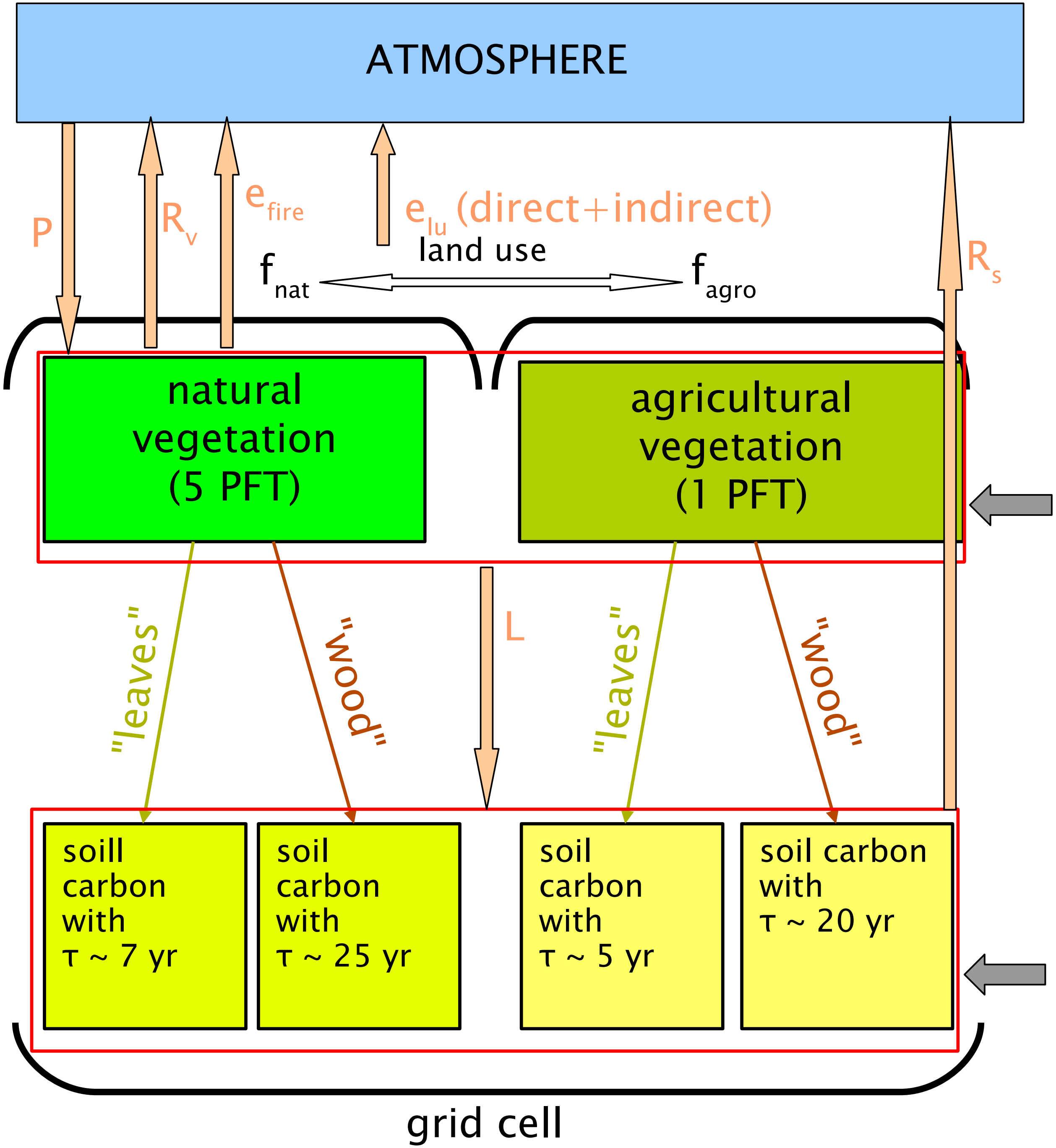
Ocean: Prognostic equation for sea surface temperature. Geostrophic large-scale dynamics. Universal vertical profiles in any oceanic layer. Oceanic salinity is prescribed. Interactive oceanic carbon cycle.

Sea ice: Diagnostic, based on the local SST

Vegetation: Spatial distribution of ecozones is prescribed. The PFT-based, spatially explicit module for terrestrial carbon cycle [Eliseev and Mokhov, 2011; Eliseev, 2011].

Turnaround time: ~ 22 sec per model year

Terrestrial carbon cycle module



- PFT-based;
- mosaic approach;
- seasonal cycle of climate input;
- annual output

photosynthesis:

$$P = P\,(T,\ w,\ q_{CO2}),$$

autotrophic respiration:

$$R_v = R_v\,(C_v,\ T)$$

litterfall: $L = L\,(C_v)$

<u>governing equation</u>:

$$d\,C_v\ /\ dt = P - R_v - L - d_{fire} - d_{lu}$$

heterotrophic respiration:

$$R_s = R_s\,(C_s,\ T,\ w,\ f_{agro/nat})$$

<u>governing equation</u>:

$$d\,C_s\ /\ dt = L - R_s$$

Simulations

Duration: 1500-2100

External forcings:
- anthropogenic (fossil fuel+industrial+land use) CO_2 emissions;
- atmospheric concentrations of CH_4, N_2O, CFC-11, and CFC-12;
- atmospheric burdens of sulphate aerosols (MOZART-2 simulations)
- total solar irradiance;
- stratospheric aerosol optical depth due to volcanic eruptions.

For 21st century, anthropogenic forcings (except land use) are adopted from SRES scenarios. Land use scenarios are prescribed in accordance to the HYDE (before year 2000) and Land Use Harmonization (LUH) product thereafter. Natural forcings are neglected.

Different ensemble members are constructed by varying values of two global parameters conditioning the dynamics of carbon cycle:
- half saturation point $q_{1/2}$ in the Michaelis-Menten law for CO_2 fertilisation: from 150 ppmv to 450 ppmv;
- multiplier $k_{nat/agro}$ for heterotrophic respiration representing respiration enhancement due to cultivation: from 1.0 to 1.3.

The total number of ensemble members N_{mem}=25.

Postprocessing. Bayesian averaging

For empirical data set D, and for any variable Y (not necessarily covered by D)
- ensemble mean

$$E(Y \mid D) = \Sigma Y_k w_k,$$

- ensemble STD

$$\sigma(Y \mid D) = \{ \Sigma [\sigma_k^2 + Y_k^2] w_k - E(Y \mid D)^2 \}^{1/2},$$

where Y_k is Y for ensemble member M_k, $k=1,2,...,N_{mem}$, σ_k – sample STD for the same ensemble member.

Weights for individual ensemble members:

$$w_k = P (M_k \mid D).$$

Empirical data sets

- Mauna Loa observatory measurements for q_{CO2} (1958–2005);
- carbon fluxes from the atmosphere to the ocean (F_o) and to the terrestrial ecosystems (F_l) as figured in IPCC AR4 for 1980's and 1990's.

$$w_k = w_{k,q} * w_{k,Fo} * w_{k,Fl}.$$

Different land use scenarios are considered to be equally probable.

Choice of priors:

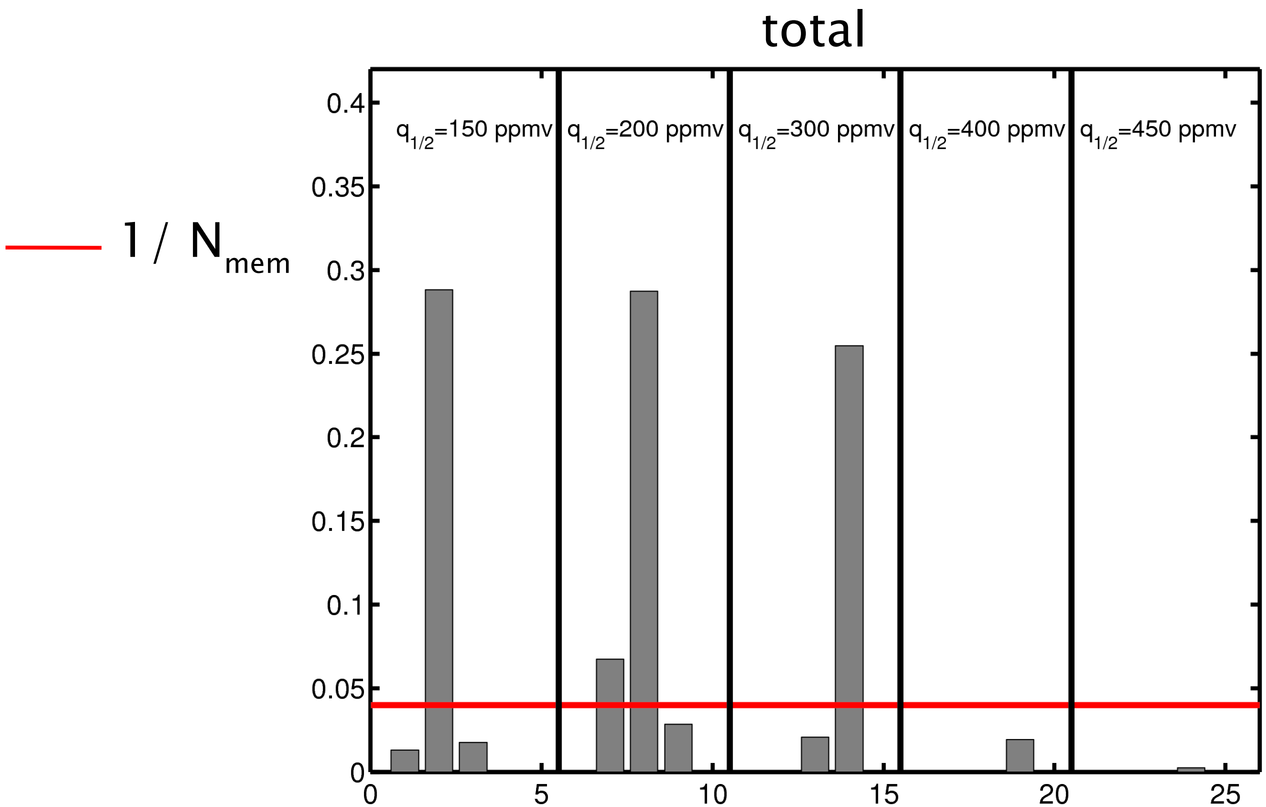
For all q, F_o, and F_l, Gaussian priors are chosen with

$$\sigma_q = 5 \text{ ppmv},$$

$$\sigma_{Fo,1980s} = 0.8 \text{ PgC/yr}, \qquad \sigma_{Fo,1990s} = 0.4 \text{ PgC/yr},$$

$$\sigma_{Fl,1980s} = 0.9 \text{ PgC/yr}, \qquad \sigma_{Fl,1990s} = 1.3 \text{ PgC/yr}.$$

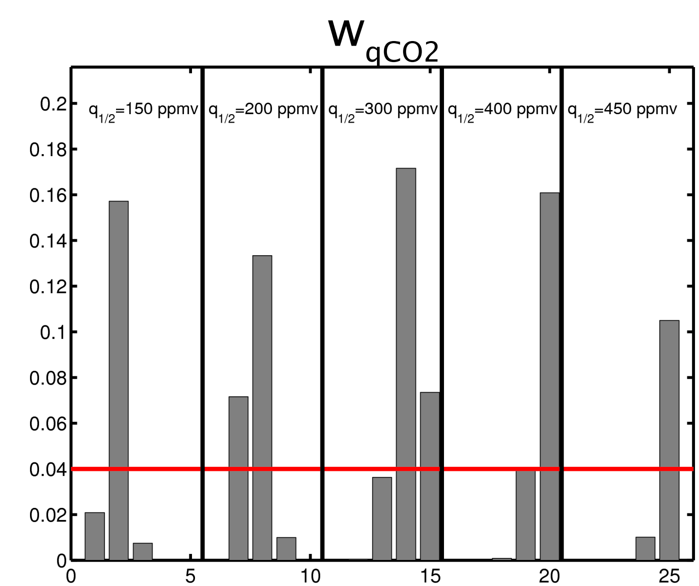
Bayesian weights

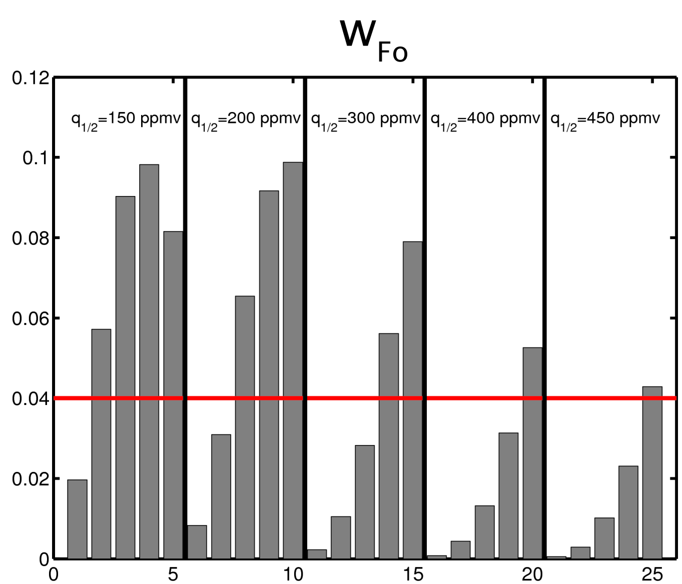


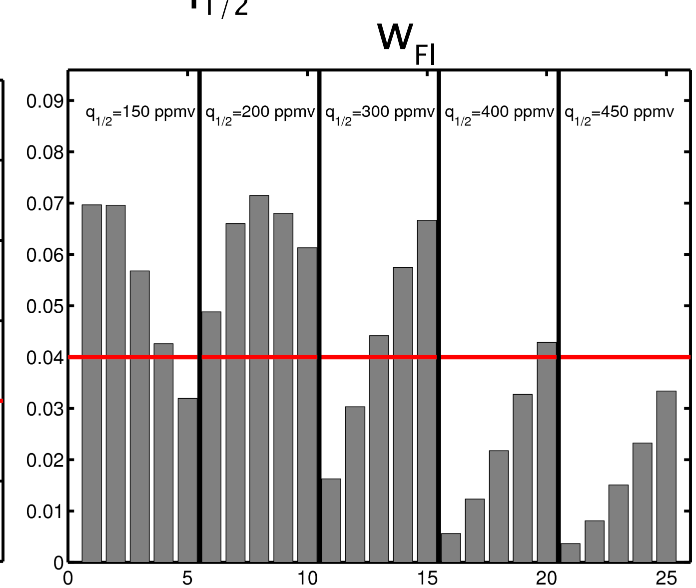
- w depends most markedly on w_q at $q_{1/2}$ < 400 ppmv; at larger $q_{1/2}$, w_{Fo} and w_{Fl} matter as well;

- limitation on oceanic fluxes favours relatively large $k_{nat/agro}$;

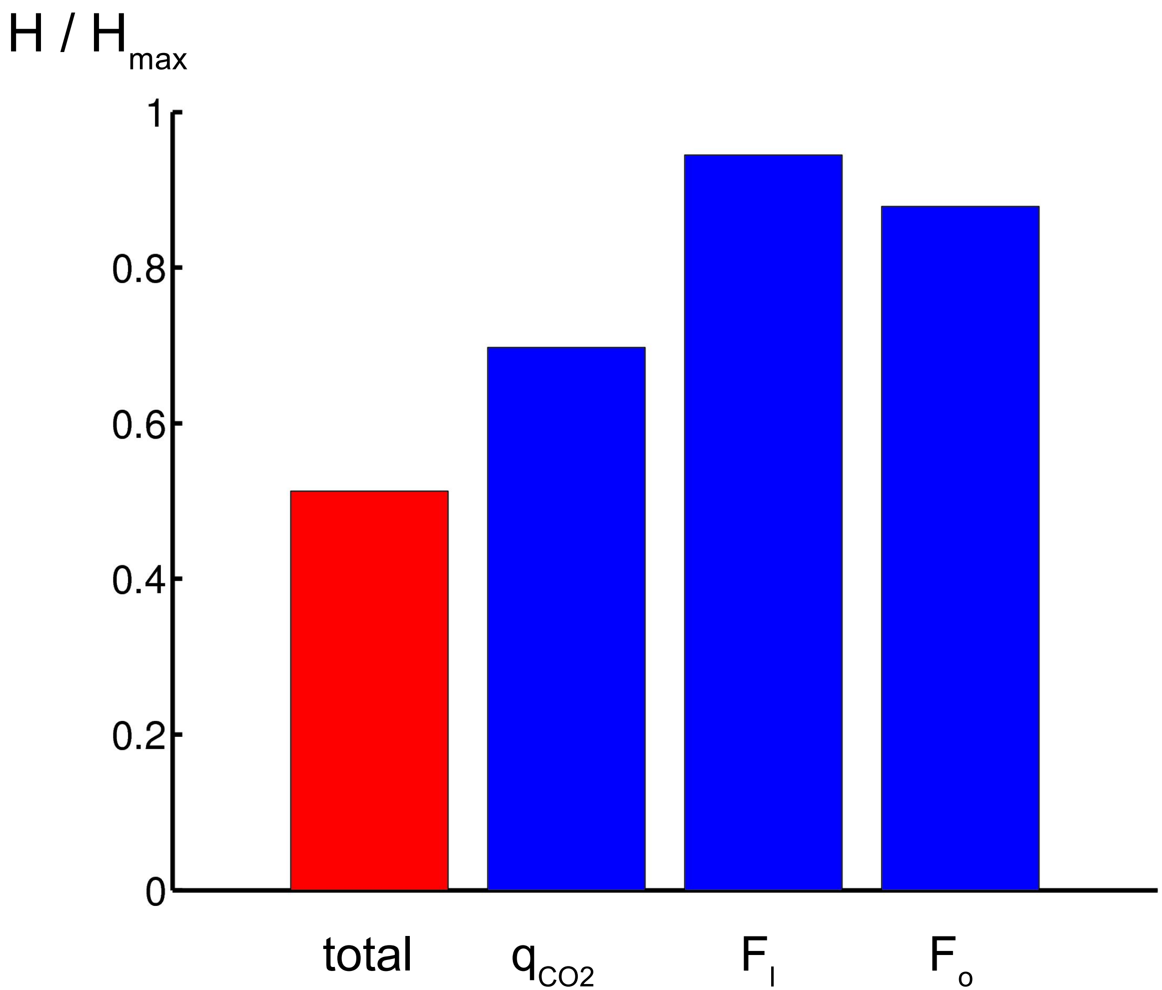
- limitation on terrestrial fluxes favours relatively small $q_{1/2}$.



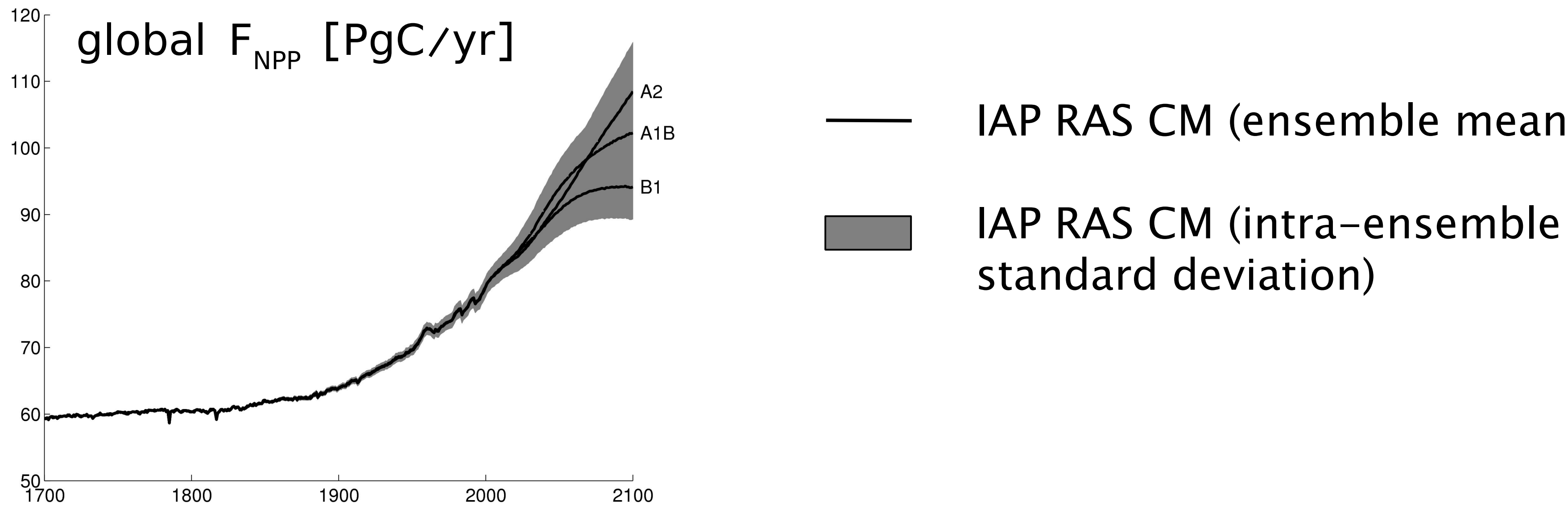




Standardised Information entropy

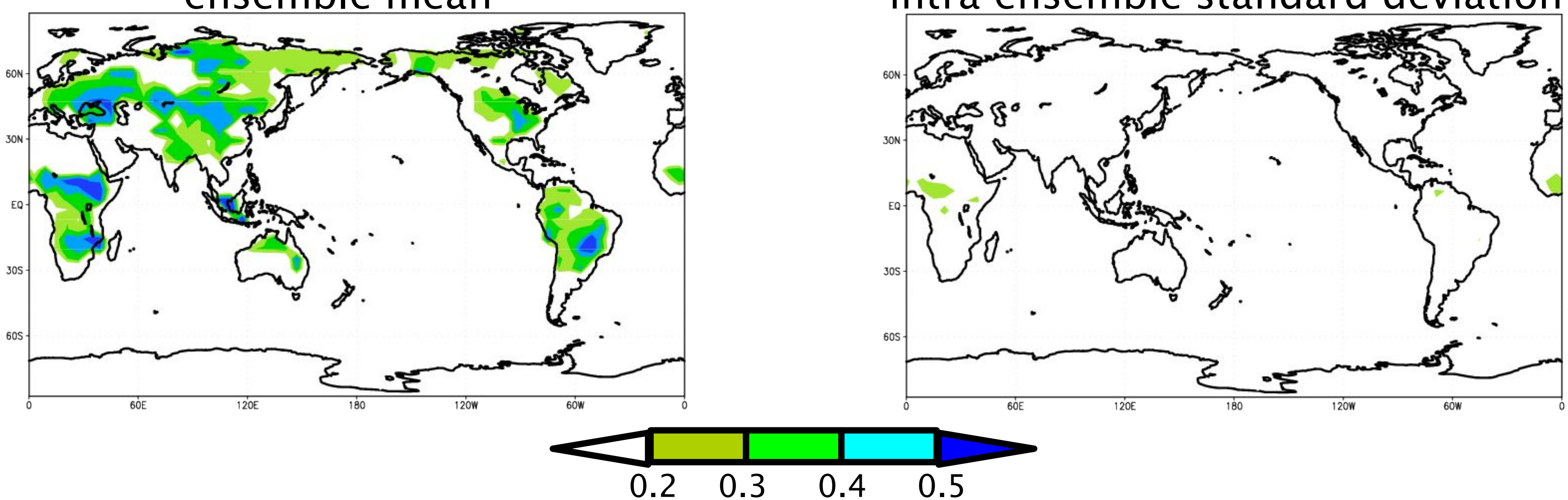


Terrestrial net primary production

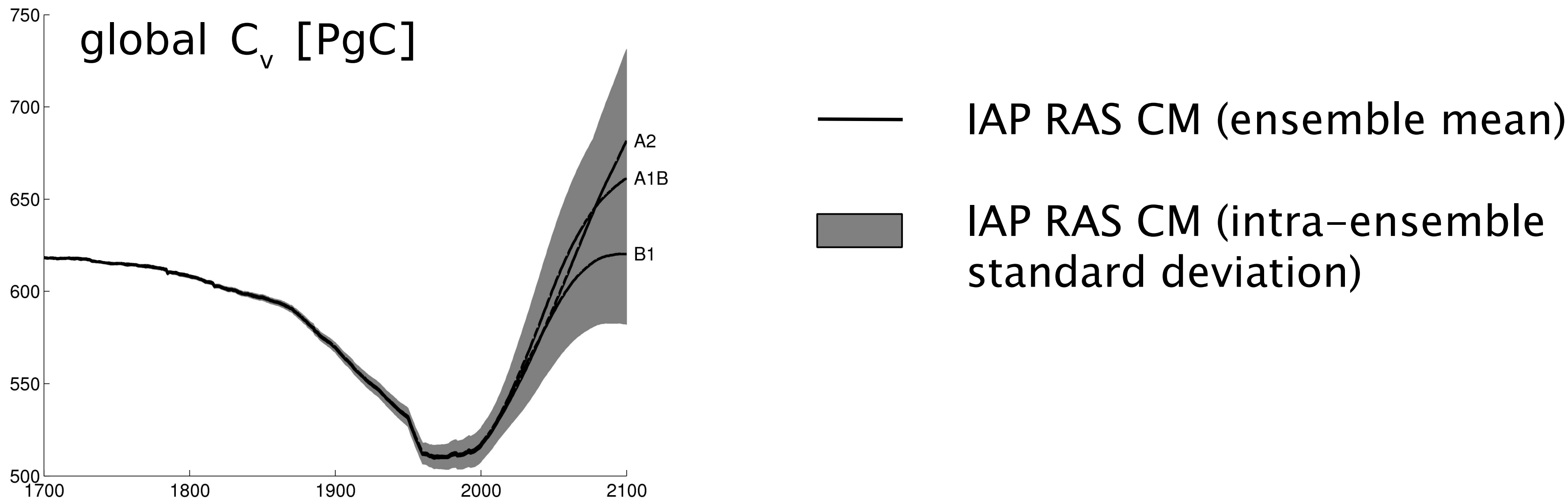


change from 1961-1990 to 2071-2100 [kgC m^{-2} yr^{-1}], SRES A2

ensemble mean | intra-ensemble standard deviation



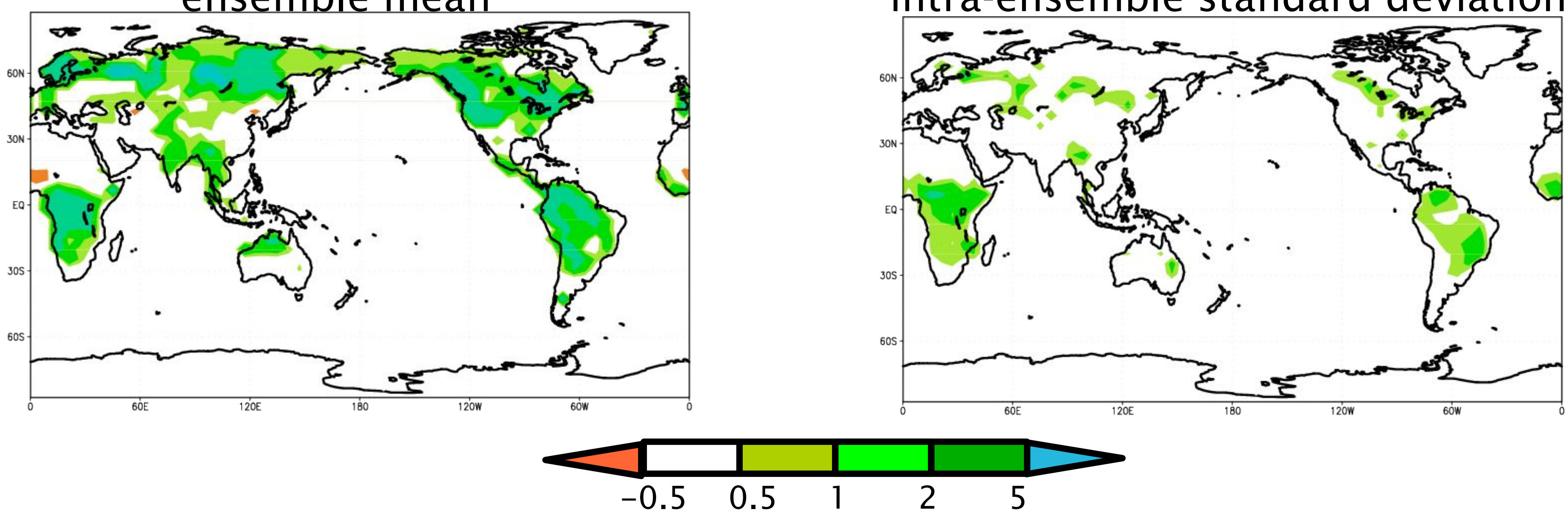
Vegetation carbon stock



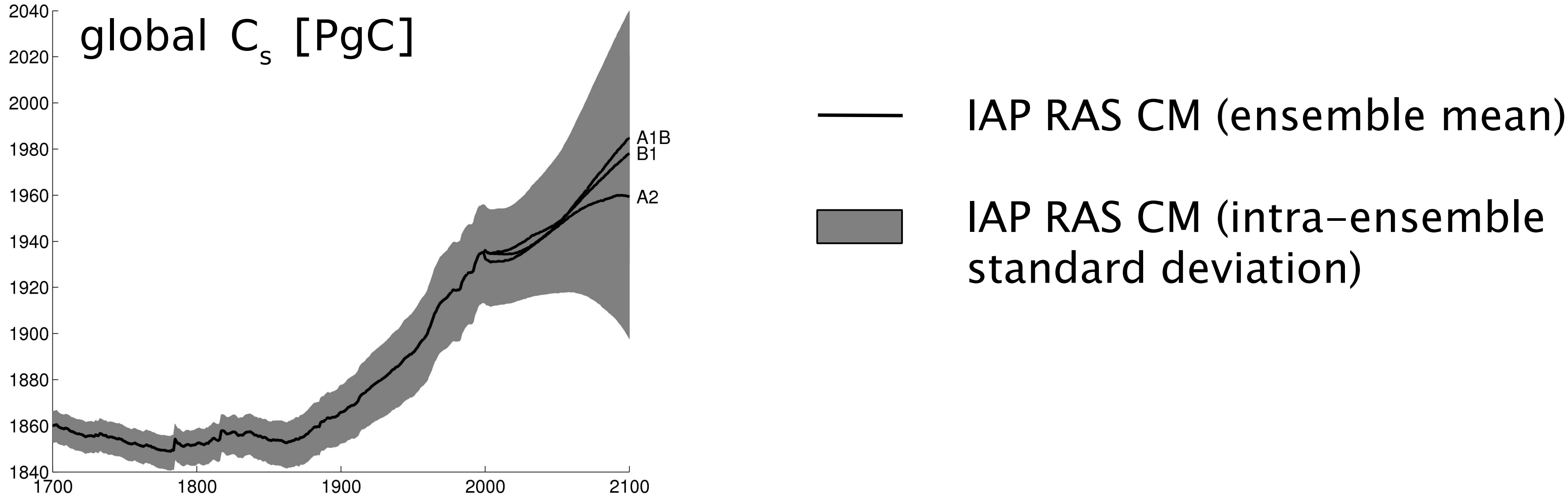
change from 1961–1990 to 2071–2100 [kgC m^{-2}], SRES A2

ensemble mean

intra-ensemble standard deviation



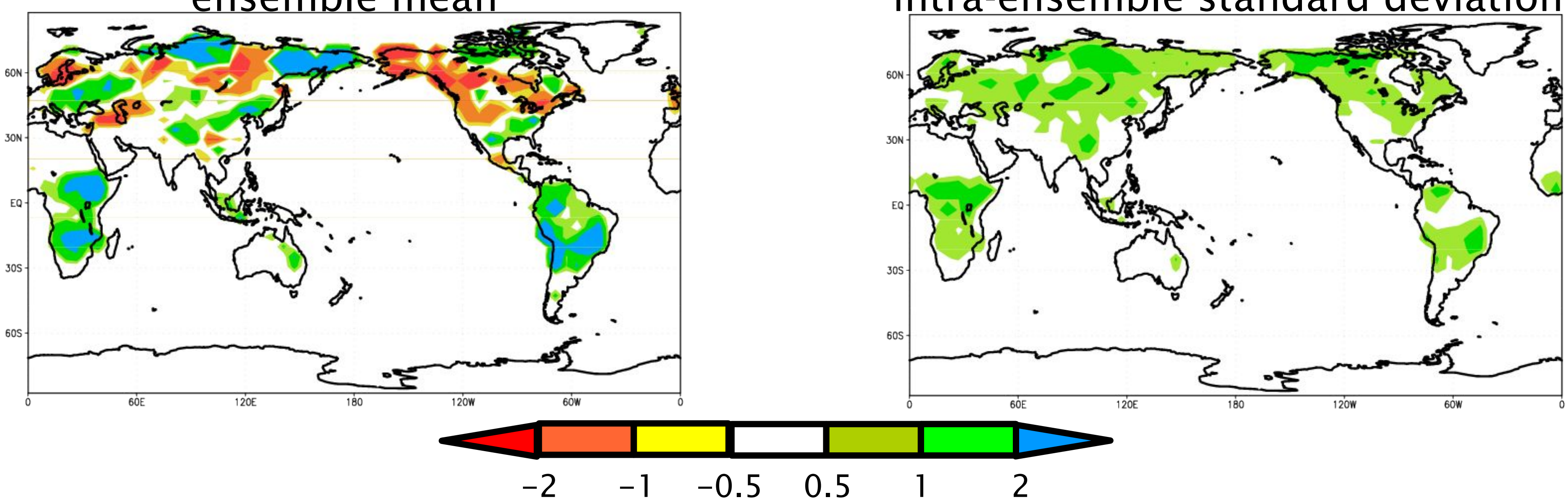
Soil carbon stock



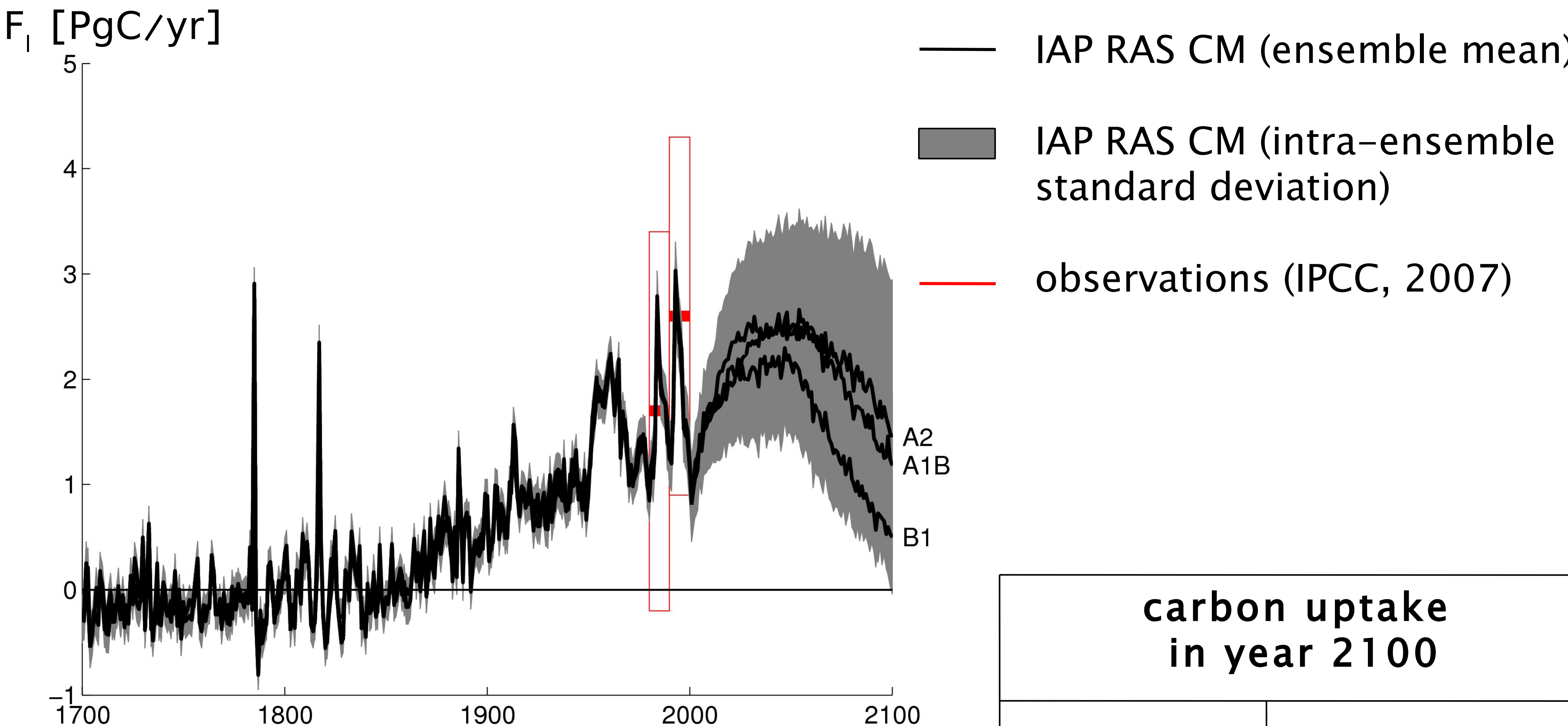
change from 1961-1990 to 2071-2100 [kgC m^{-2}], SRES A2

ensemble mean

intra-ensemble standard deviation

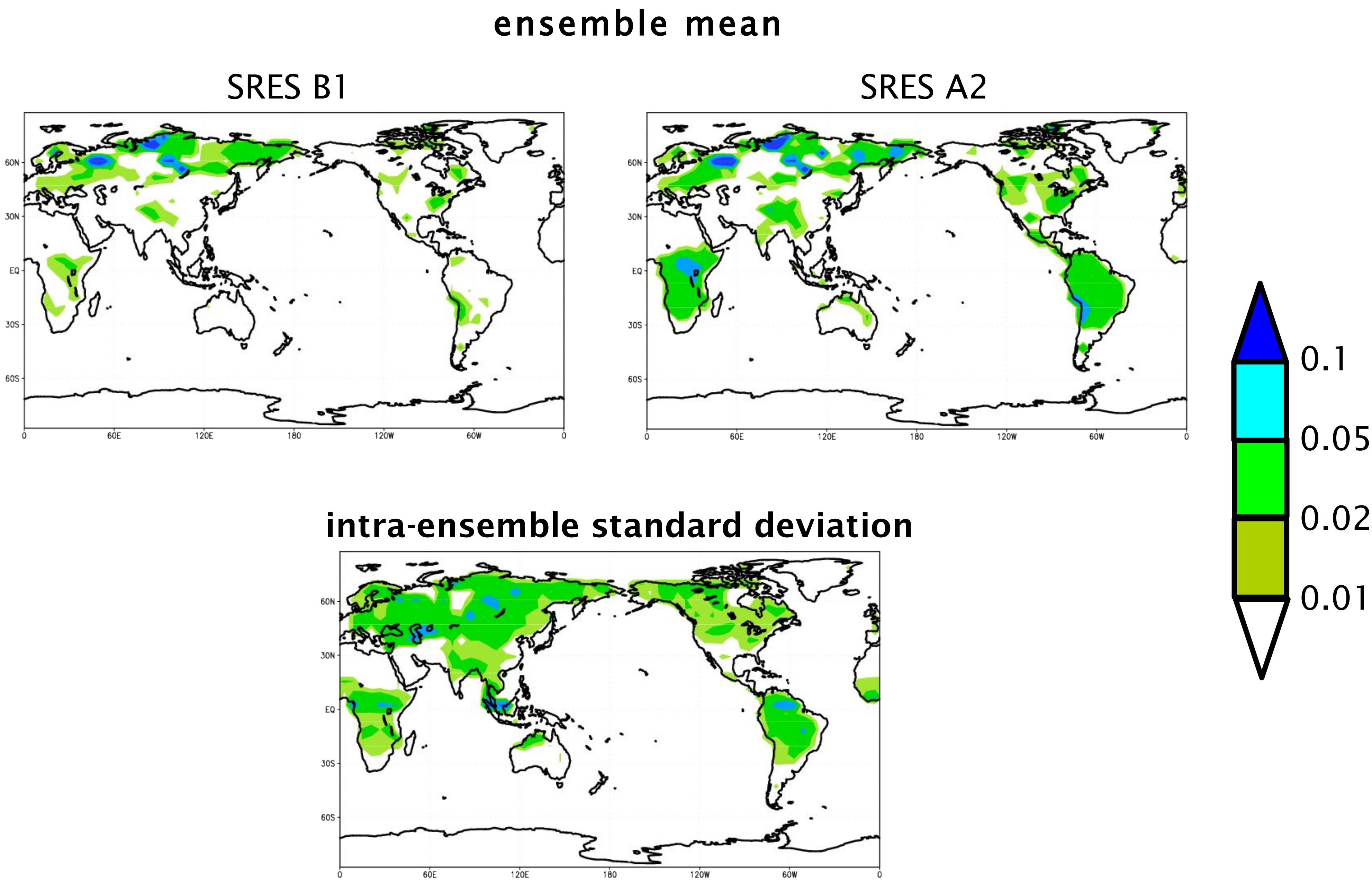


Global terrestrial carbon uptake

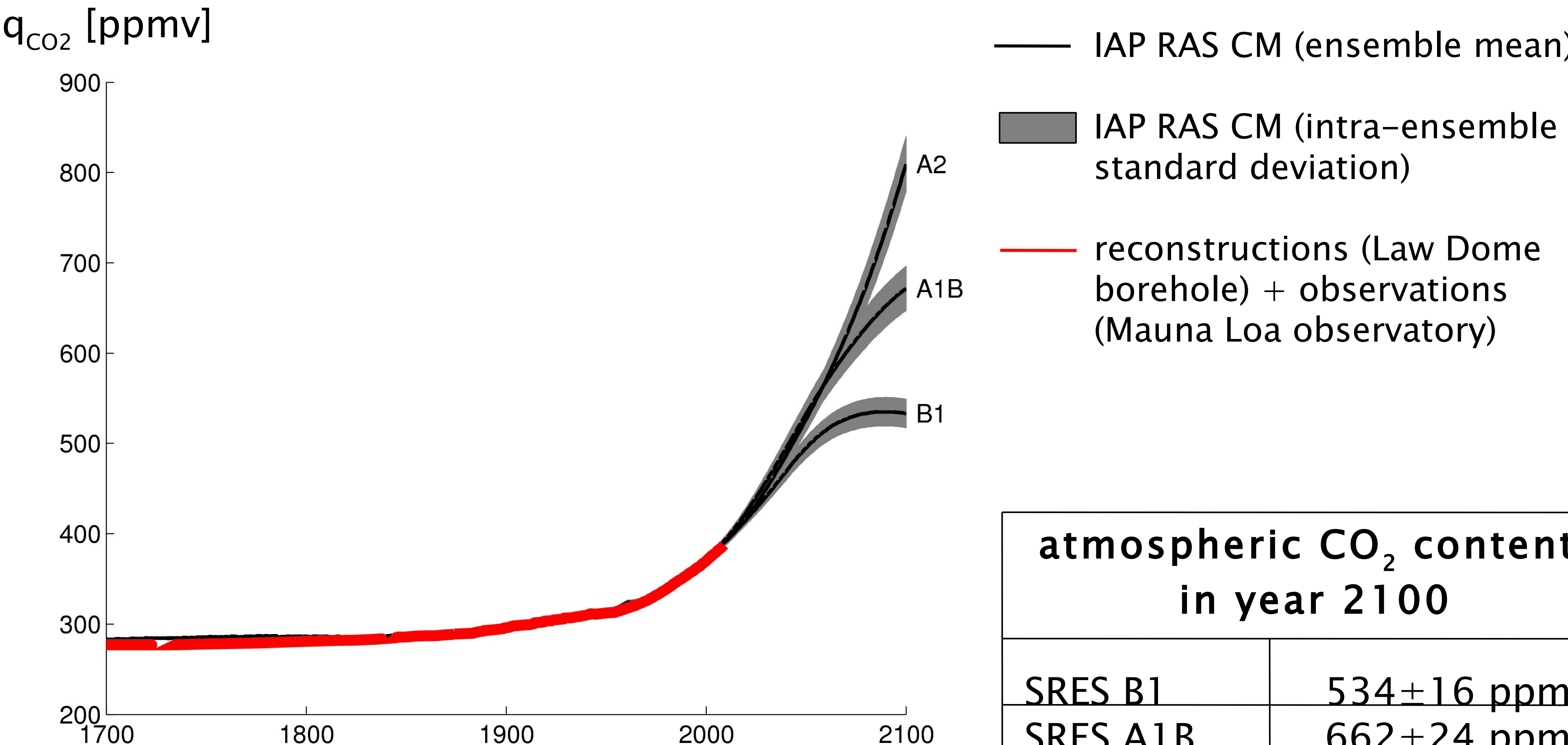


carbon uptake in year 2100	
SRES B1	0.6±0.3 PgC/yr
SRES A1B	1.4±0.7 PgC/yr
SRES A2	1.7±1.4 PgC/yr

Terrestrial carbon uptake for 2071–2100 [kgC m^{-2} yr^{-1}]

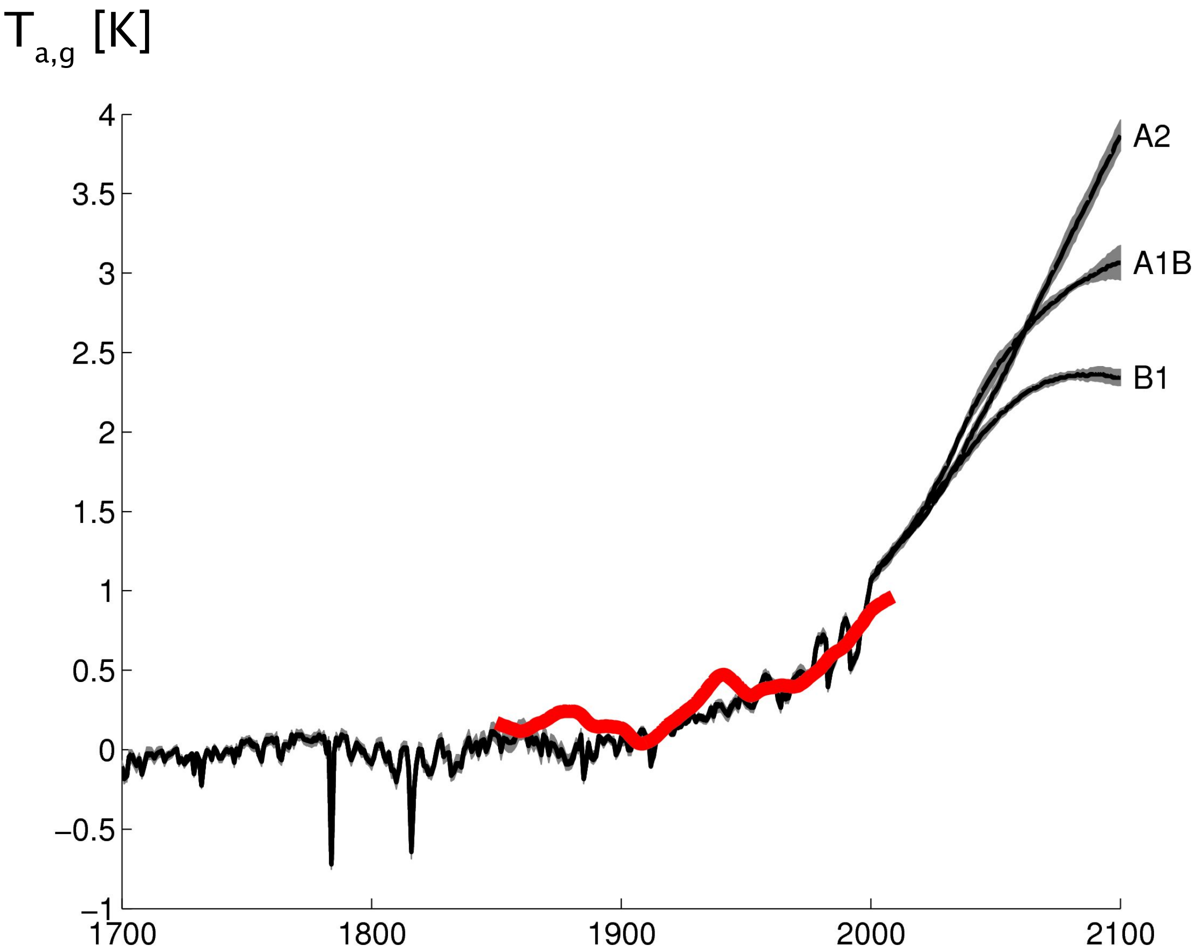


Carbon dioxide content in the atmosphere



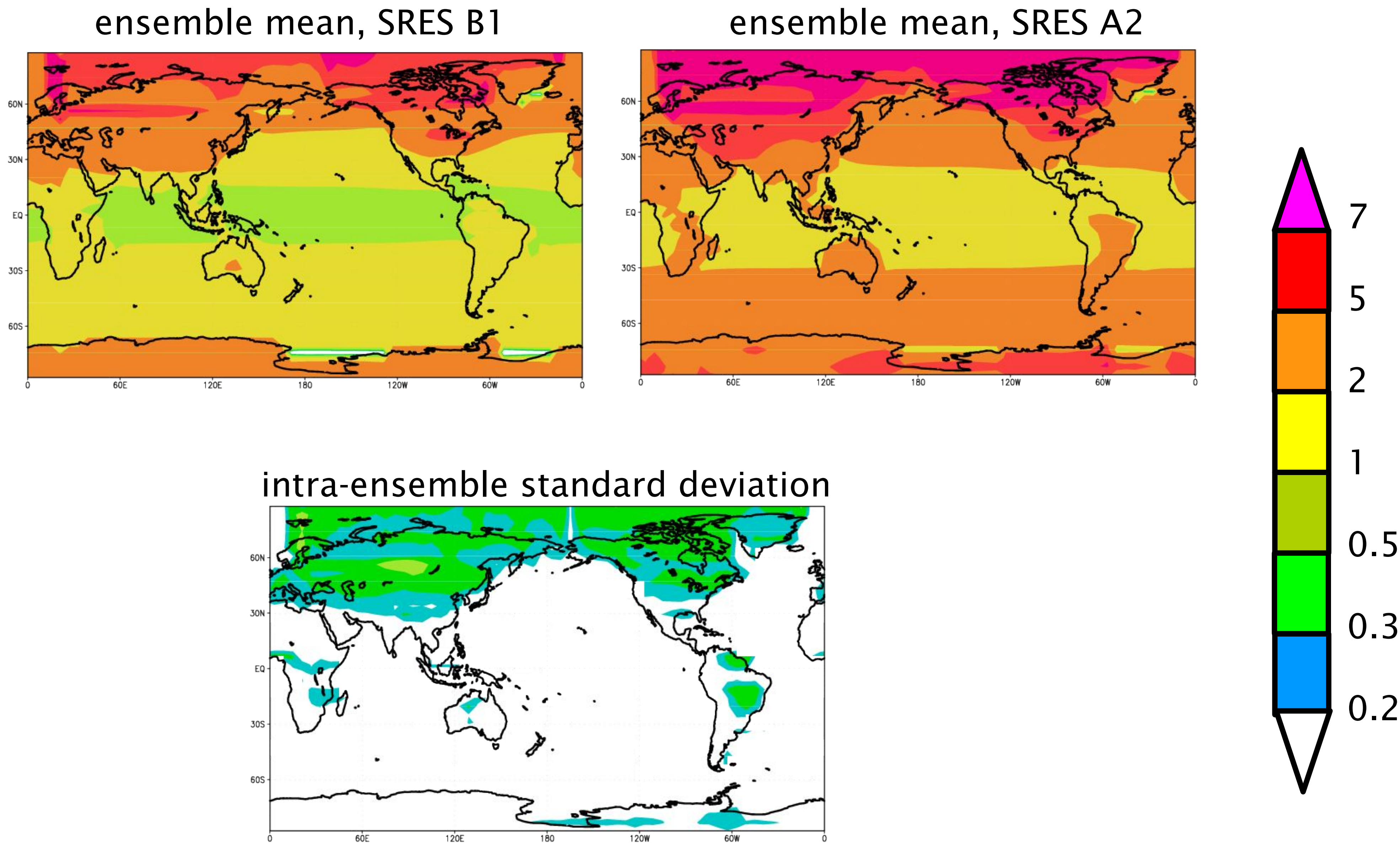
atmospheric CO_2 content in year 2100	
SRES B1	534±16 ppmv
SRES A1B	662±24 ppmv
SRES A2	773±28 ppmv

Globally averaged annual mean surface air temperature

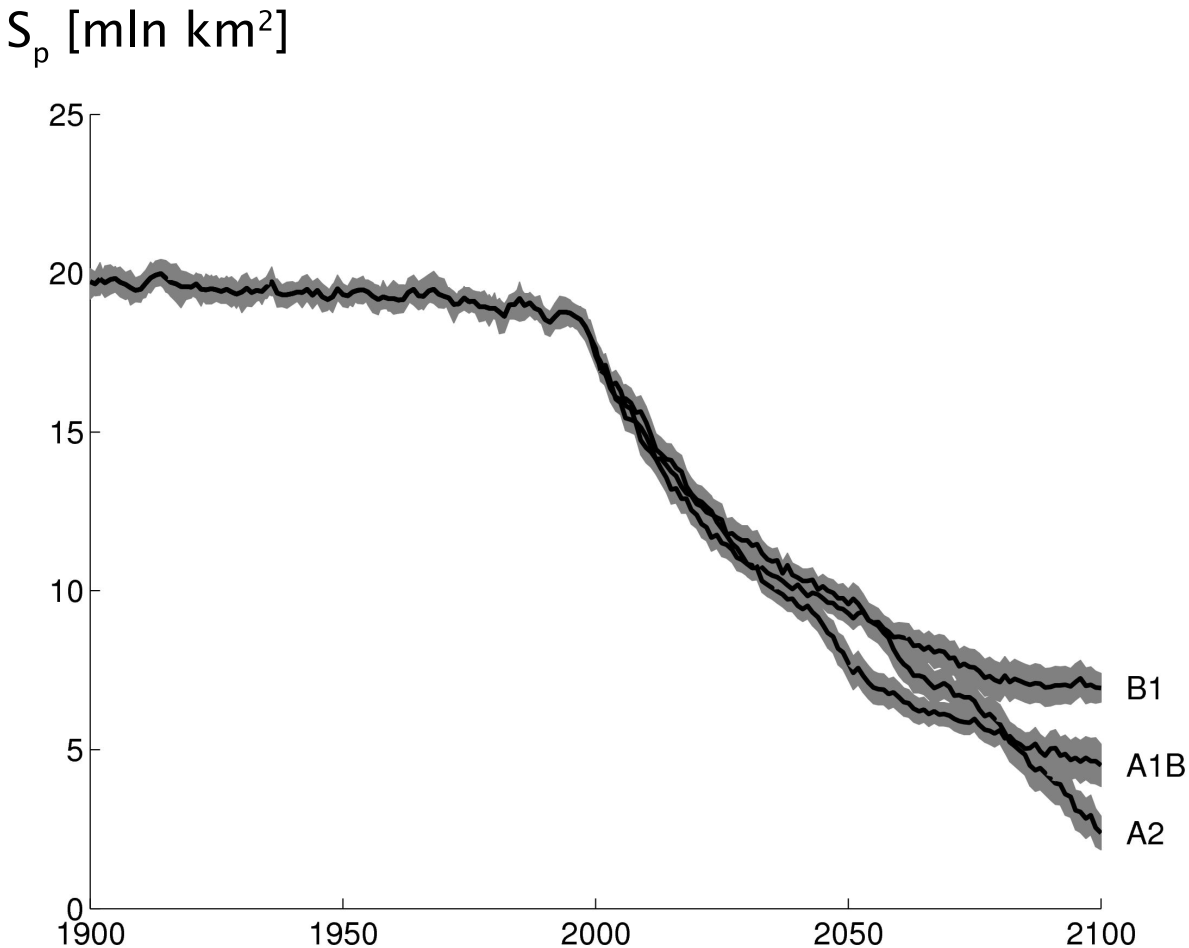


global warming from 1980–1999 to 2080–2099	
SRES B1	1.84±0.06 K
SRES A1B	2.52±0.08 K
SRES A2	3.19±0.09 K

Change in annual mean surface air temperature [K] from 1961-1990 to 2071-2100



Area covered by near-surface permafrost



contemporary value: 19.1±0.3 mln km^2	
global warming from 1980–1999 to 2080–2099	
SRES B1	7.0±0.6 mln km^2
SRES A1B	4.8±0.6 mln km^2
SRES A2	3.3±0.6 mln km^2

Conclusions

- An ensemble simulation with the IAP RAS climate model shows that, in terms of terrestrial carbon stocks and primary productivity, different SRES scenarios are statistically indistinguishable between each other.

- However, in the present ensemble, large differences in carbon dioxide emissions between SRES scenarios lead to statistically significant differences regional pattern of terrestrial carbon uptake, in build up of carbon dioxide in the atmosphere and, as a result, to statistically significant differences in temperature response between different SRES scenarios.

- In the late 21st century, only forests take up carbon robustly within the ensemble. Only boreal forests take up carbon robustly both with respect to change in governing parameters of terrestrial biota and with respect to choice of anthropogenic scenario.

Thank you for attention

Climate sensitivity

Equilibrium climate sensitivity to doubling of the CO_2 content in the atmosphere: 2.2 K

Transient response to the climate forcings

(CO_2, CH_4, N_2O, CFC-11, CFC-12, tropospheric sulphates, total solar irradiance, stratospheric aerosols due to volcanic eruptions, land use)