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Biogeophysical feedbacks enhance the Arctic terrestrial carbon sink in regional Earth system dynamics

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Index:

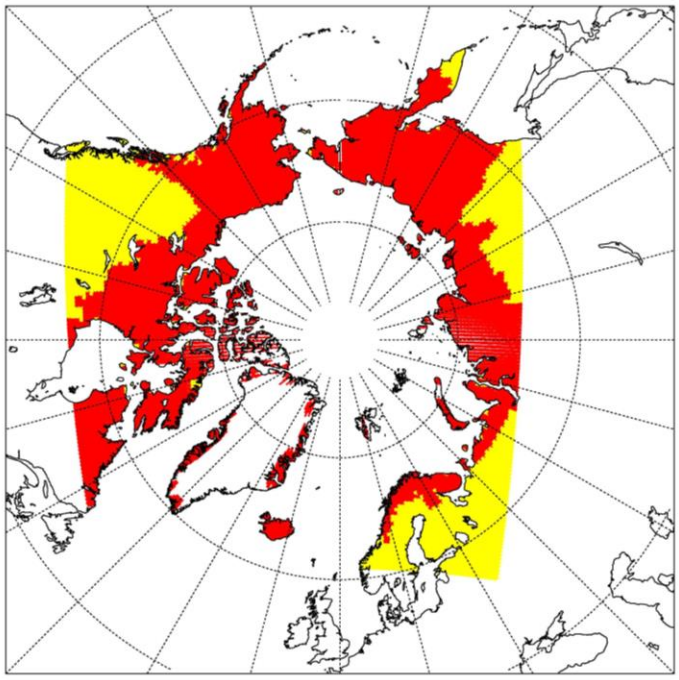

Fig. S1. The Arctic tundra domain (red) (McGuire et al., 2012) and the CORDEX-Arctic domain (red and yellow).

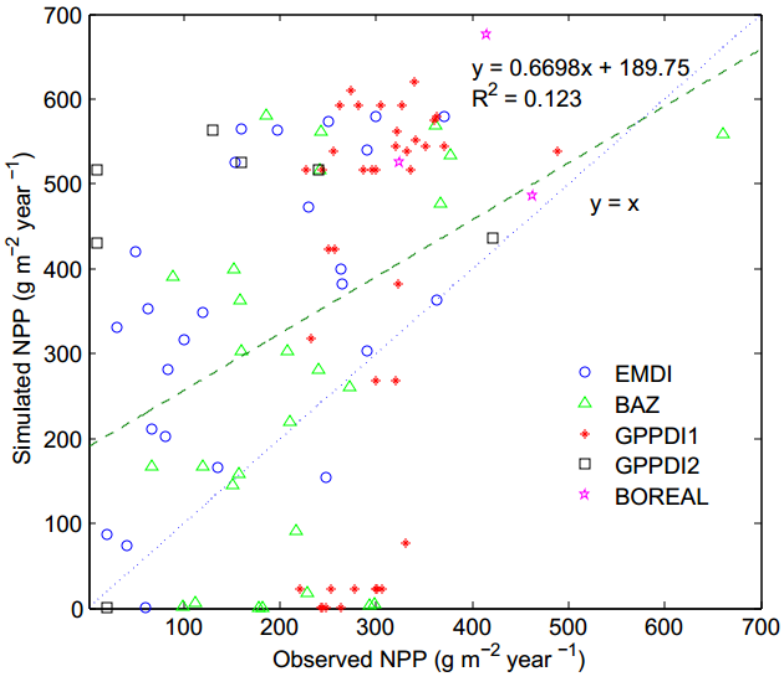

Fig. S2. Scatter plot comparing the simulated NPP flux in the RCA-GUESS simulation and the NPP flux validation datasets (EMDI (Olson et al., 2013a), BAZ (Denissenko et al., 2013), GPPDI_1 (Olson et al., 2013b), GPPDI_2 (Zheng et al., 2013), BOREAL (Gower et al., 2012)).

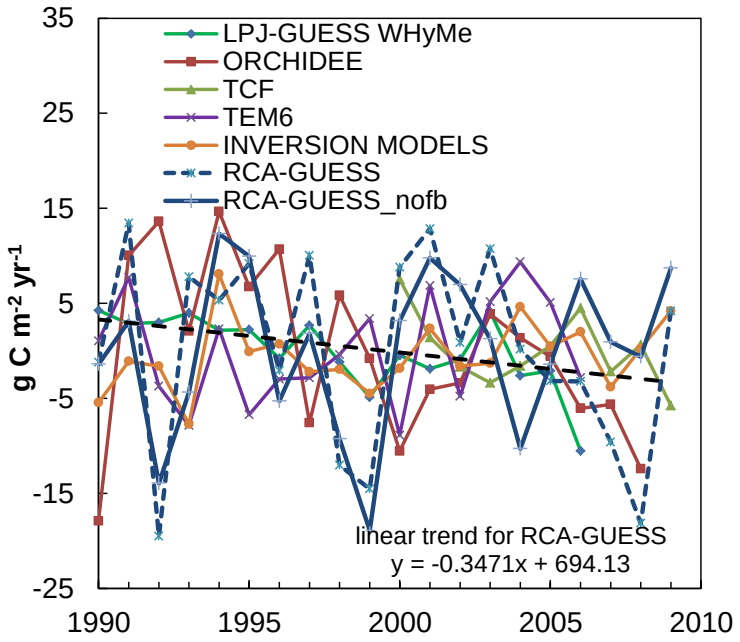

Fig. S3. The inter-annual variation of NEE anomalies for the RCA-GUESS feedback and non-feedback runs, process-based models (LPJ-GUESS WHyMe, ORCHIDEE, TCF, TEM6) and the ensemble mean of inversion models for the period 1990-2009 averaged over the Arctic tundra domain defined by McGuire et al. (2012).

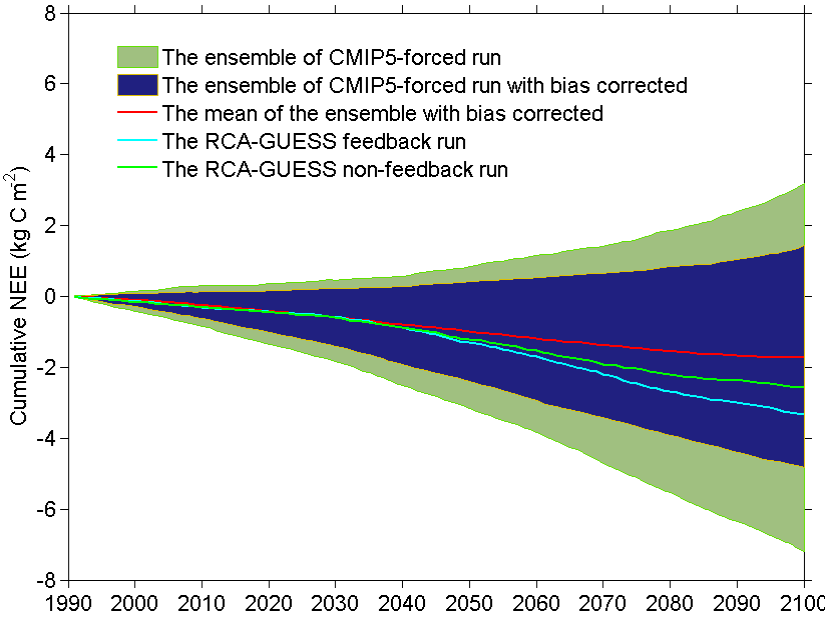

Fig. S4. The cumulative NEE simulated by the RCA-GUESS feedback and non-feedback runs for the CORDEX-Arctic domain compared to the stand-alone simulations of LPJ-GUESS forced by the CMIP5 products for the land areas above 60 °N (Ahlström et al., 2012b) (dark color: forcing bias corrected; light color: forcing bias uncorrected).

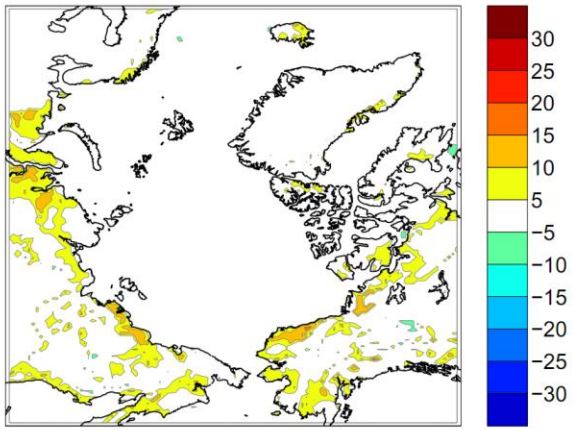

Fig. S5. The effects of biogeophysical feedbacks on the sum of net short-wave and net long-wave radiation fluxes (W m^{-2}) in the summer (June, July and August) for 2071-2100.

Table S1. Parameters of PFTs used in RCA-GUESS (BNE-boreal needle-leaved evergreen trees, BINE-boreal shade-intolerant needle-leaved evergreen trees, BNS-boreal needle-leaved deciduous trees, TBS-temperate broad-leaved deciduous trees, IBS-boreal shade-intolerant deciduous trees, GRS-C3 grass).

Parameter	Description (Units)	BNE	BINE	BNS	TBS	IBS	GRS
alphar	Recruitment shape parameter	3	10	3	3	10	-
bulk_dens	Bulk density (kg m^{-3})	20	20	20	20	20	2
crownarea_max	Max. tree crown area (m^2)	50	50	50	50	50	-
cton_leaf	Leaf C:N mass ratio (-)	29	29	29	29	29	29
cton_root	Root C:N mass ratio (-)	29	29	29	29	29	29
cton_sap	Sapwood C:N mass ratio (-)	330	330	330	330	330	-
est_max	Max. sapling establishment rate (individual m^{-2} yr^{-1})	0.05	0.2	0.05	0.05	0.2	-
fireresist	Fire resistance (0-1)	0.3	0.3	0.3	0.1	0.1	0.5
gdd5min_est	Min. GDD5 for establishment (ºC day)	500	500	350	1100	300	0
gmin	Min. canopy conductance (mm s^{-1})	0.3	0.3	0.3	0.5	0.5	0.5
greff_min	Threshold for growth suppression mortality (kg m^{-2} yr^{-1})	0.04	0.08	0.04	0.04	0.08	-
intc	Interception coefficient	0.06	0.06	0.06	0.02	0.02	0.01
kest_repr	Constant in equation for budburst chilling time	200	200	200	200	200	-
kest_bg	Coefficient in equation for budburst chilling time	0.1	0.1	0.1	0.1	0.1	-
kest_pres	Exponent in equation for budburst chilling time	1	1	1	1	1	-
k_allom1	Constant in allometry equation	150	150	150	200	200	-
k_allom2	Constant in allometry equation	60	60	60	60	60	-

k_allom3	Constant in allometry equation	0.67	0.67	0.67	0.67	0.67	-
k_chilla	Constant in equation for budburst chilling time	0	0	0	0	0	-
k_chillb	Coefficient in equation for budburst chilling time	100	100	100	100	100	-
k_chilk	Exponent in equation for budburst chilling time	0.05	0.05	0.05	0.05	0.05	-
k_latosa	Tree leaf to sapwood area ratio	5000	5000	5000	6000	6000	-
k_rp	Constant in allometry equation	1.6	1.6	1.6	1.6	1.6	-
leaflong	Leaf longevity (yr)	3	3	3	0.5	0.5	1
longevity	Expected longevity under non-stressed conditions (yr)	500	500	300	400	300	-
phengdd5ramp	GDD on 5 ºC base to attain a full leaf cover (ºC day)	0	0	0	200	200	100
pstemp_min	Photosynthesis: min. Temperature (ºC)	4	4	4	2	-4	-4
pstemp_max	Photosynthesis: max. Temperature (ºC)	38	38	38	38	38	10
pstemp_low	Low temperature for optimal photosynthesis (ºC)	10	10	10	25	10	30
pstemp_high	High temperature for optimal photosynthesis (ºC)	15	15	15	25	15	45
parff_min	Min. forest floor PAR for establishment (J m^{-2} day^{-1})	350	2500	350	350	2500	1250
respcoeff	Maintenance respiration coefficient	1	1	1	1	1	1
rootdist	Fraction of roots in the up soil layer	0.6	0.6	0.6	0.6	0.6	0.9
sla	Specific leaf area (m^2 kg^{-1})	9.3	9.3	9.3	24.3	24.3	32.4
turnover_leaf	Leaf turnover (fraction yr^{-1})	0.33	0.33	0.33	1	1	1
turnover_root	Fine root turnover (fraction yr^{-1})	0.7	0.7	0.7	0.7	0.7	0.7
turnover_sap	Sapwood turnover (fraction yr^{-1})	0.05	0.1	0.05	0.05	0.1	-
tcmin_surv	Min. temperature of coldest month for survival	-31	-31	-1000	-14	-30	-1000
tcmin_est	Min. temperature of coldest month for establishment (ºC)	-30	-30	-1000	-13	-30	-1000

tcmax_est	Max. temperature of coldest month for survival (ºC)	-1	-1	-2	6	7	1000
twmin_est	Min. temperature of warmest month for survival (ºC)	5	5	-1000	5	-1000	-1000
woodens	Sapwood and heartwood density (kg C m^{-3})	200	200	200	200	200	-

Table S2. The key numerical equations used for the RCA-GUESS coupling processes and the quantification of biogeophysical feedback impacts on vegetation change.

Variables adjusted by LPJ-GUESS		
Individual LAI:	$LAI = \sum_n LAI_n \times S_n$	1.1
Beer's law:	$A_{total} = 2.0 - \exp(-0.5 \times LAI_{broad-leaved}) - \exp(-0.5 \times LAI_{needle-leaved})$	1.2
	$A_{tree} = (1.0 - \exp(-0.5 \times LAI_{tree})) / A_{total}$	1.3
	$A_{herbaceous} = 1.0 - \exp(-0.5 \times LAI_{berbaceous})$	1.4
Processes affected in RCA		
Surface resistance:	$r_s = r_{s,\min} \times F_1 \times F_2^{-1} \times F_3^{-1} \times F_4^{-1} \times F_5^{-1} / LAI$	1.5
Aerodynamic resistance:	$r_a = 1/g_b = 1/f(LAI)$	1.6
	$r_d = f^{-1}(LAI)$	1.7
Latent heat flux:	$E = \rho \times L_e \times (q_s(T_s) - q_{am}) / (r_a + r_s)$	1.8
Sensible heat flux:	$H = \rho \times c_p \times (T_s - T_{am}) / r_a$	1.9
Tiled-weighted Albedo:	$\alpha_{total} = \sum(A_n \times \alpha_n) / \sum A_n$	2.0
Impacts of biophysics to vegetation change		
Normalized phenology index:	$C_{NPI} = (LAI_{eg} - LAI_d) / (LAI_{eg} + LAI_d)$	2.1
Normalized physiognomy index:	$C_{NPMI} = (LAI_w - LAI_g) / (LAI_w + LAI_g)$	
The percentage change for the above indices:	$\Delta C = (C_1 - C_2) \times 100 / 2$	2.3

S : phenology state of PFTs.
A : projective vegetation cover.
r_s : surface resistance.
F_{1-5} : five influencing factors: the photosynthetically active radiation, the water stress, the vapour pressure deficit, the air temperature dependence and the soil temperature dependence.
r_a : aerodynamic resistance based on the conductance g_b between the canopy and the canopy air. $f()$: increasing function (see Samuelsson et al. (2006) for details).
r_d : aerodynamic resistance between the canopy floor and the canopy air. $f^{-1}()$: decreasing function (see Samuelsson et al. (2006) for details).
ρ : air density.
L_e : latent heat of vaporisation of water.
q_s : surface saturated specific humidity.

q_{am} : specific humidity at the first atmospheric level (~ 90 meter).

T_s : surface temperature.

T_{am} : temperature at the first atmospheric level (~ 90 meter).

eg : evergreen PFTs.

d : deciduous PFTs.

w : evergreen PFTs.

g : deciduous PFTs.

Table S3. Aggregation of the International Satellite Land Surface Climatology Project (ISLSCP) II Potential Natural Vegetation (PNV) Cover dataset and the Kaplan PNV dataset (Kaplan et al., 2003) to five vegetated classes for comparison with plant functional types in RCA-GUESS.

Aggregate class	**The validation datasets**	**RCA-GUESS PFTs**
Evergreen forests	Boreal evergreen Forest/Woodland, Temperate broad-leaved evergreen Forest/Woodland, Temperate needle-leaved evergreen Forest/Woodland,	BNE-boreal needle-leaved evergreen trees, BINE-boreal intolerant needle-leaved evergreen trees,
Deciduous forests	Boreal deciduous Forest/Woodland	BNS-boreal needle-leaved deciduous trees, TBS-temperate deciduous trees, IBS-temperate intolerant deciduous trees,
Mixed evergreen and deciduous forests	Mixed forests	Taken from the grid cells other than the rest classes
Herbaceous vegetation	Dense shrubland, Open shrubland, Low- and high-shrub tundra*, Savanna, Grassland/Steppe	GRS-C3 grass
Snow and ice	Polar desert/Rock/Ice	None

*Kaplan et al, 2003

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