Supplemental Material

Supporting Information for "Recent warming has resulted in smaller gains in net carbon uptake in northern high latitudes"

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Prediction of temperature sensitivity of net ecosystem production (NEP) based on conceptual model:

GPP=NEP+ER, where NEP is net ecosystem production and ER is ecosystem respiration. The temperature sensitivity of each component can be written as:

$$\frac{dGPP}{dTsa}=\frac{dNEP}{dTsa}+\frac{dER}{dTsa} \quad (1)$$

Here we define NEP/GPP as the ecosystem carbon use efficiency (CUE), then equation (1) can be written as:

$$\frac{dGPP}{GPP\cdot dTsa}=CUE\frac{dNEP}{NEP\cdot dTsa}+(1-CUE)\frac{dER}{ER\cdot dTsa} \quad (2)$$

The standardized temperature sensitivity of GPP ($\sigma_{GPP/Tsa}$), NEP ($\sigma_{NEP/Tsa}$) and ER ($\sigma_{ER/Tsa}$) therefore can be related in equation (2). We used the TP model proposed by Raich et al. to model ER: $\mathrm{ER}=\mathrm{ER}_{\mathrm{ref}}\times \mathrm{f(T)}\times \mathrm{f(P)}$, where $\mathrm{ER}_{\mathrm{ref}}$ is the respiration rate at the reference temperature ($\mathrm{T}_{\mathrm{ref}}$), f(T) and f(P) is used to represent of temperature and precipitation influence. Here we used Arrhenius type equation to model f(T): $\mathrm{f(t)}=\mathrm{e}^{\mathrm{E}_0(\frac{1}{\mathrm{T}_{\mathrm{ref}}-\mathrm{T}_0}-\frac{1}{\mathrm{T}-\mathrm{T}_0})}$. E_0 is the activation energy parameter and represents the ecosystem respiration sensitivity to temperature. Here we used the previous study calibrated value (125 K) for evergreen needleleaf forest (Migliavacca et al., 2011). $\mathrm{T}_{\mathrm{ref}}$ is fixed at 288.15 K and T_0 is fixed at 227.13 K. Based on this equation, the following equation is obtained: $\sigma_{\mathrm{ER}/Tsa}=E_0/(T-227.13)^2$. The long term change of summer temperature over the study period increased about 1K, which has a small impact (less than 0.2%/K) on $\sigma_{\mathrm{ER}/Tsa}$. The CUE of boreal ecosystem is around 0.1(Luyssaert et al., 2007). Thus if the temporal evolution of CUE and $\sigma_{\mathrm{ER}/Tsa}$ is ignored, it means 1% change in $\sigma_{\mathrm{GPP}/Tsa}$ will cause 10% change in $\sigma_{\mathrm{NEP}/Tsa}$. For summer mean temperature is around 14°C (287K). Evaluating equation (2) with T=287K, CUE=0.1 and $\sigma_{\mathrm{GPP}/Tsa}$ =2%, we get $\sigma_{\mathrm{NEP}/Tsa}$ = − 11%, where 2%

corresponds to a typical temperature sensitivity of GPP in summer according to our estimation in Fig. 8d. This conceptual analysis implies $\sigma_{\mathrm{NEP}/Tsa}$ is very likely to be negative in summer based on this conceptual framework analysis.

Table S1

Temperature sensitivity of s81 NCE over NHL in the first 17 years (1981-1997) and the last 17 years (1998-2014) and the corresponding temperature sensitivity of CDR in the same moving time windows.

	1981-1997	1998-2014
$\sigma_{CDR/Tsa}$ in spring	10.2±12% (p>0.1)	−18.5±23% (p>0.1)
$\sigma_{CDR/Tsa}$ in summer	−7.5±7.8% (p>0.1)	−15.1±14% (p<0.05)
$\sigma_{NCE/Tsa}$ in spring	39.4±8.7% (p<0.01)	17.2±12% (p>0.1)
$\sigma_{NCE/Tsa}$ in summer	−8.9±3% (p<0.05)	−14.6±4% (p<0.01)

Table S2

Summary of the nine process-based carbon model in TRENDY project.

Model	Spatial resolution	Vegetation	N-cycle
CLM4CN	1° × 1°	Imposed	Y
LPJ	0.5° × 0.5°	Dynamic	N
LPJGUESS	0.5° × 0.5°	Dynamic	N
OCN	1° × 1°	Imposed	Y
HYLAND	0.5° × 0.5°	Imposed	N
TRIFFD	0.5° × 0.5°	Imposed	N
SDGVM	0.5° × 0.5°	Dynamic	N
VEGAS	0.5° × 0.5°	Dynamic	N
ORCHIDEE	2° × 2°	Imposed	N

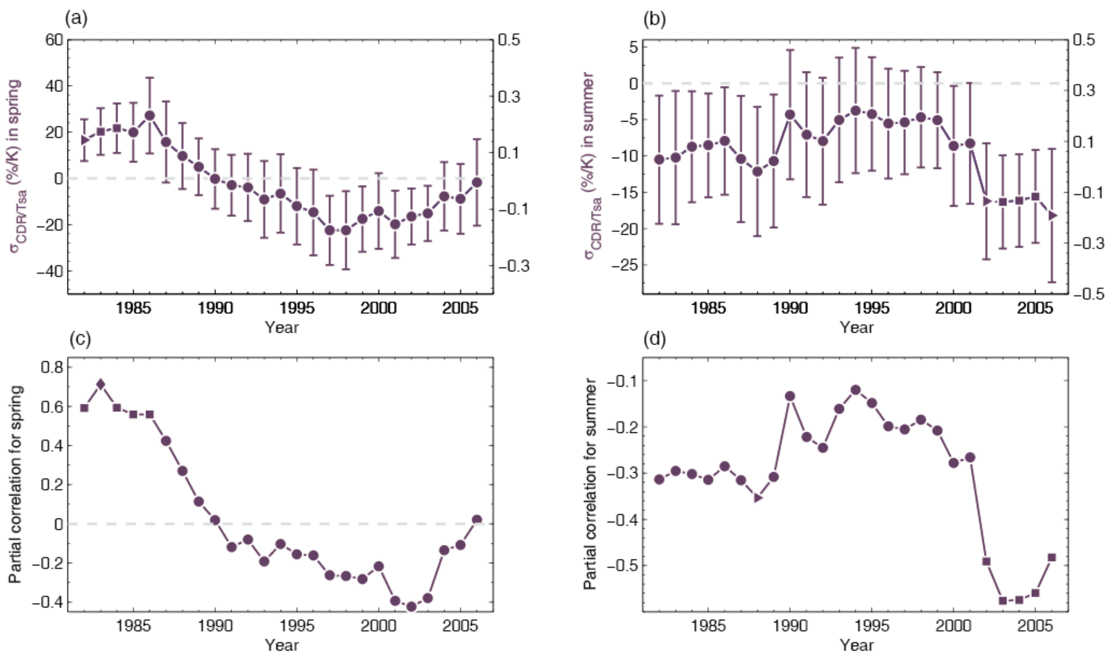

Figure S1: Temporal evolution of partial correlation between CO_2 drawdown rate and Tsa as well as $\sigma_{CDR/Tsa}$ over 17-year moving windows. (a) and (b) shows the standardized temperature sensitivity of CDR ($\sigma_{CDR/Tsa}$, %/K). (c) and (d) show the partial correlation between CDR and Tsa in spring and summer when controlling Prec. All of the variables are detrended by its first order difference before doing correlation and regression. Unlike Figure 3, here spring CDR is derived using the end of June as the end of spring and summer CDR is derived using the first day of July as the start of summer. The symbols in the line mean the same as the symbols in Figure 3. The error bars indicate the standard errors derived from 17-yr moving windows with bootstrap estimates.

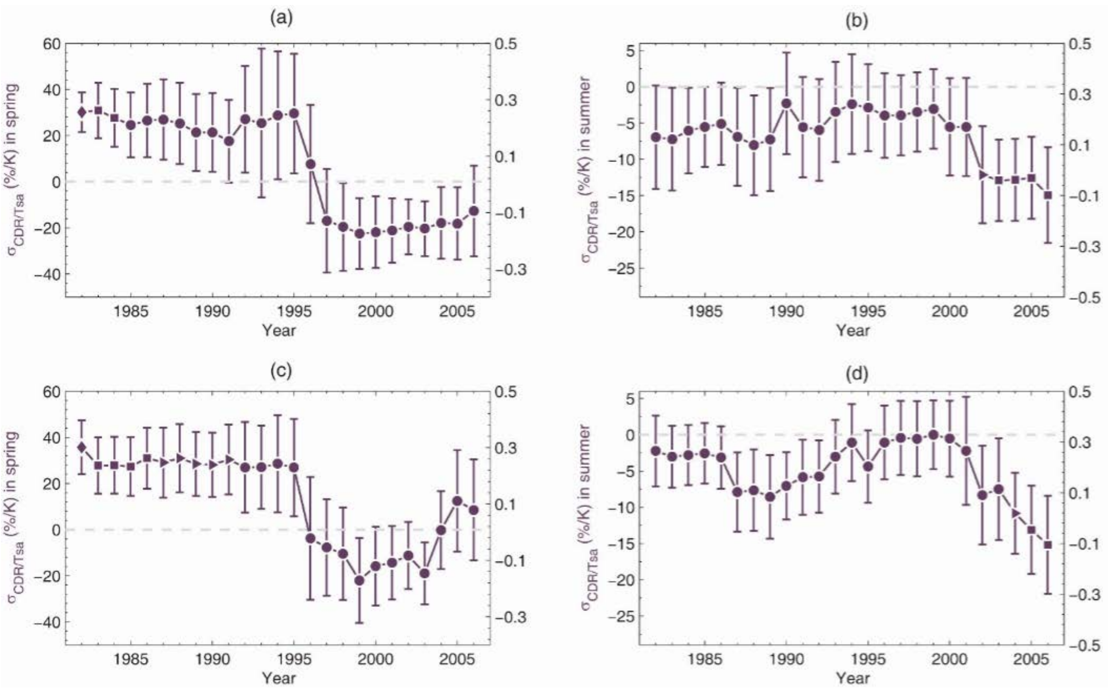

Figure S2: Temporal evolution of $\sigma_{CDR/Tsa}$ over 17-year moving windows. (a) and (b) shows the standardized temperature sensitivity of CDR ($\sigma_{CDR/Tsa}$, %/K) when not accounting for precipitation and just using temperature as the independent variable in the regression. (c) and (d) show $\sigma_{CDR/Tsa}$ when using the original CDR, Tsa and Prec without detrending. The symbols in the line mean the same as the symbols in Figure 3. The error bars indicate the standard errors derived from 17-yr moving windows with bootstrap estimates.

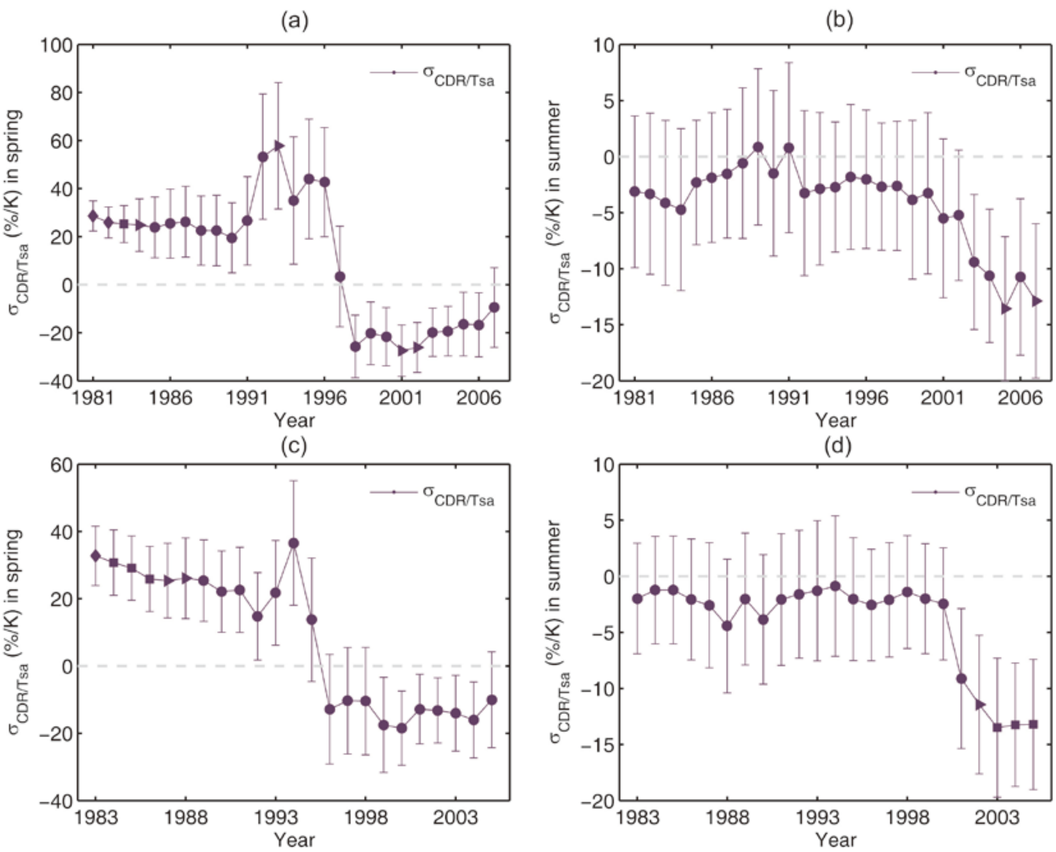

Figure S3: Temporal evolution of $\sigma_{CDR/Tsa}$ over 15-year moving windows (a,b). Temporal evolution of $\sigma_{CDR/Tsa}$ over 19-year moving windows (c,d). The symbols in the line mean the same as the symbols in Figure 3. The error bars indicate the standard errors derived from 17-yr moving windows with bootstrap estimates.

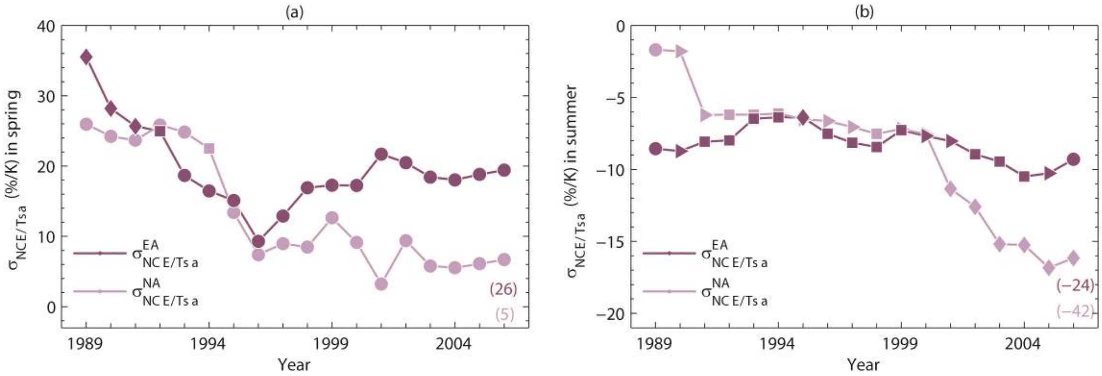

Figure S4: Temperature sensitivity of spring (May) and summer $\sigma_{\mathrm{NCE}/Tsa}$ (Jul-Aug) using Jena inversion 8.1 carbon exchange in the 17 year windows during 1981-2014. When $\sigma_{\mathrm{NCE}/Tsa}$ is positive, it means warming will stimulate carbon uptake, otherwise, warming causes carbon loss. NCE data is area weighted over EA and NA along with climate variables. $\sigma_{NCE/Tsa}$ is obtained by regressing detrended NCE over detrended Tsa and detrended Prec and then the regression coefficient is standardized by NCE. Another version of Jena inversion (s99) is also employed to show the temperature sensitivity of NCE in the latest 16 years (1999-2014), which is shown as the numbers in parenthesis corresponding to year of 2006.

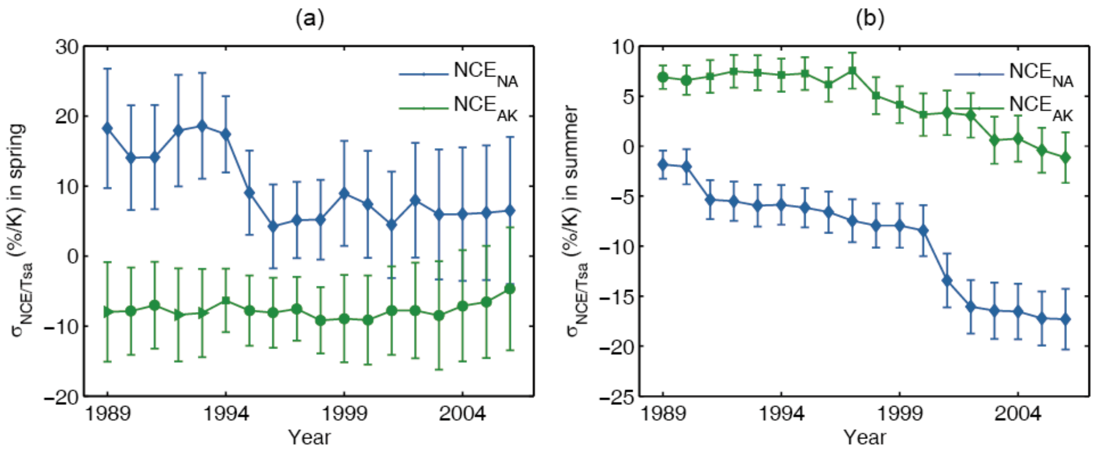

Figure S5: When North America continent is further divided into Alaska (AK) and the remaining land (NA) areas, the temperature sensitivity of spring (May) and summer $\sigma_{NCE/Tsa}$ (Jul-Aug) in the 17 year windows during 1981-2014. NCE data is area weighted over NA and AK along with climate variables.

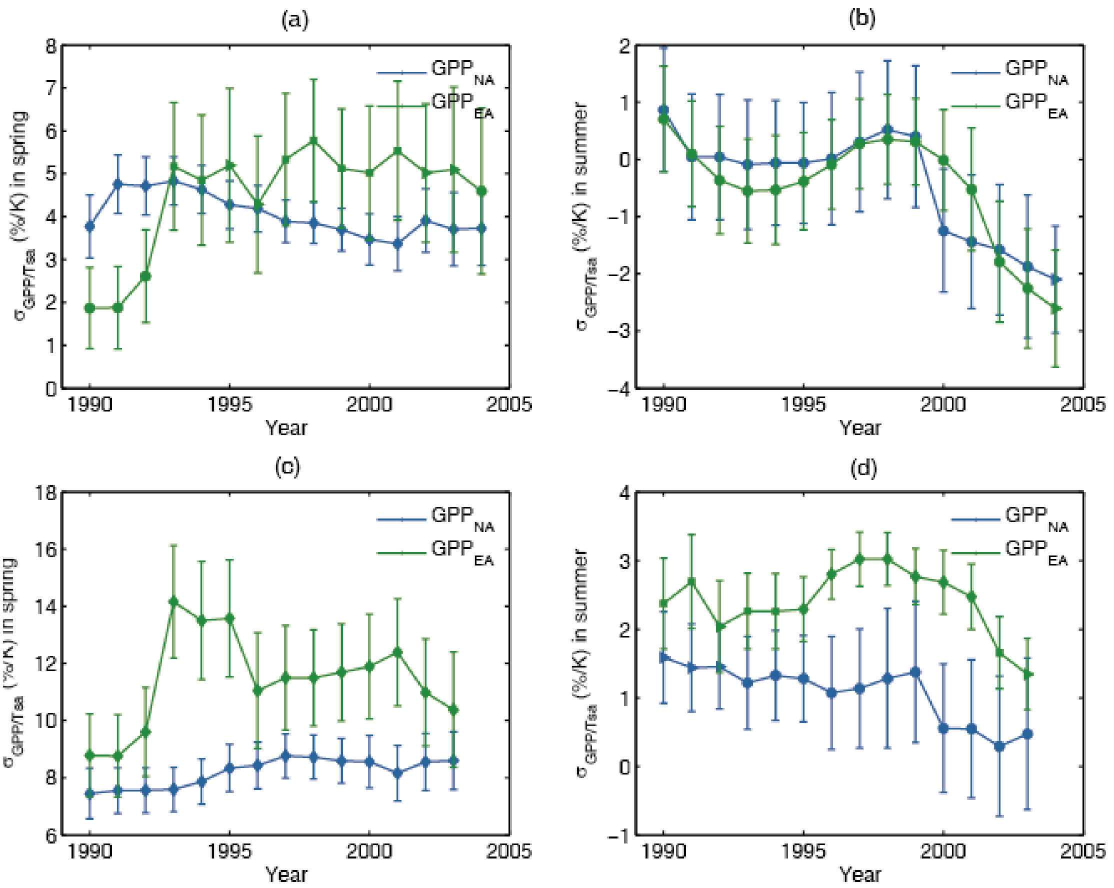

Figure S6: The temperature sensitivity of spring (May) and summer (Jul-Aug) $\sigma_{GPP/Tsa}$ from GPP_{LUE} (a,b) and GPP_{MTE} (c,d) in the 17-year windows during 1982-2012 over Northern Eurasia and North America. Both GPP_{LUE} GPP_{MTE} and climate variables are area weighted over vegetated area of Eurasia and North America. The symbols in the line mean the same as the symbols in figure 3. The error bars indicate the standard errors derived from 17-yr moving windows with bootstrap estimates.

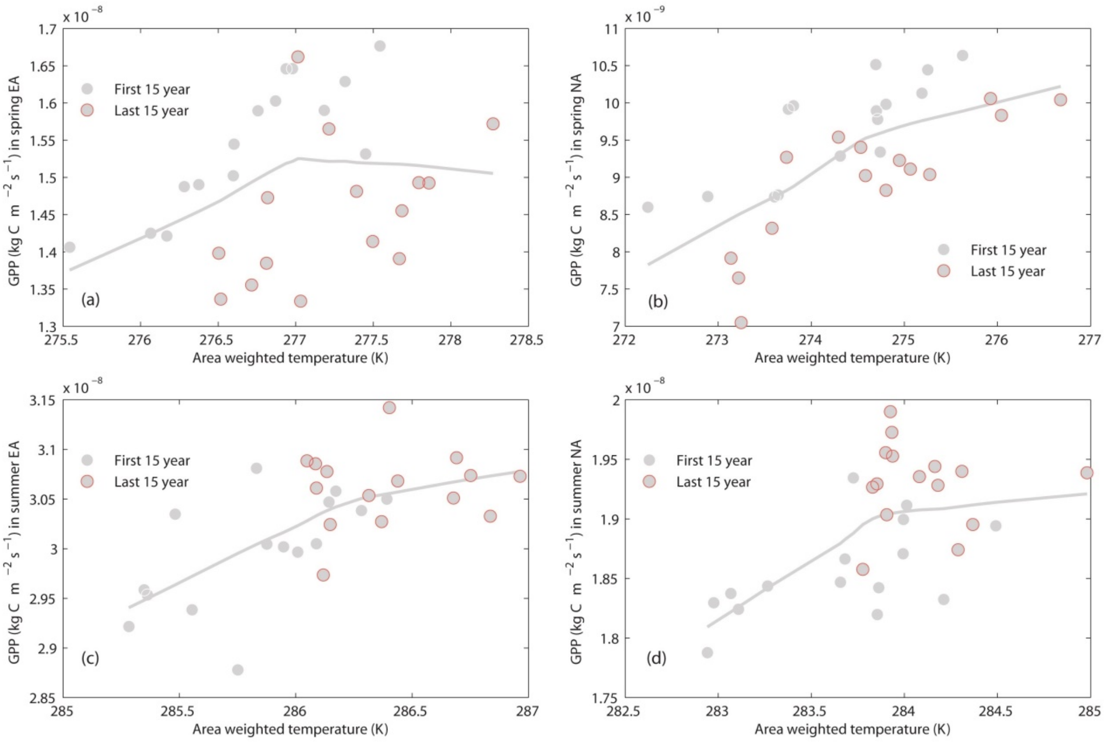

Figure S7: The spatial mean GPP_{MTE} vs. area weighted temperature for the spring EA (a), spring NA (b), summer EA (c) and summer NA (d) during 1982-2011. The first 15 years corresponds to 1982-1996 and last 15 years corresponds to 1997-2011. The GPP_{MTE}-temperature response curve is obtained by locally-weighted polynomial regression (LOWESS).

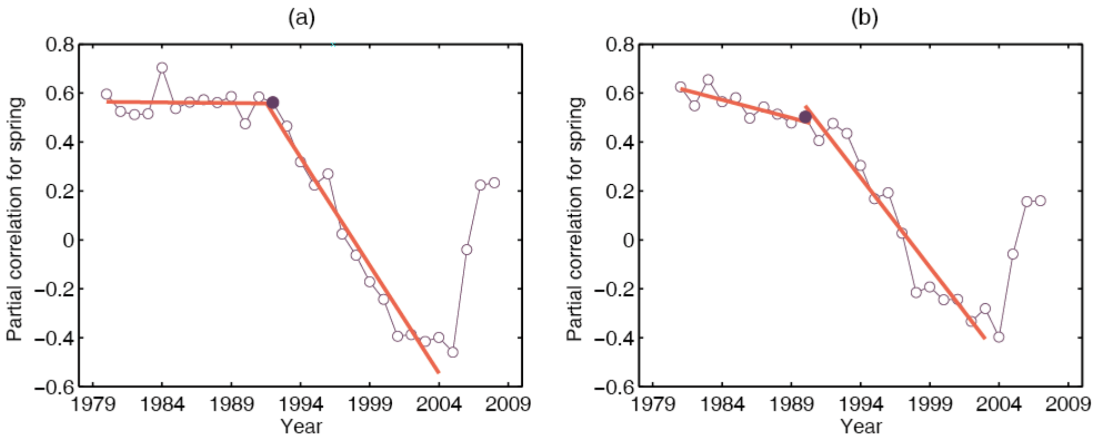

Figure S8: Breakpoints in the time series of partial correlation between spring temperature and CDR in 13 years running windows (a) and 15 years running windows (b). The marked point represents the breakpoint. The breakpoint is determined by piece-wise linear model.

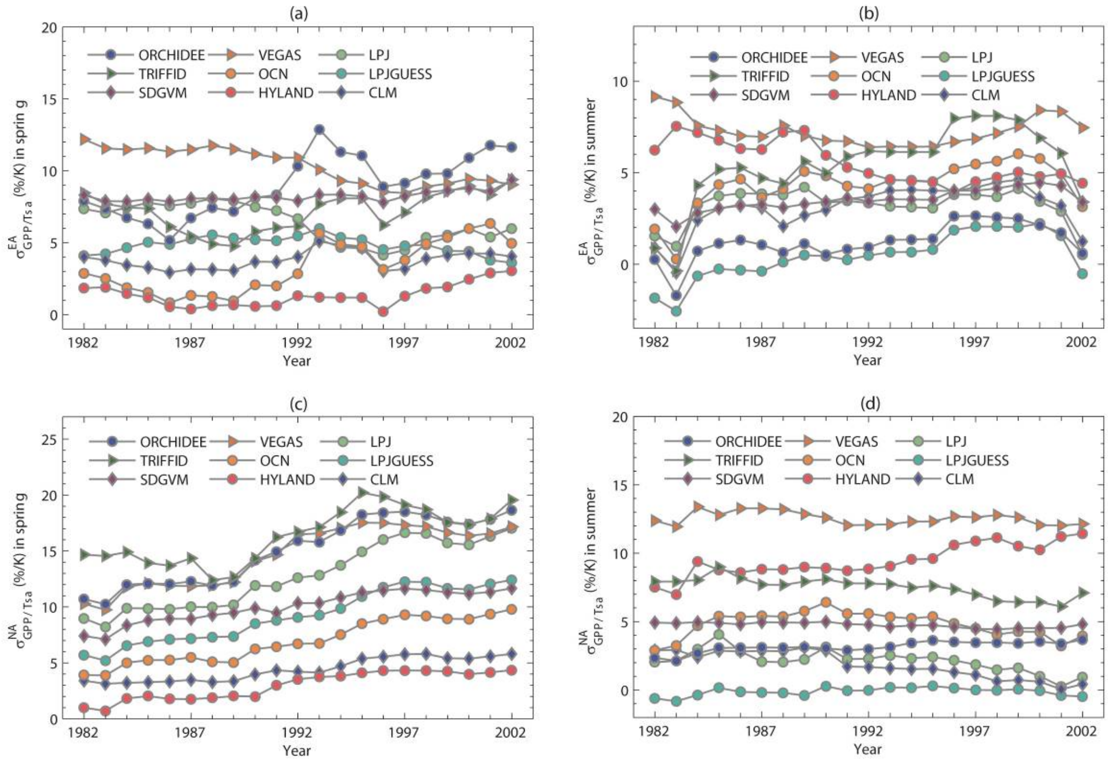

Figure S9: Temperature sensitivity of spring (a,c) and summer (b,d) GPP $\sigma_{GPP/Tsa}$ derived from trendy model results in the 17 year windows during 1974-2010 over the Eurasia (a,b) and North America (c,d).

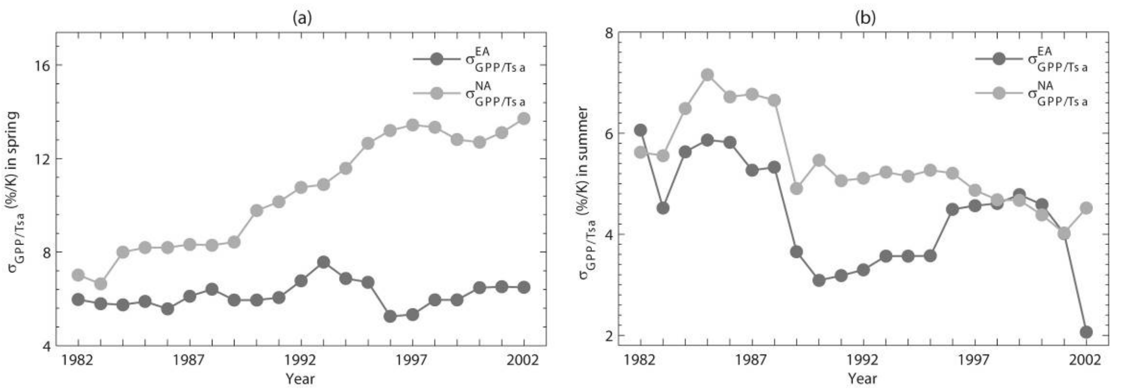

Figure S10: Temperature sensitivity of mean spring (a) and summer (b) GPP ($\sigma_{GPP/Tsa}$) by averaging 9 model results from trendy in the 17 year windows during 1974-2010 over the Eurasia and North America.

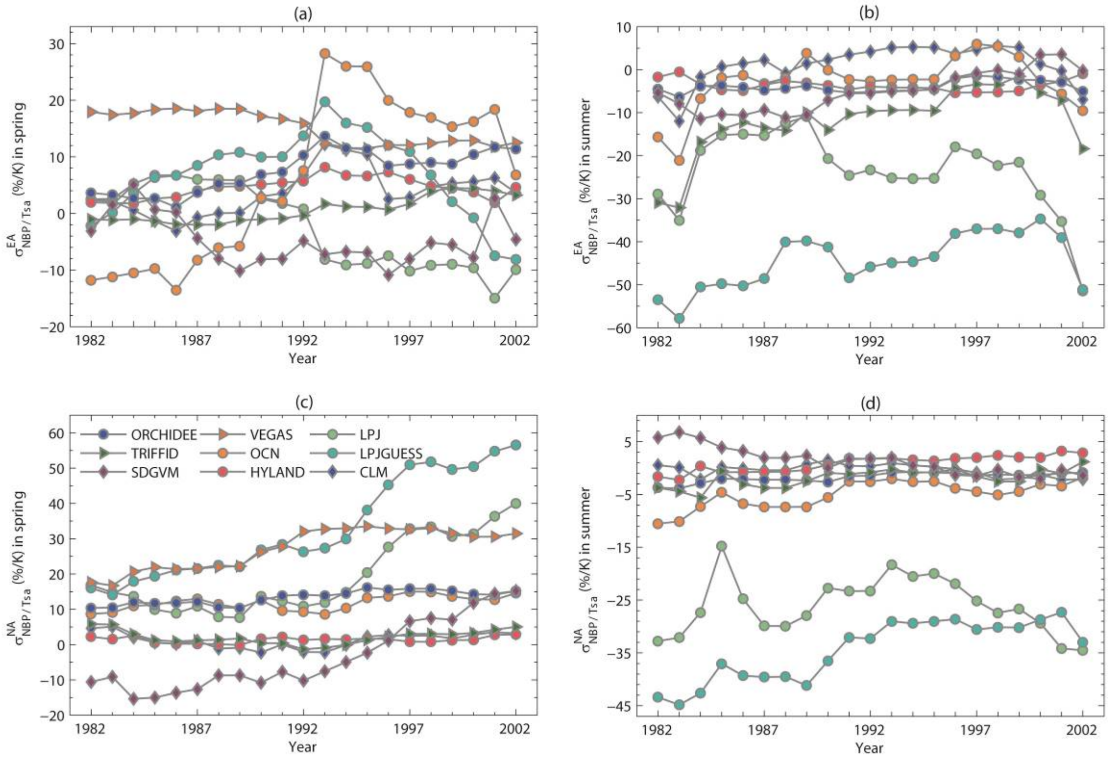

Figure S11: Temperature sensitivity of spring (a,c) and summer (b,d) NBP $\sigma_{NBP/Tsa}$ derived from trendy model results in the 17 year windows during 1974-2010 over the Eurasia (a,b) and North America (c,d).

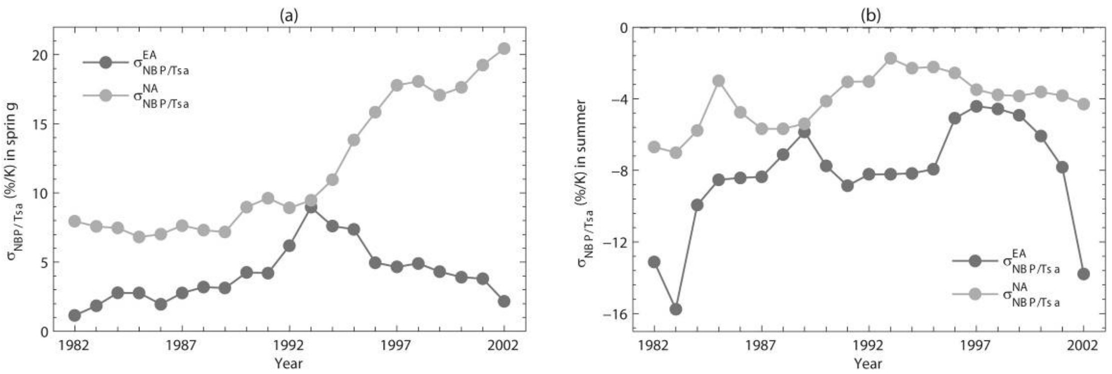

Figure S12: Temperature sensitivity of mean spring (a) and summer (b) NBP ($\sigma_{NBP/Tsa}$) by averaging 9 model results from trendy in the 17 year windows during 1974-2010 over the Eurasia and North America.

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