

Atmospheric Impacts on Arctic Terrestrial Carbon Exchange beyond 2100 in the CESM

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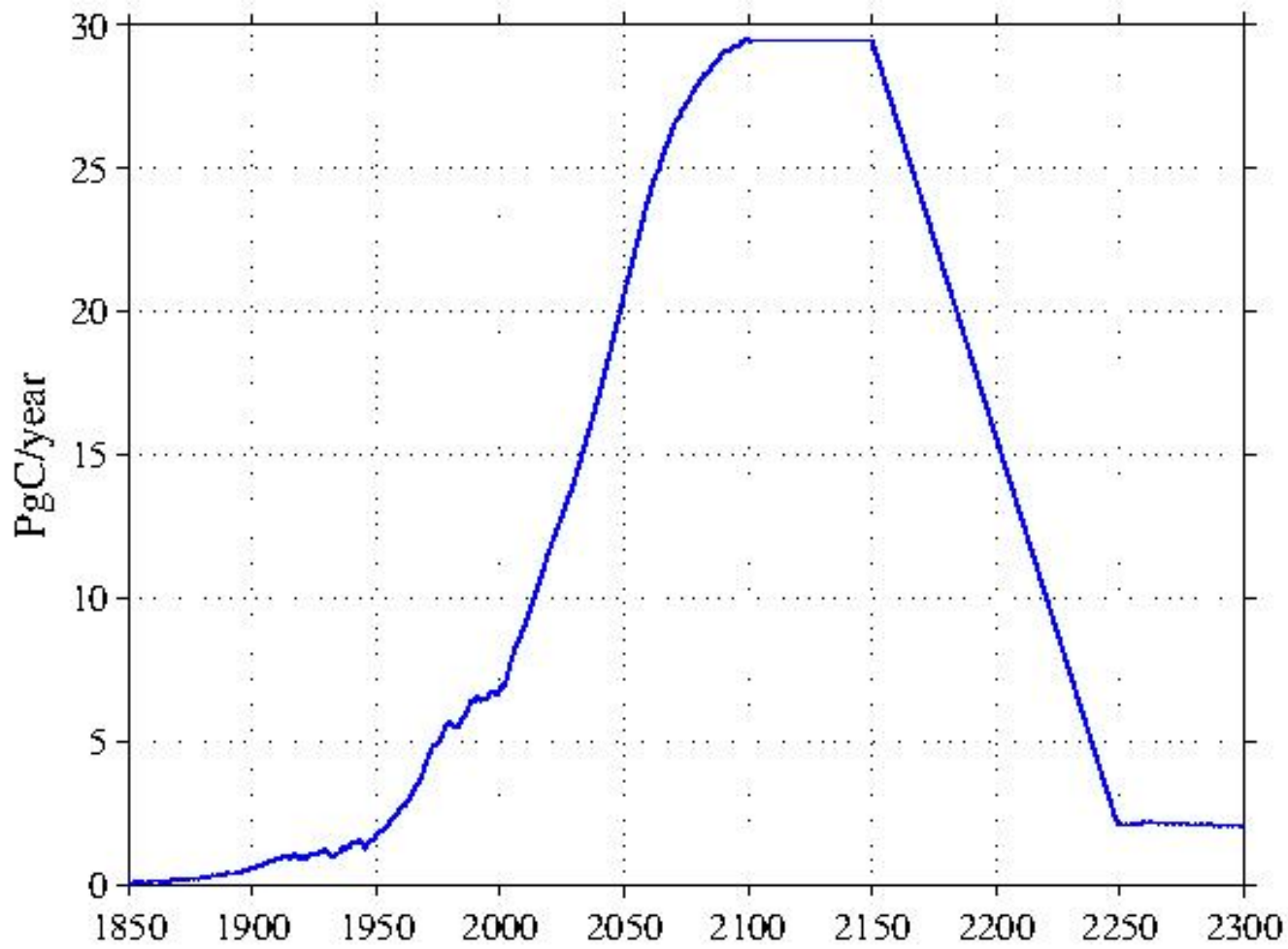


Outline

- How does persistently high CO₂ affect Arctic climate & biogeochemistry after 2100?
- How do changes in temperature and precipitation impact the regional variability of Arctic terrestrial carbon exchange during the growing season?
 - Growing season length changes
 - Shifts in annual cycles of GPP, HR, NEE
 - Changes in annual means and variability
- Summary/conclusions

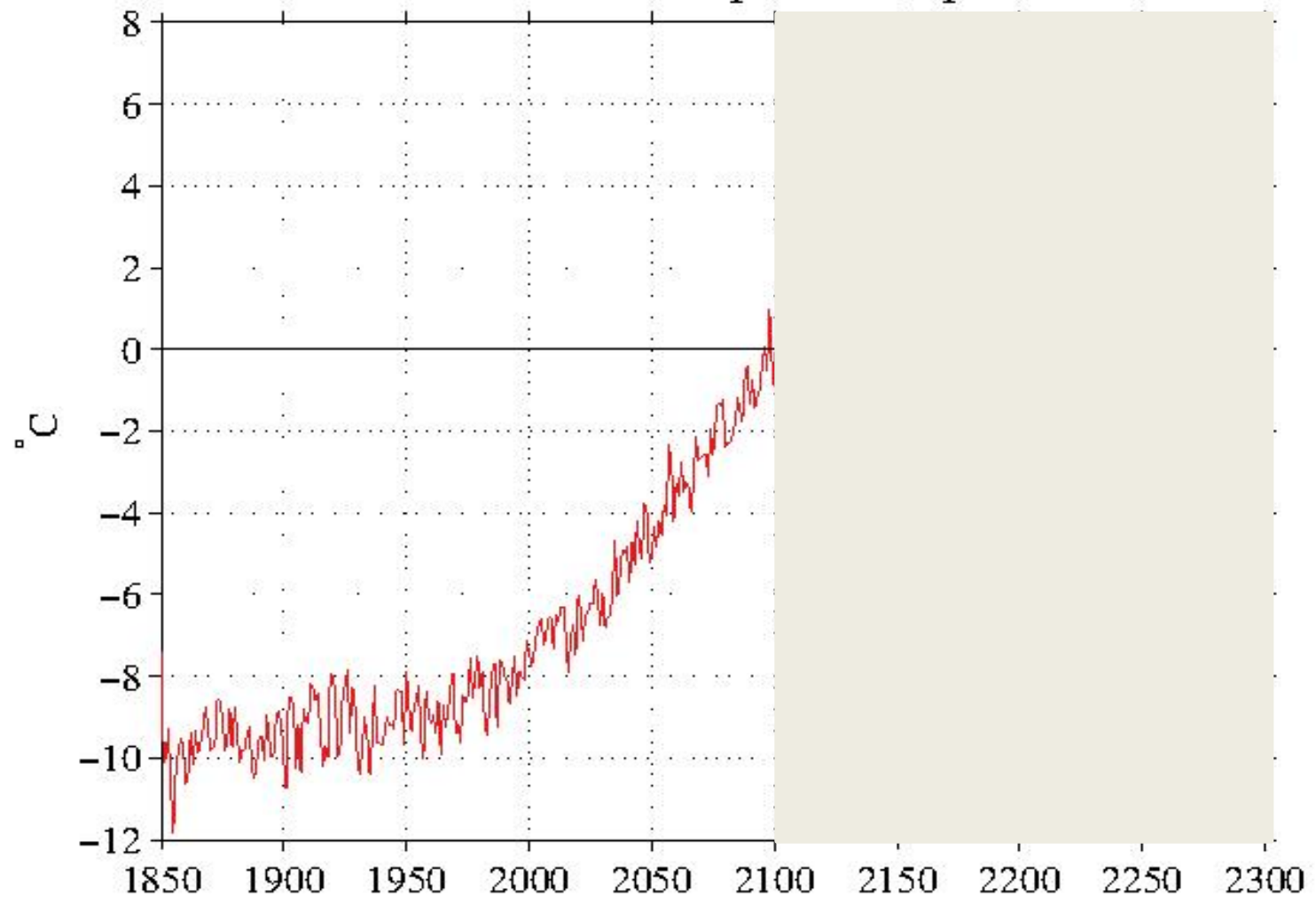
How does the Arctic atmosphere respond to high CO₂ emissions after 2100?

Annual total global land fossil fuel CO₂ emissions in the CESM ECP8.5 BDRD experiment



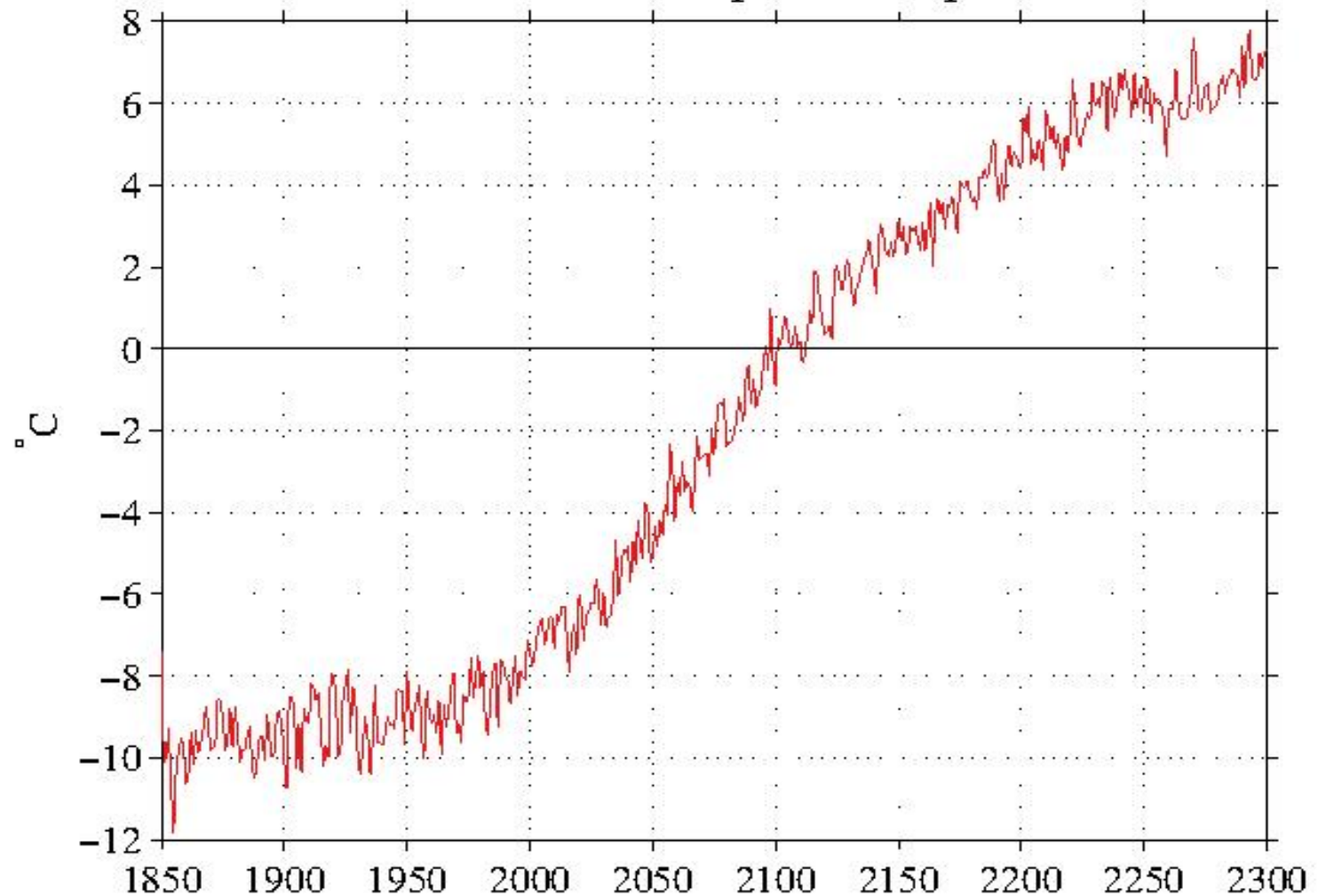
Warming through 2100

Annual Mean Arctic Bottom-Level Atmospheric Temperature



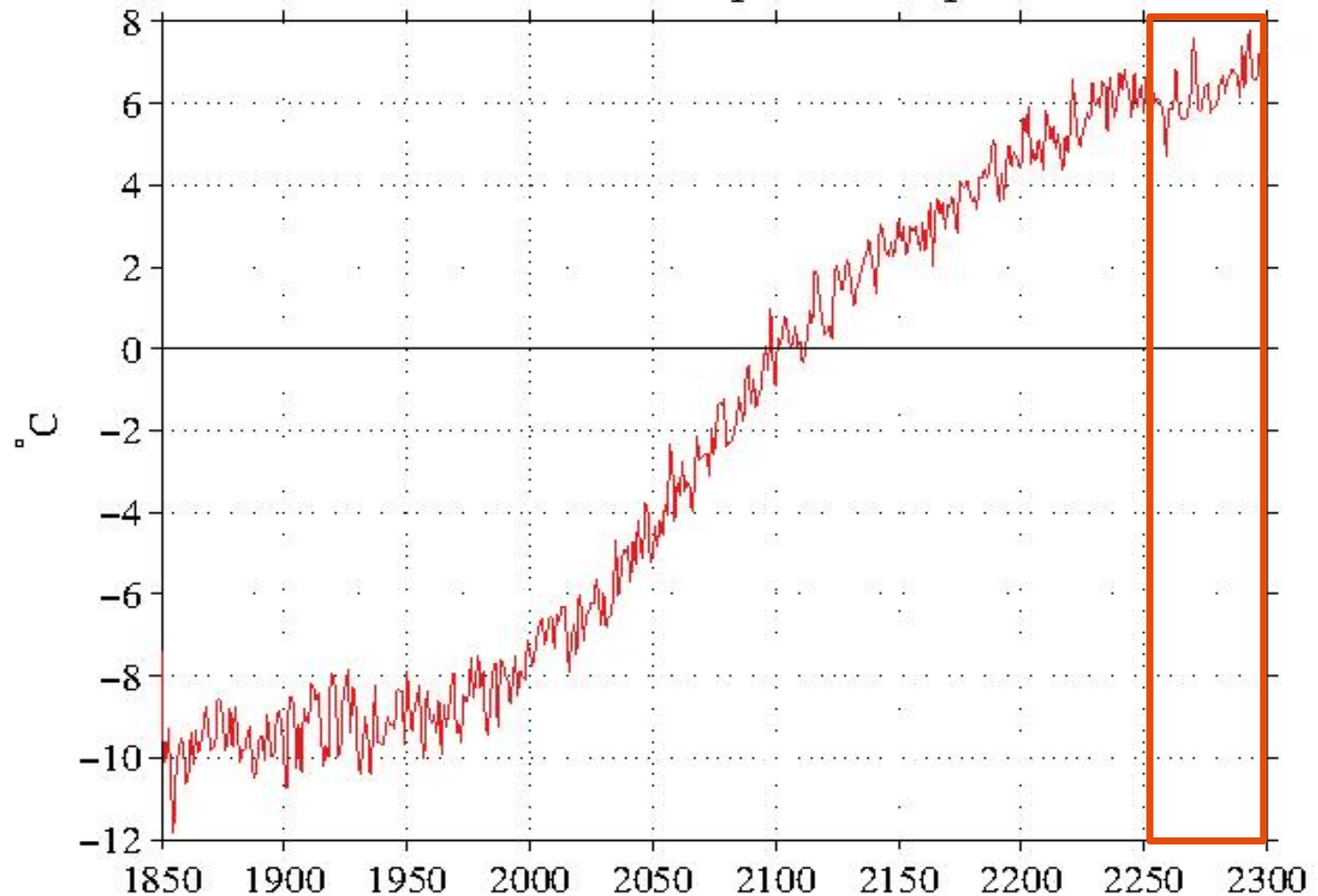
More warming after 2100

Annual Mean Arctic Bottom-Level Atmospheric Temperature



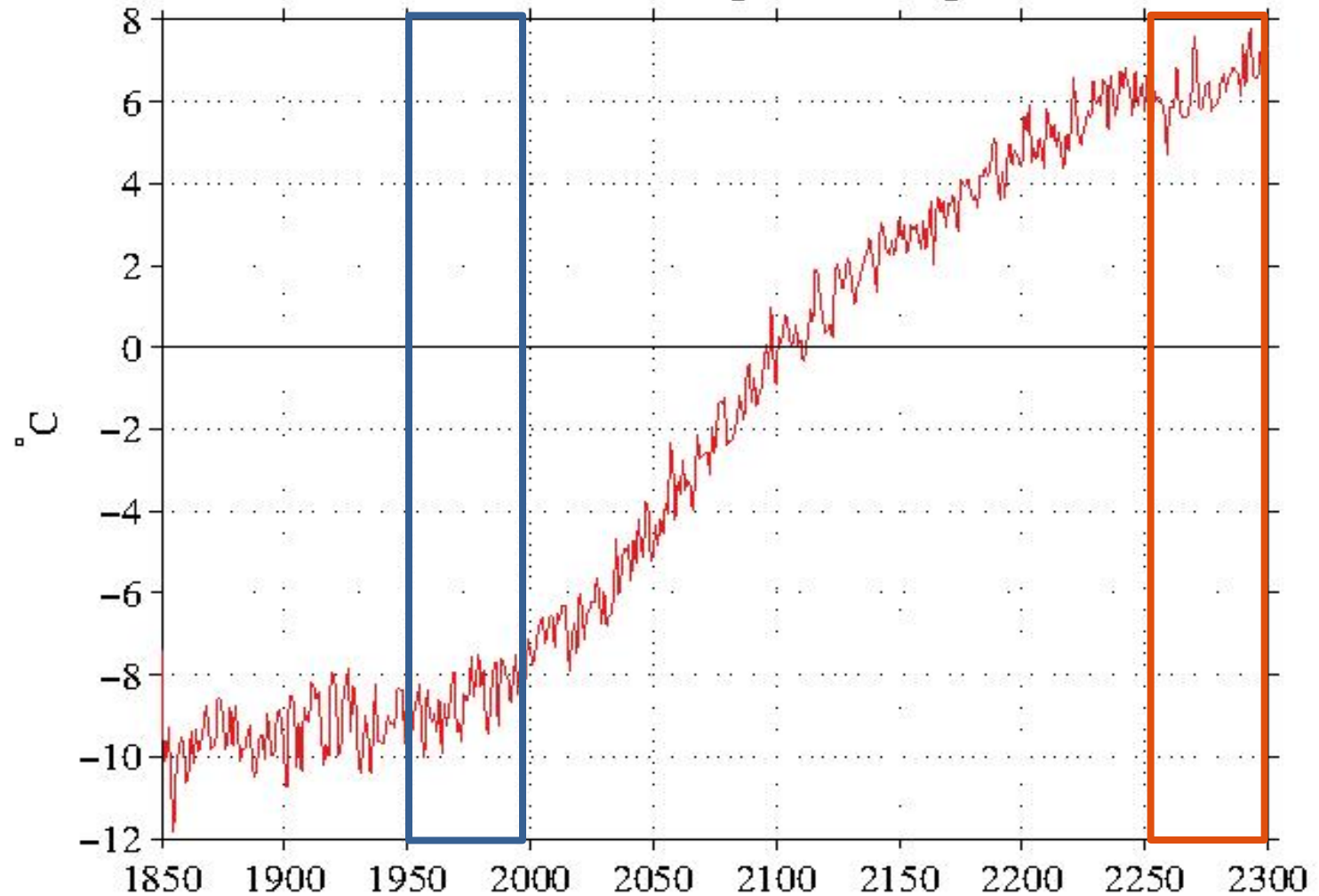
Future Arctic climate has annual mean temperatures near 6°C...

Annual Mean Arctic Bottom-Level Atmospheric Temperature



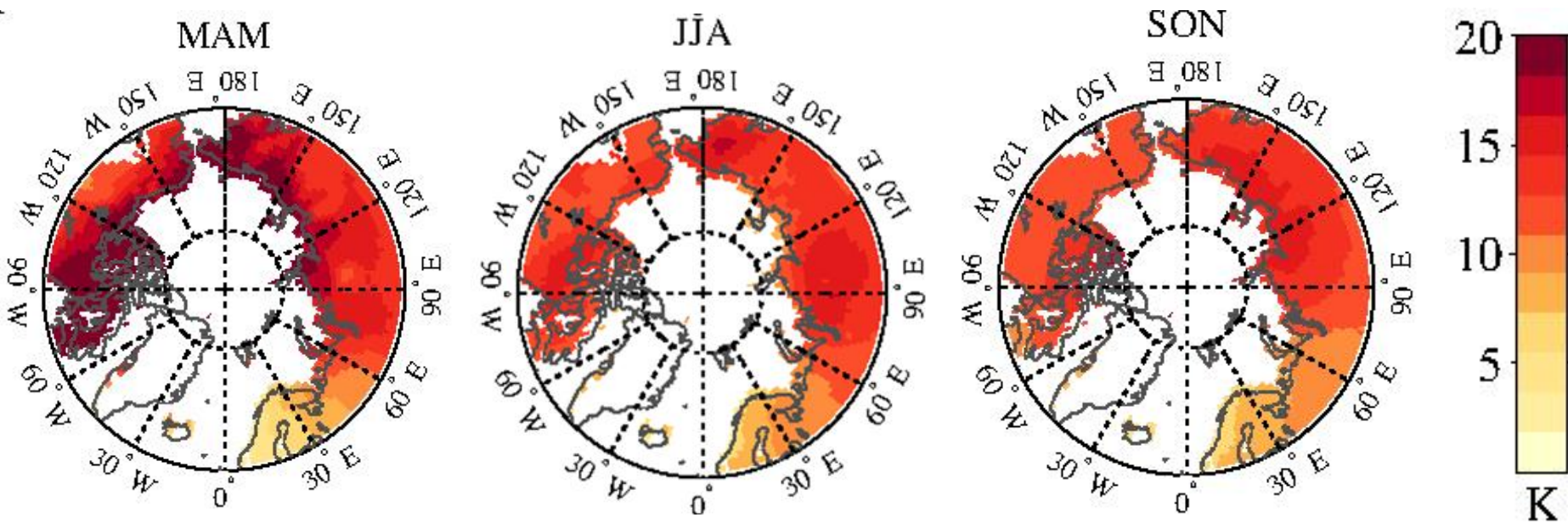
...15°C warmer than the “present-day” Arctic climate!

Annual Mean Arctic Bottom-Level Atmospheric Temperature



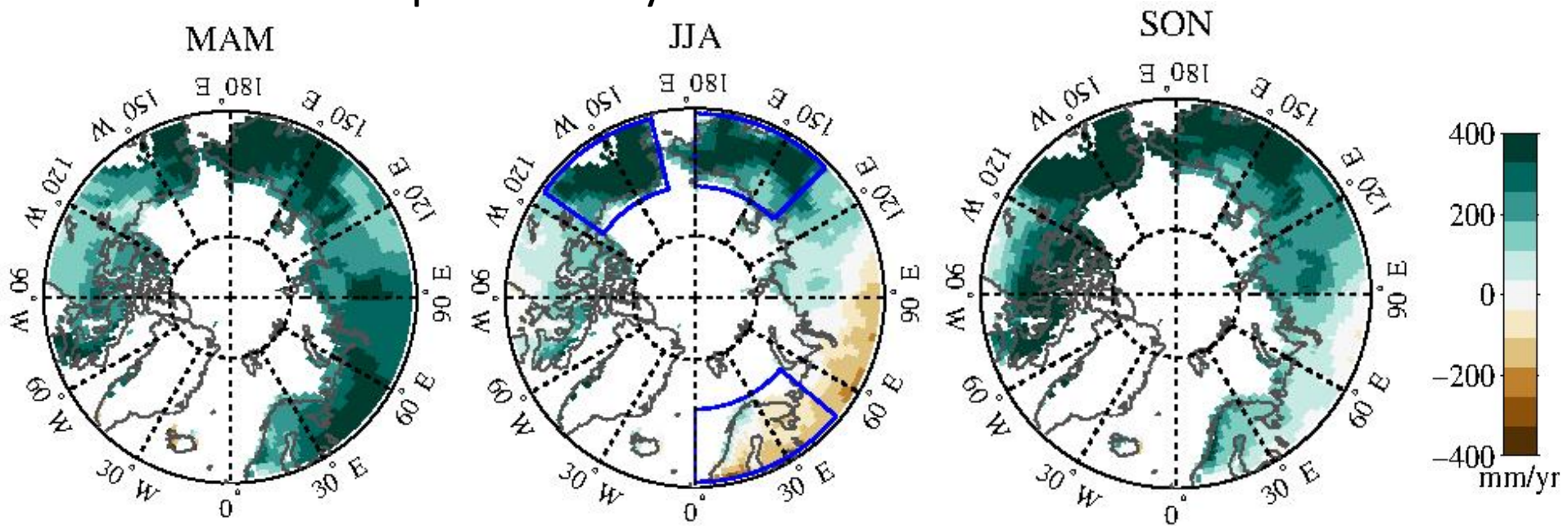
Warming occurs over the entire terrestrial Arctic in all seasons

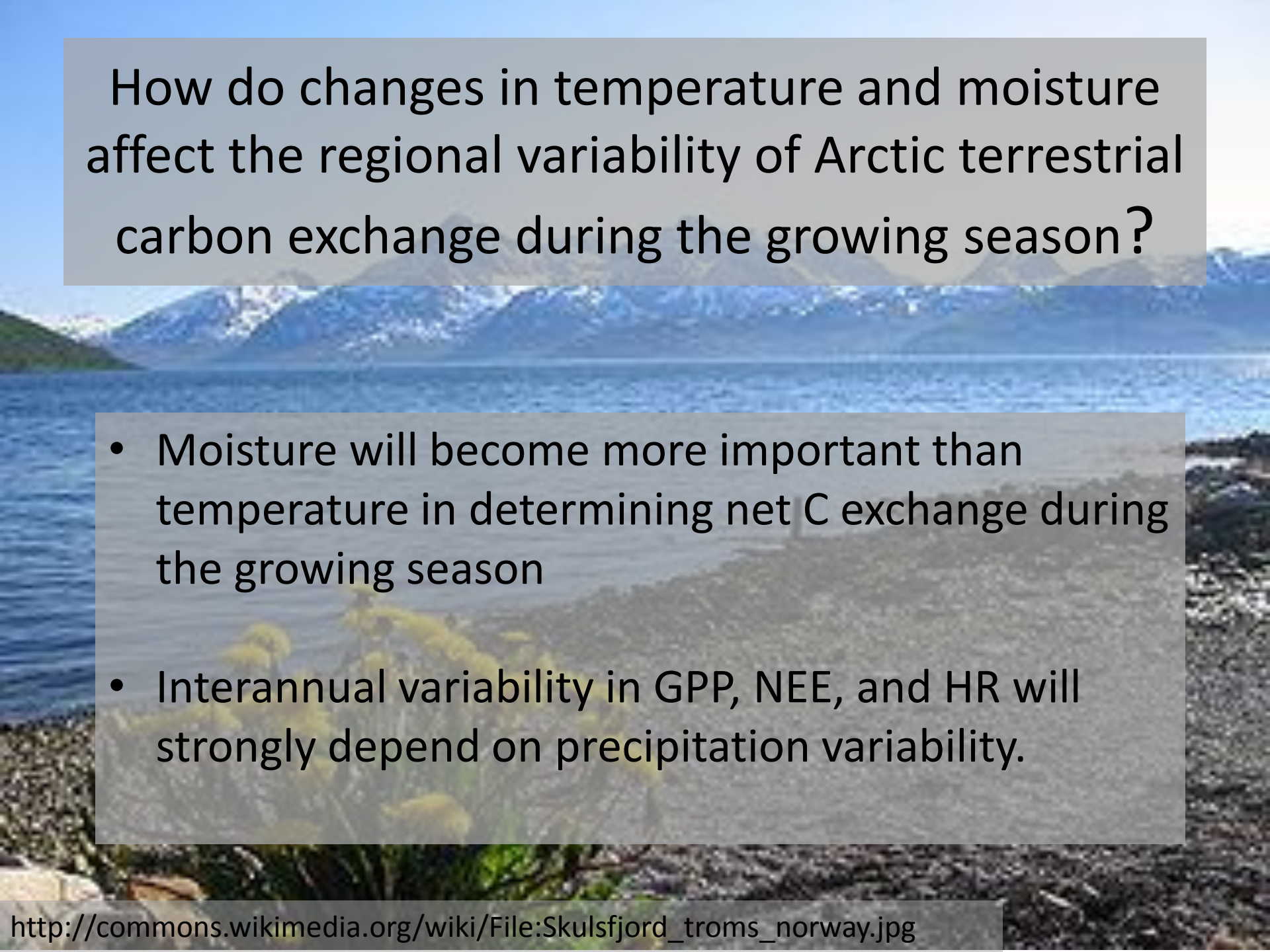
Change in the bottom-level atmospheric temperature (ΔT) between present-day (1951—2000) and future (2251—2300) climates



Warm-season precipitation changes vary regionally

Change in precipitation rate (ΔP) between
present-day and future climates





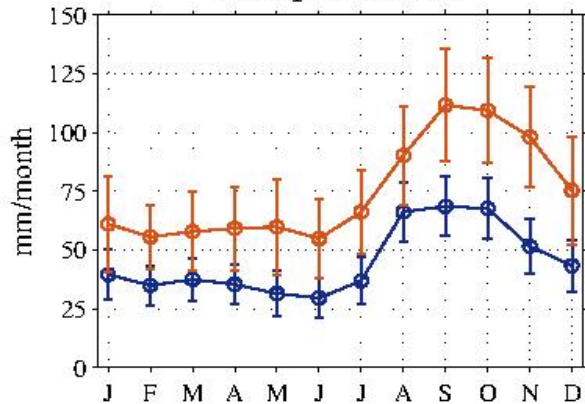
How do changes in temperature and moisture affect the regional variability of Arctic terrestrial carbon exchange during the growing season?

- Moisture will become more important than temperature in determining net C exchange during the growing season
- Interannual variability in GPP, NEE, and HR will strongly depend on precipitation variability.

Regions with large growing season ΔP

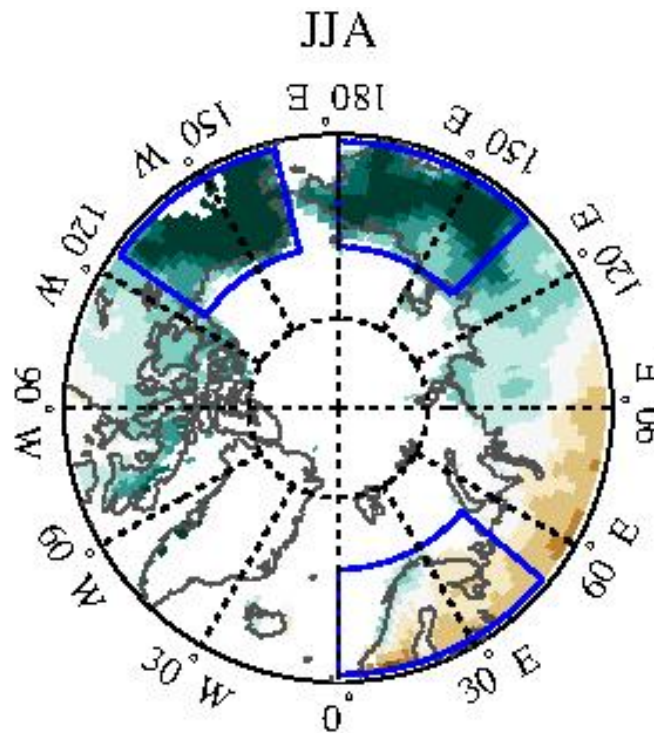
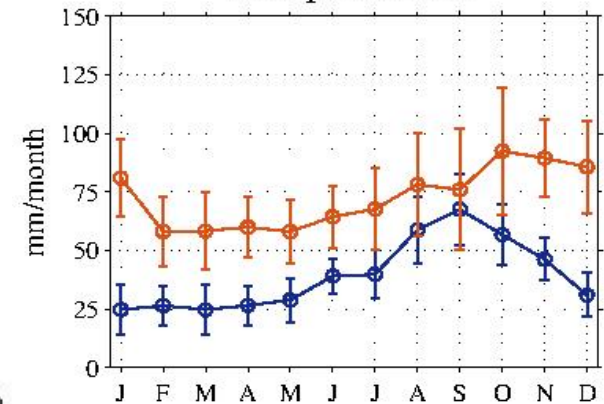
Alaska

Precipitation rate



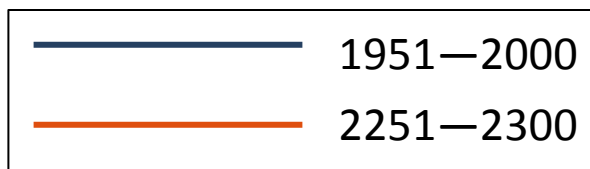
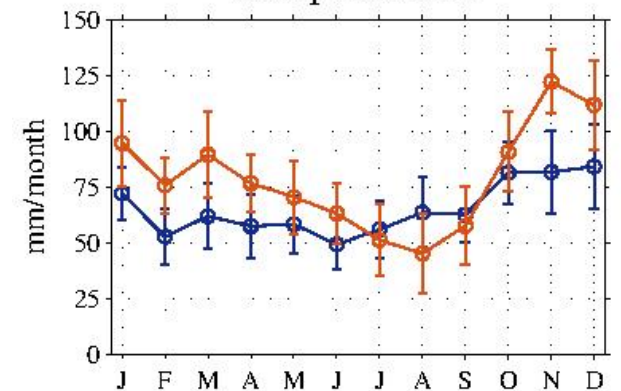
Siberia

Precipitation rate



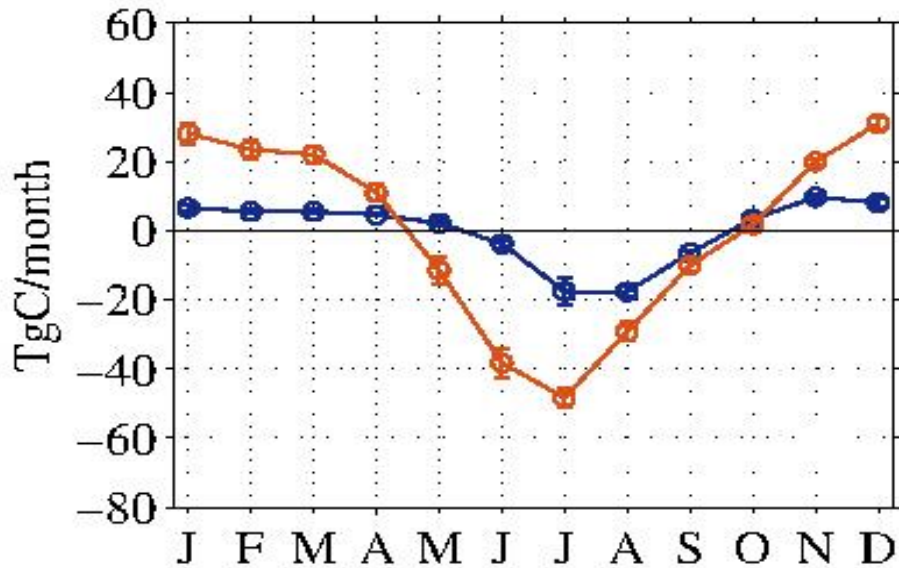
Fennoscandia

Precipitation rate



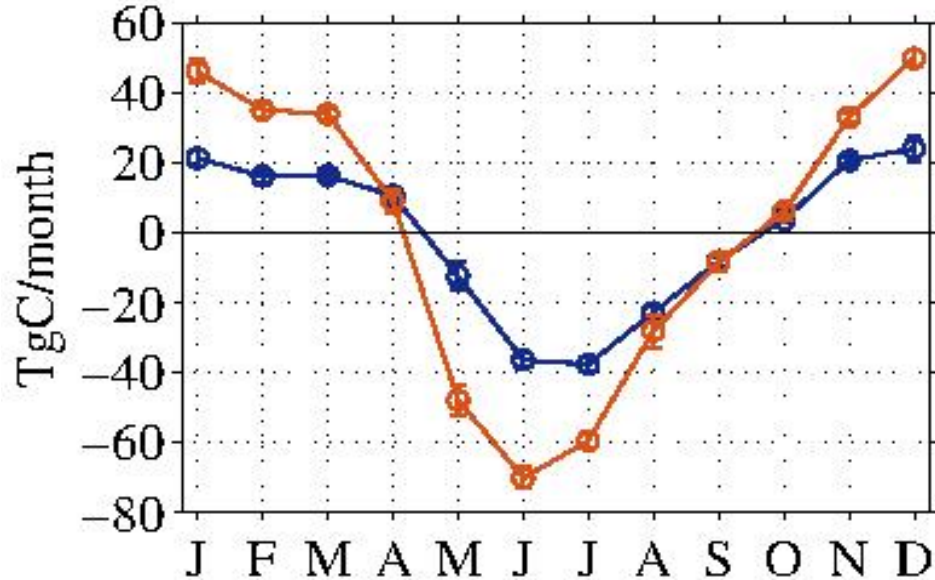
Growing Season Shifts

Alaska
NEE

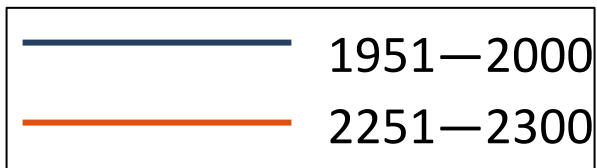


GS lengthens from Jun—Sep to May—Sep

Fennoscandia
NEE



No change in GS



NEE < 0 = net C uptake by land

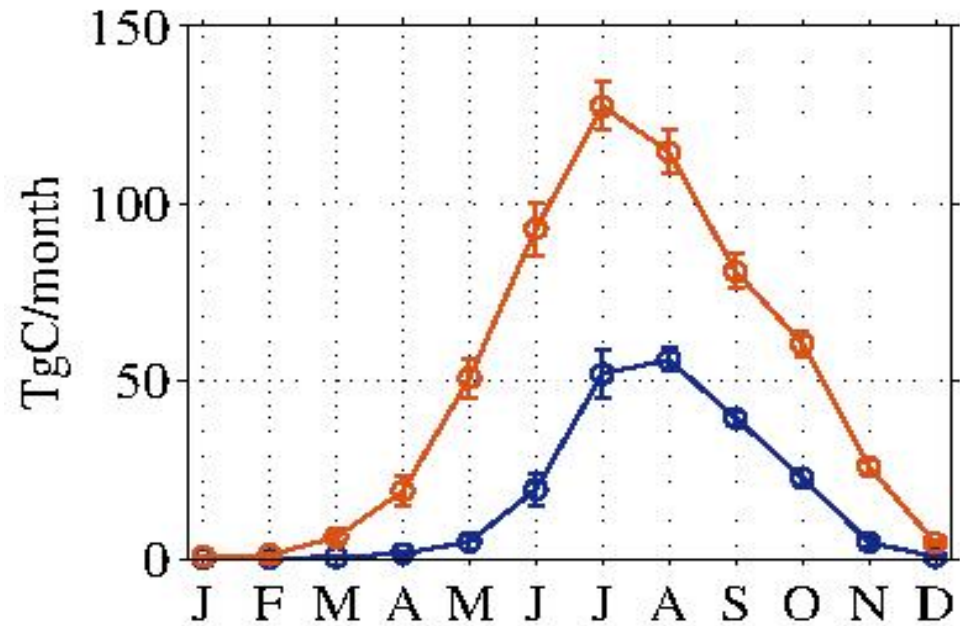
NEE > 0 = net C release

Growing Season (GS): months in each period with average NEE < 0

GPP Annual Cycles

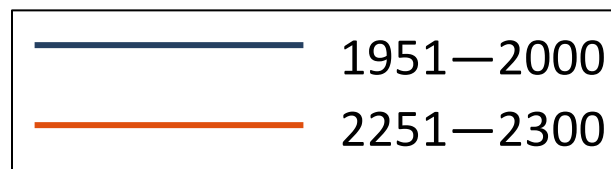
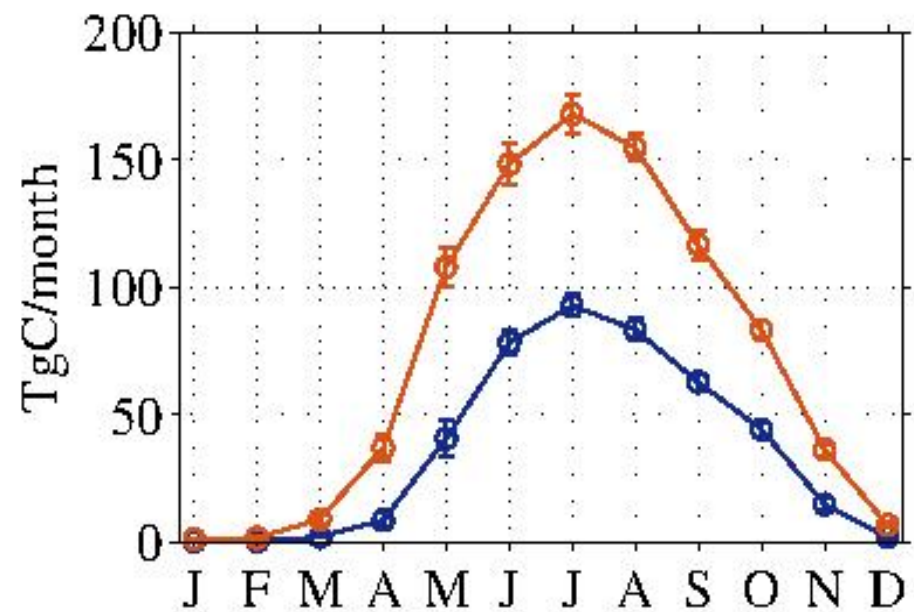
Alaska

GPP



Fennoscandia

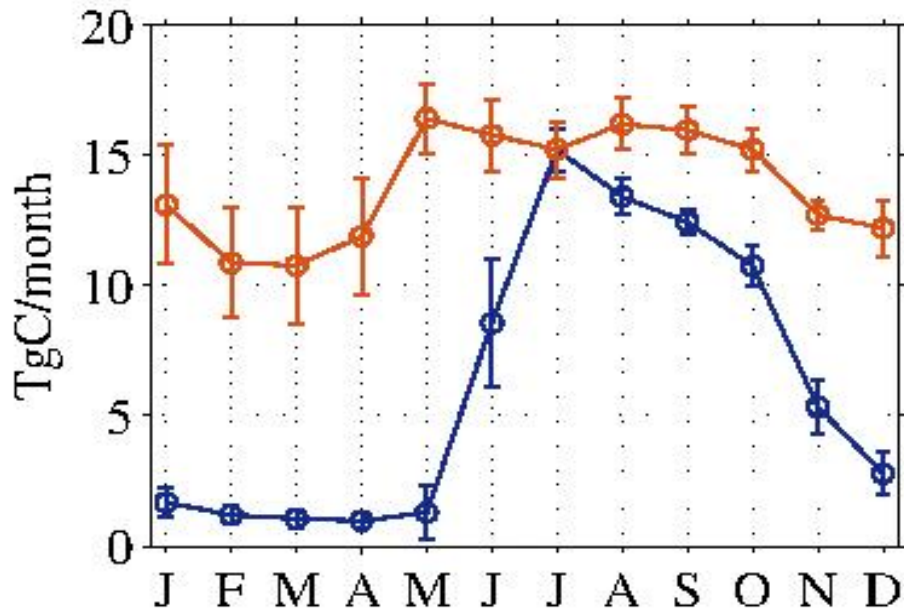
GPP



HR Annual Cycles

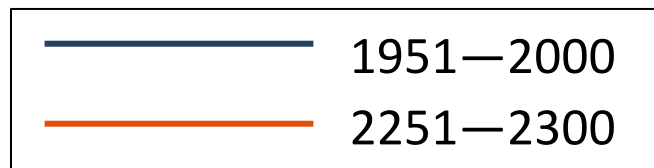
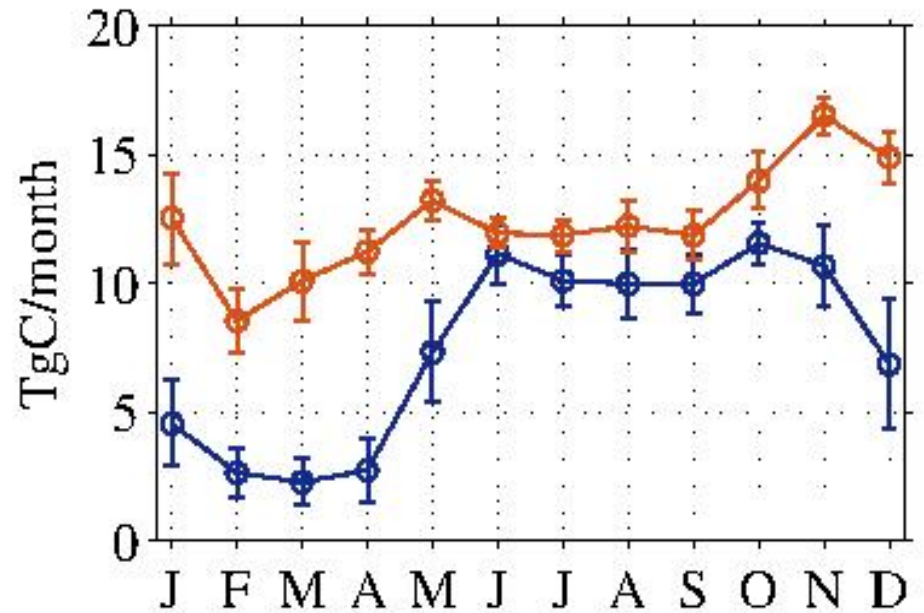
Alaska

HR



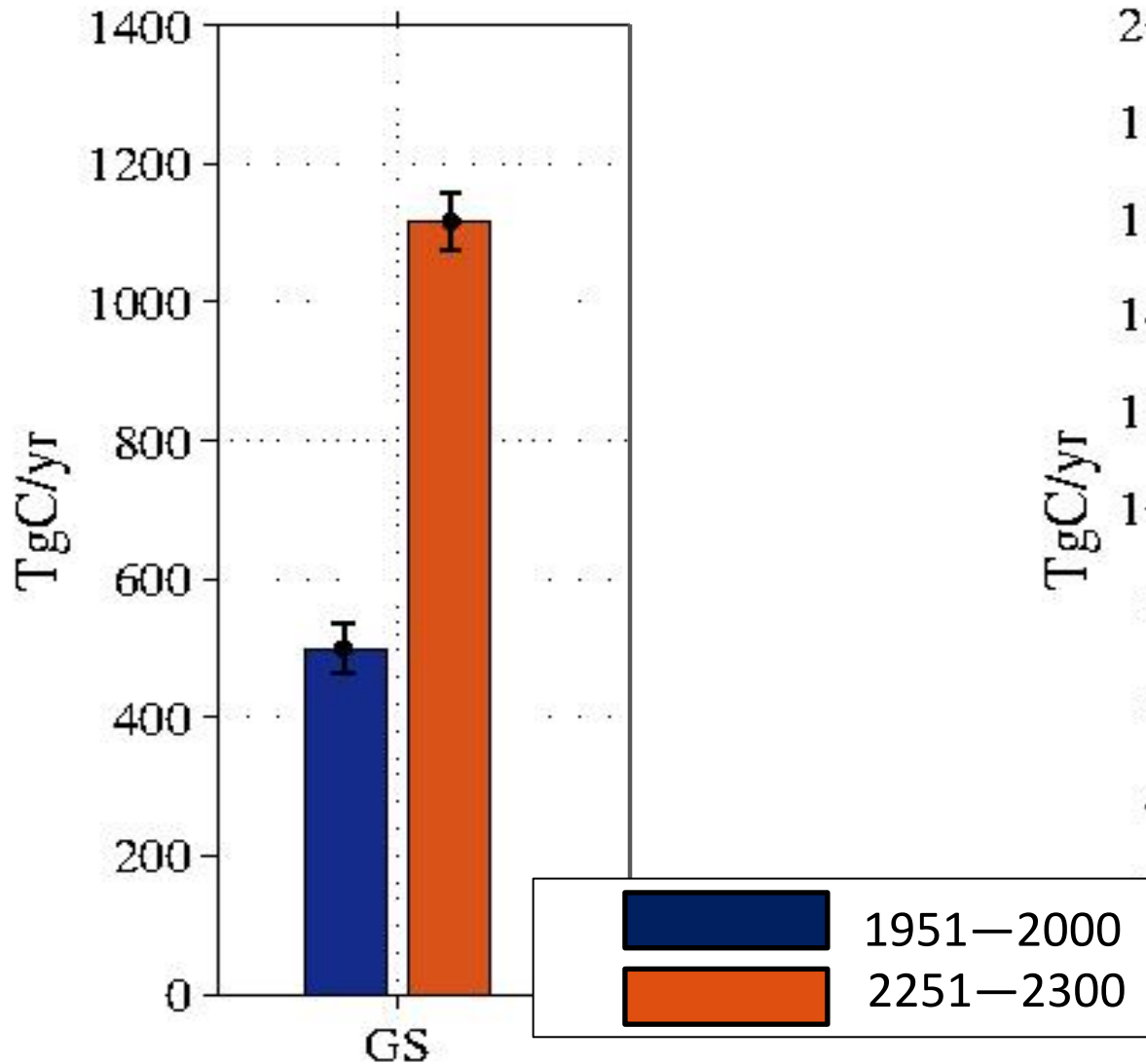
Fennoscandia

HR

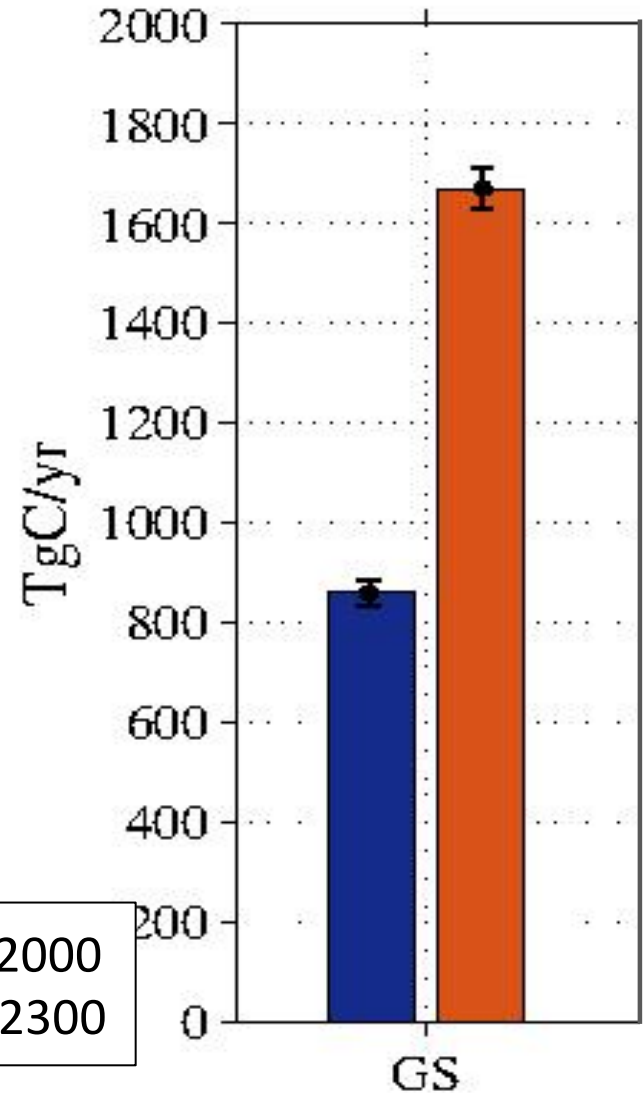


GPP Growing Season Means and Standard Deviations

Alaska



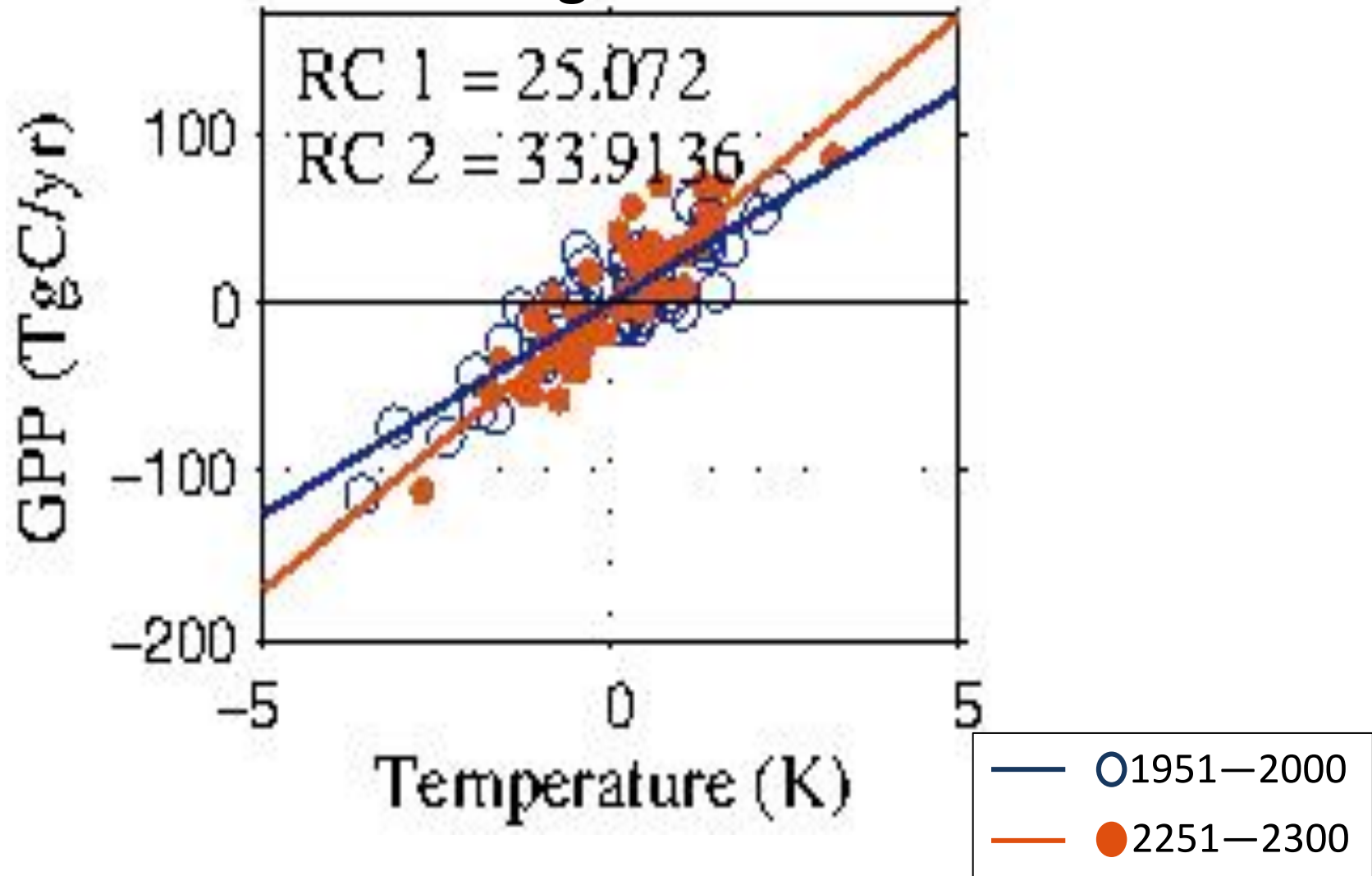
Fennoscandia



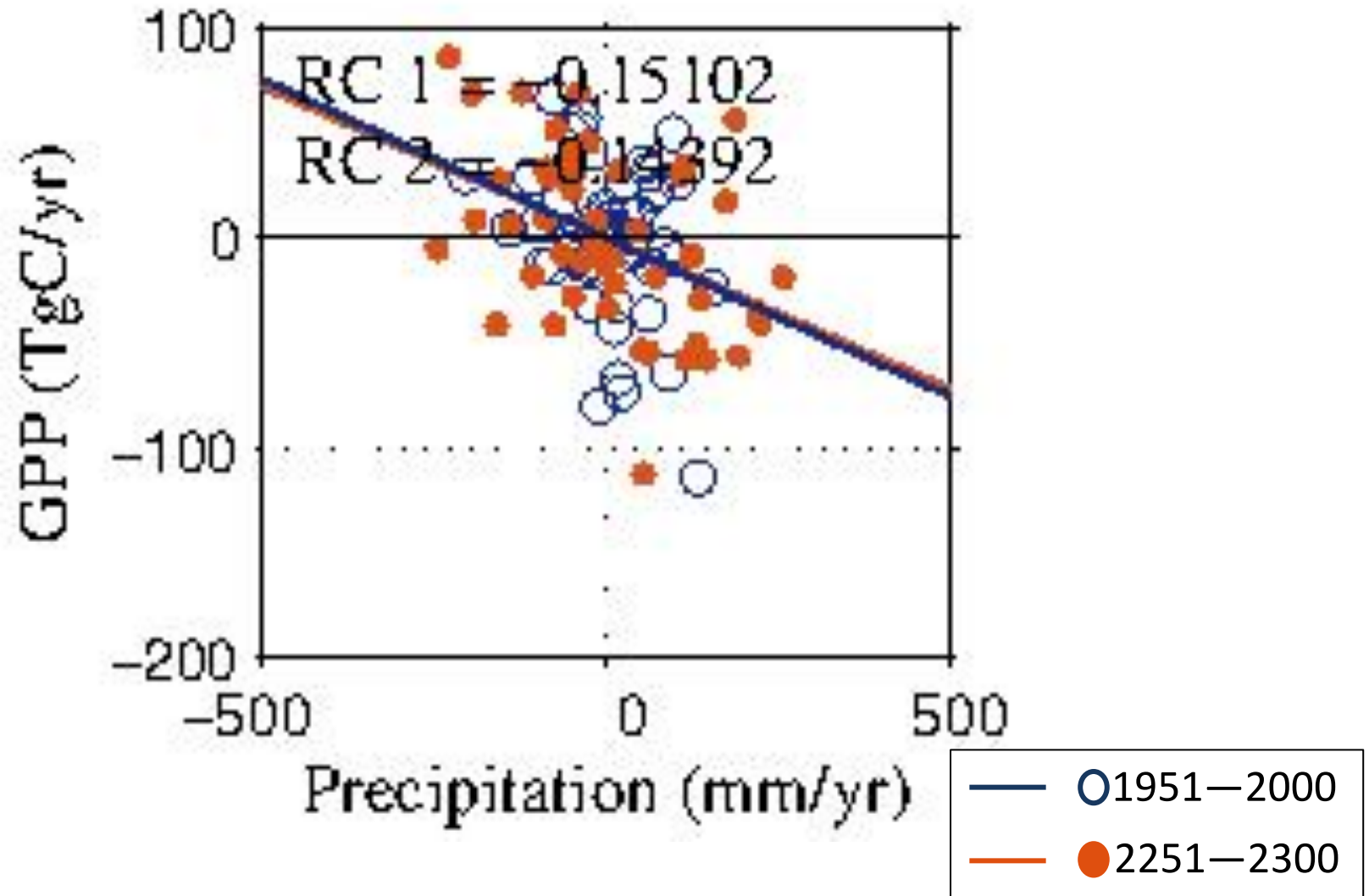
GPP vs T

Alaska

Growing Season



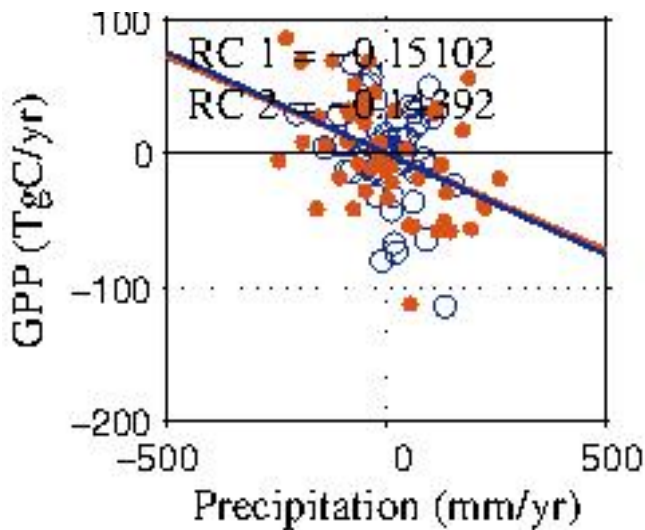
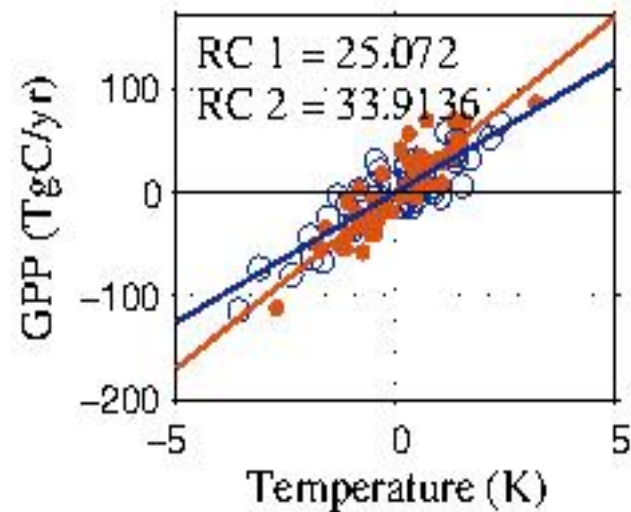
GPP vs P Alaska Growing Season



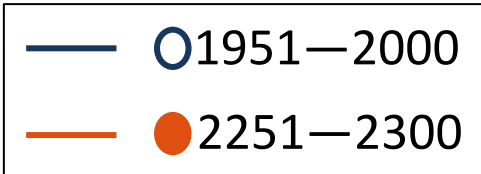
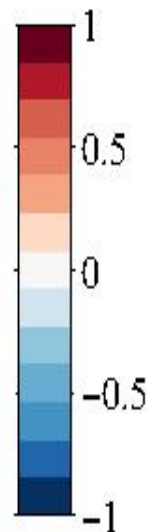
Alaska GPP Correlations

2251—2300

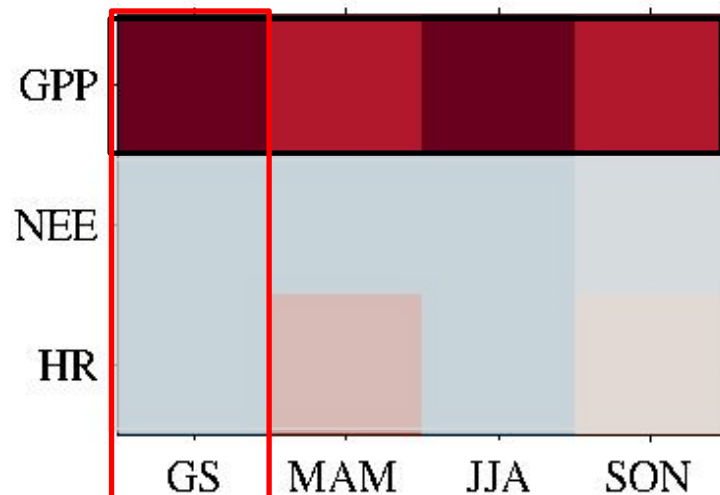
Growing Season



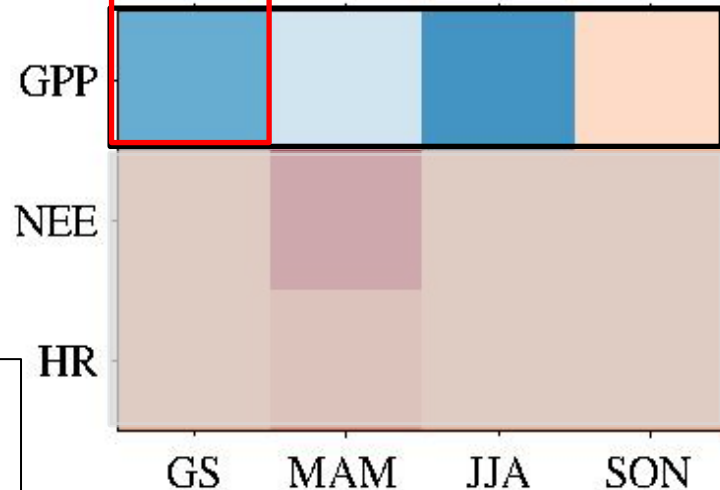
Correlation Coefficient



Temperature

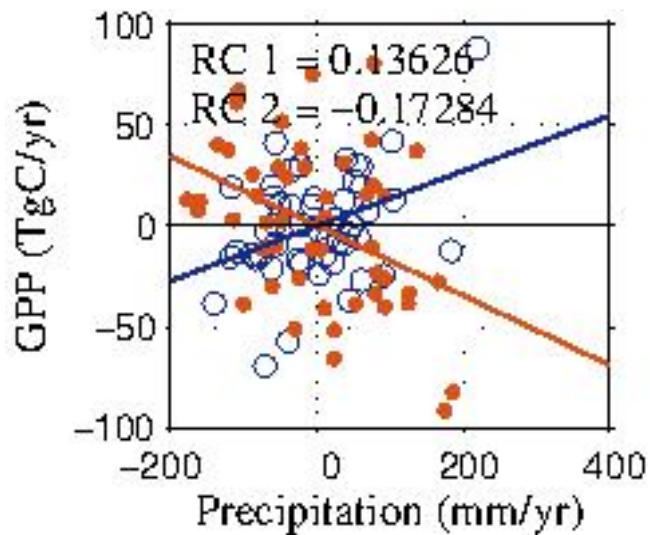
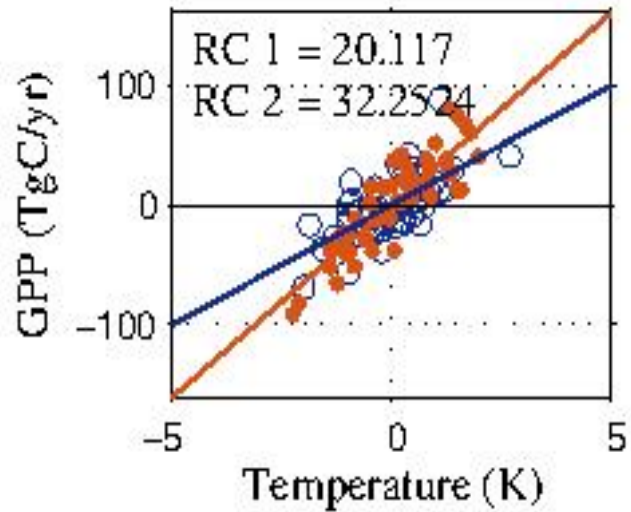


Precipitation

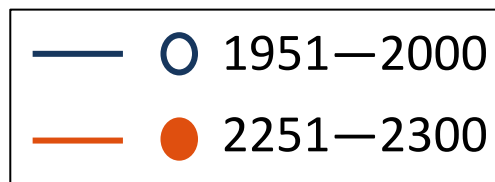
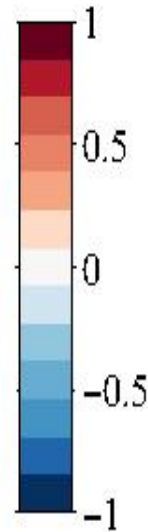


Fennoscandia GPP Correlations

Growing Season

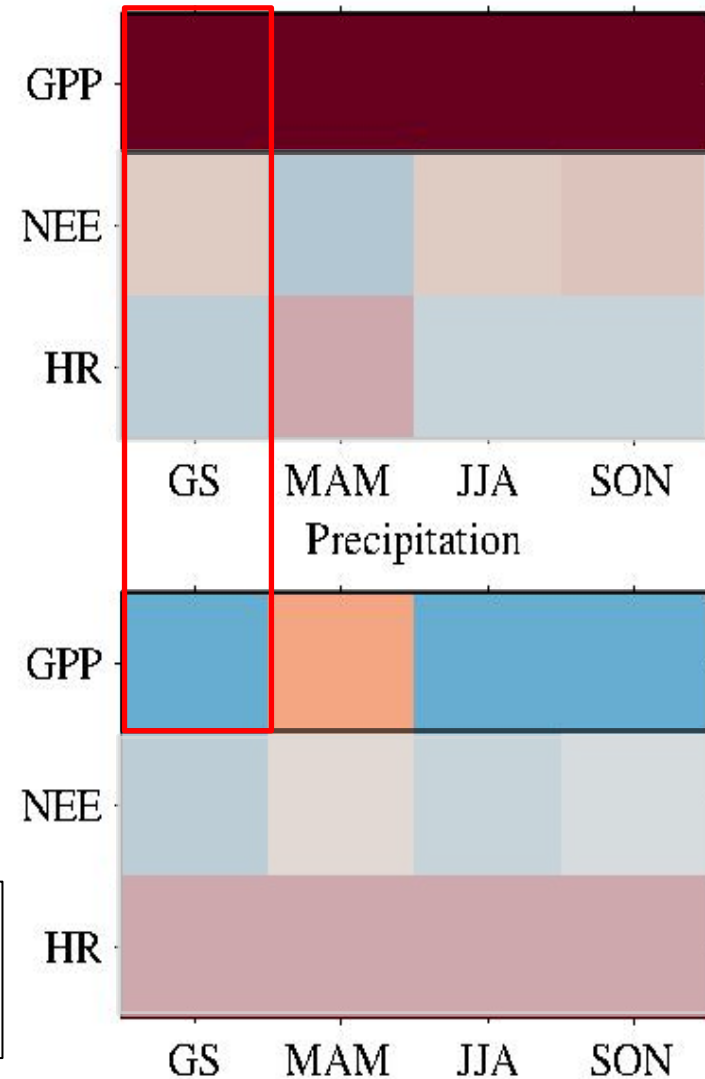


Correlation Coefficient



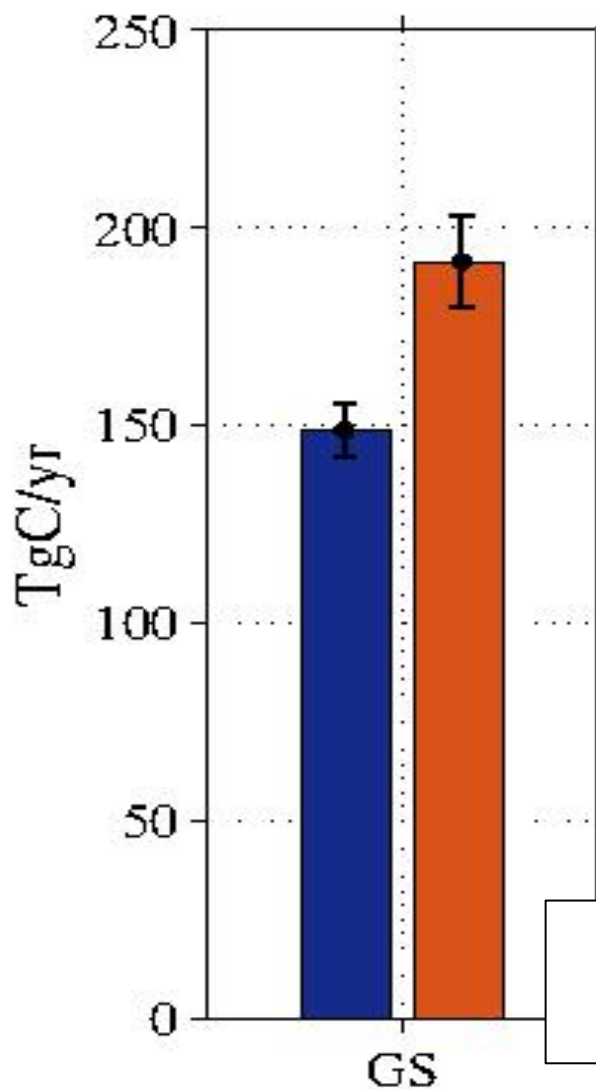
2251—2300

Temperature

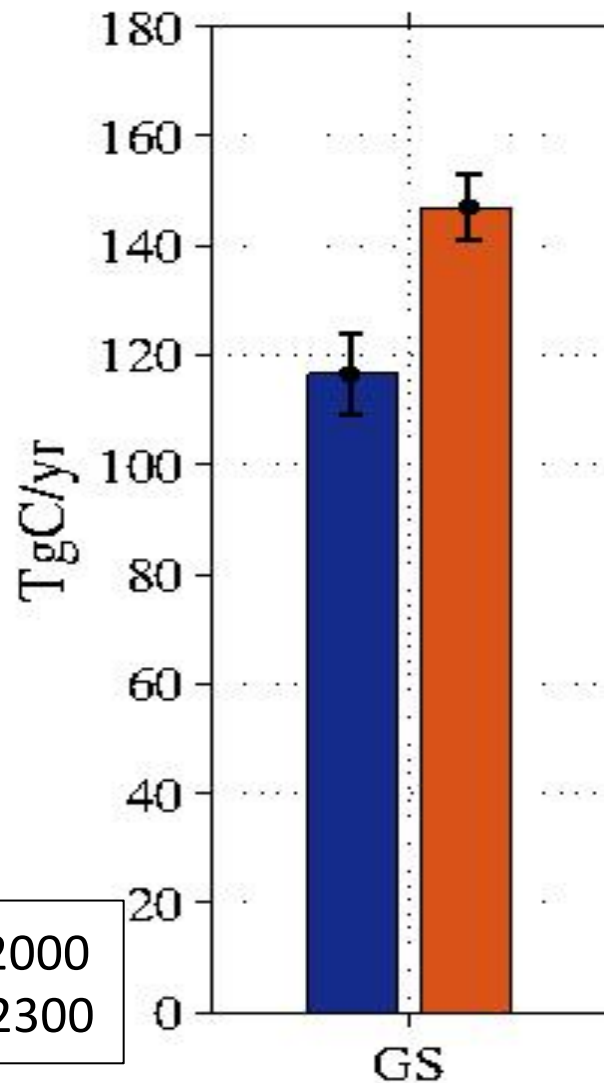


HR Growing Season Means and Standard Deviations

Alaska



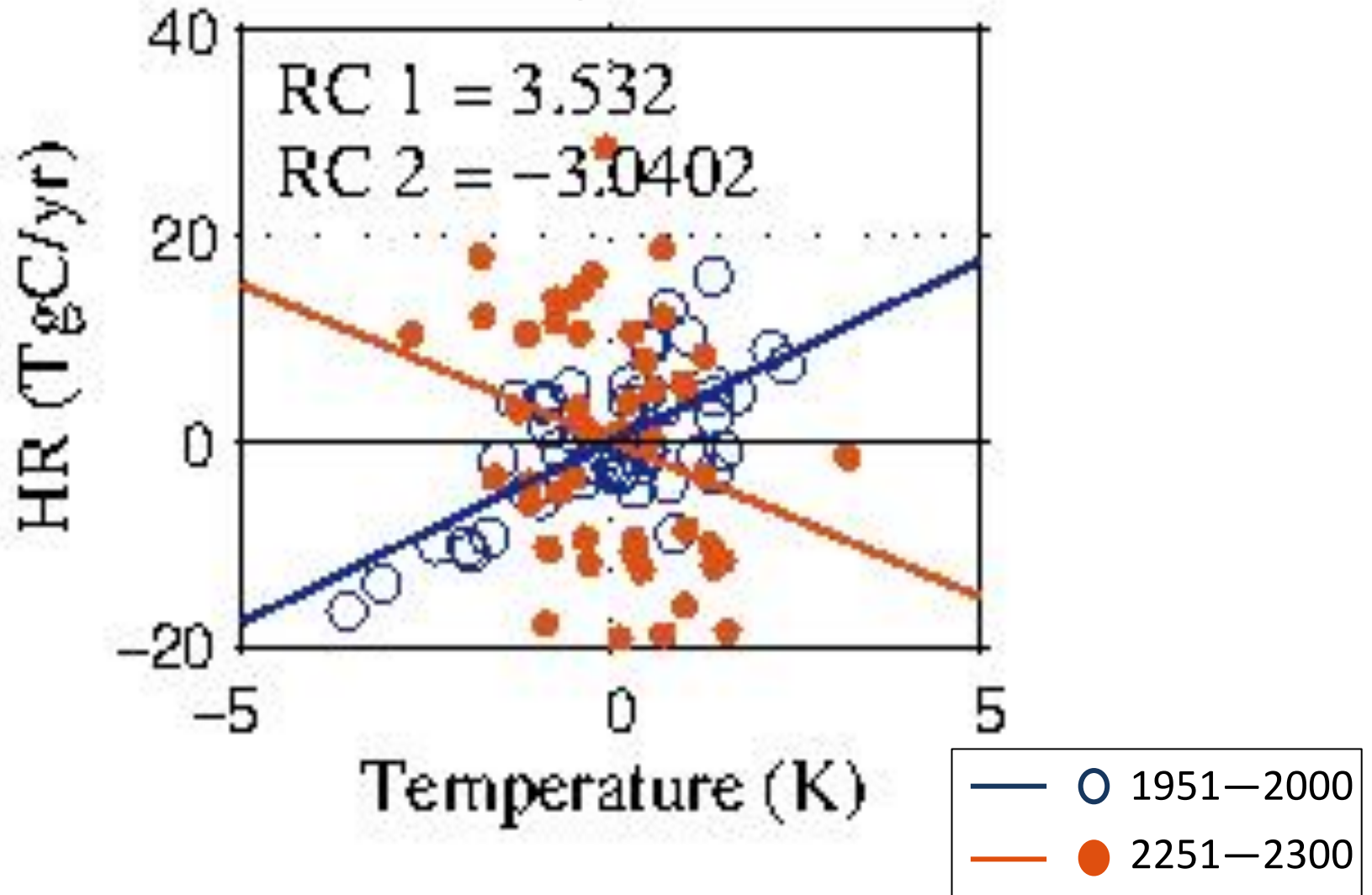
Fennoscandia



HR vs T

Alaska

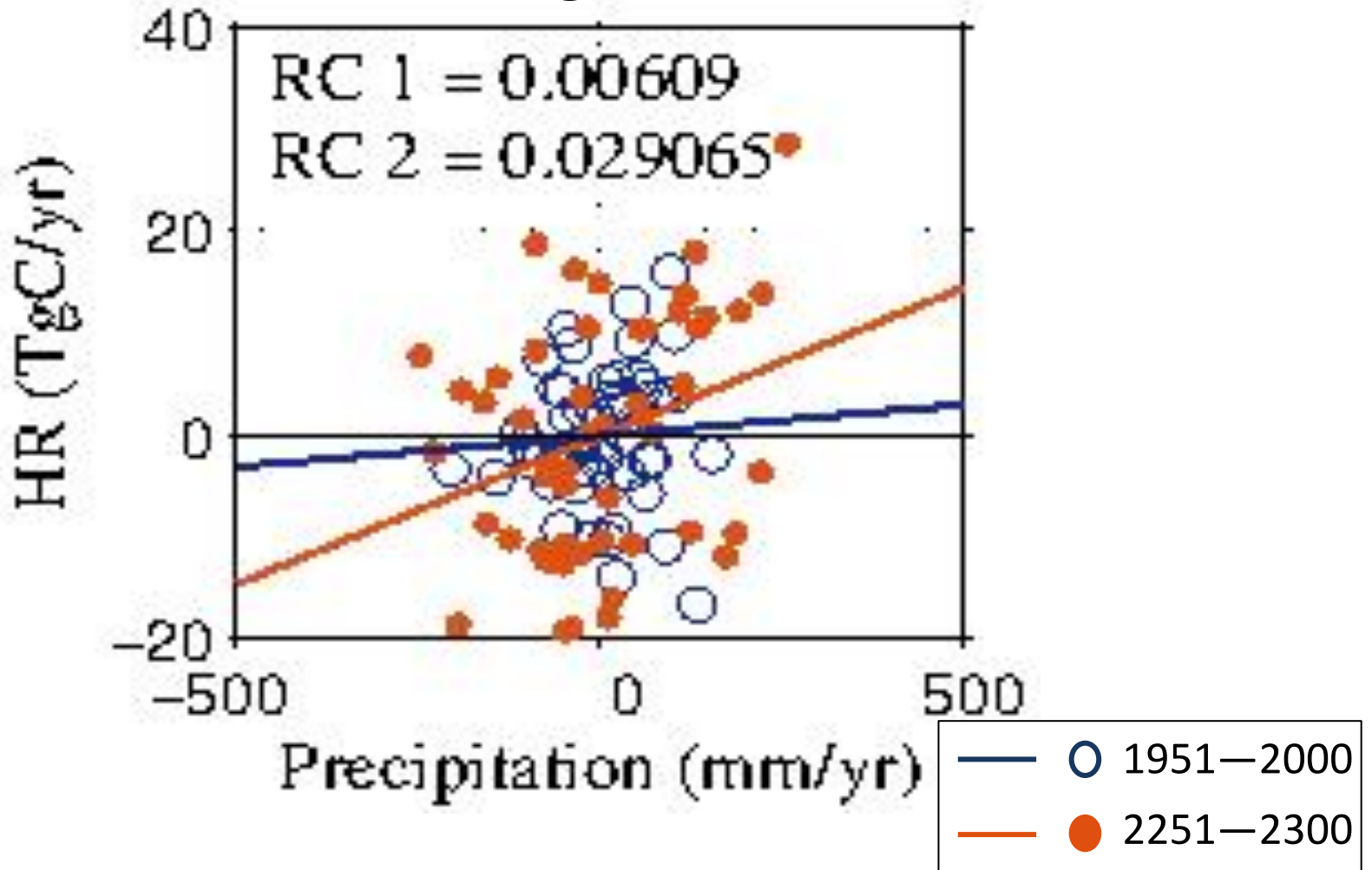
Growing Season



HR vs P

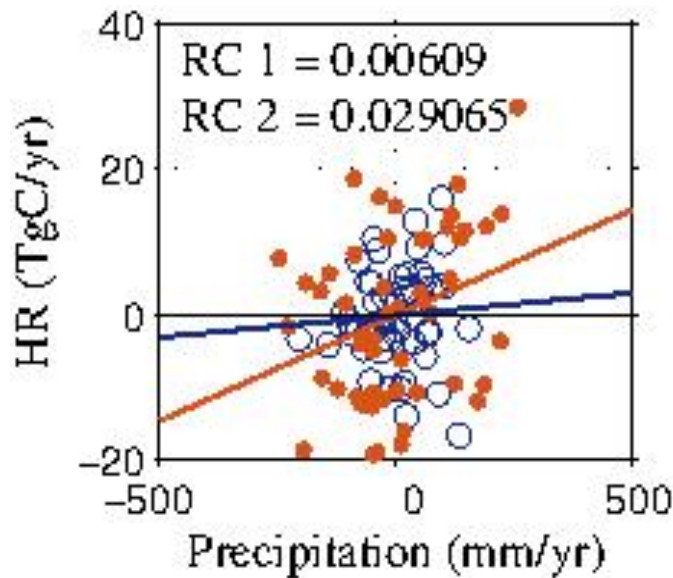
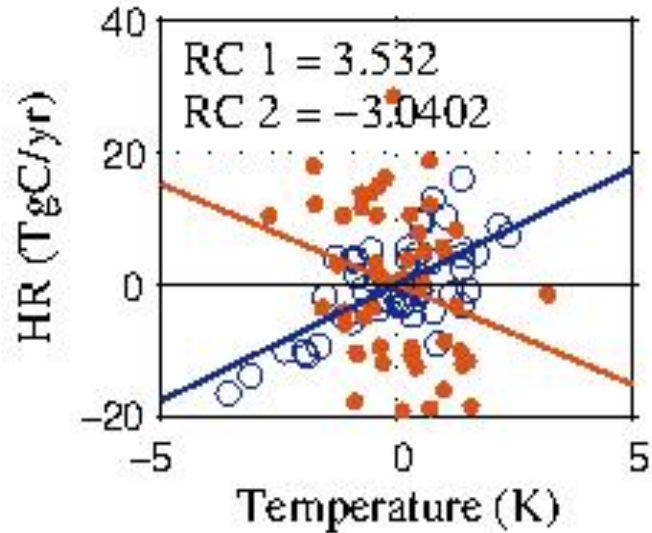
Alaska

Growing Season

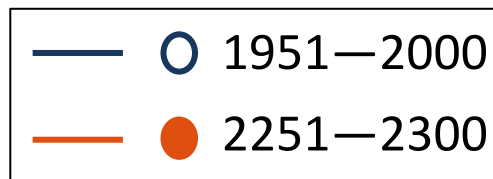
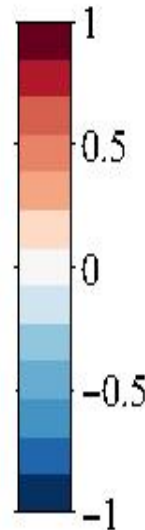


Alaska HR Correlations

Growing Season

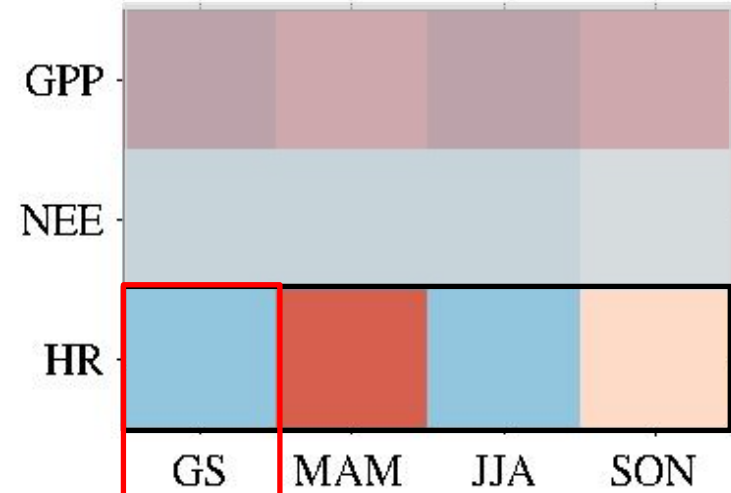


Correlation Coefficient

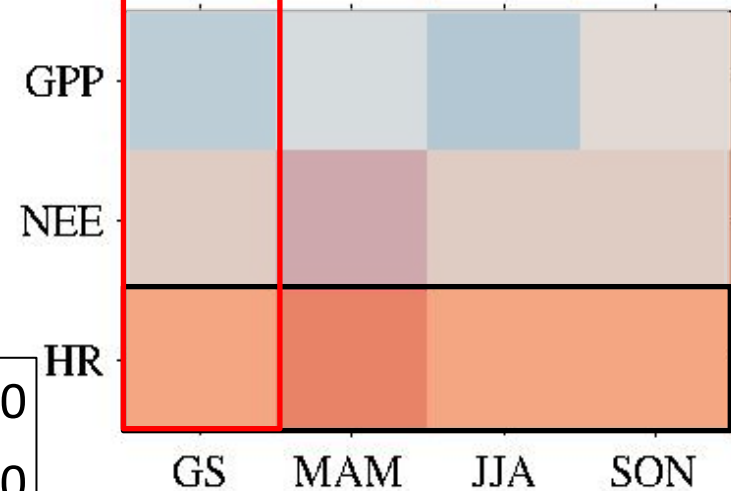


2251—2300

Temperature

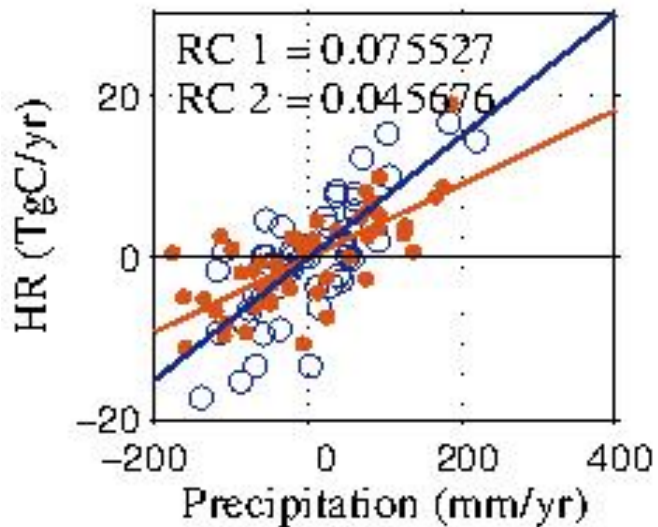
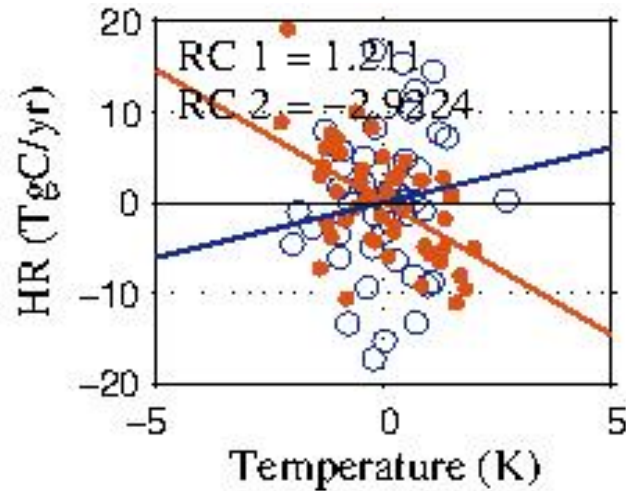


Precipitation

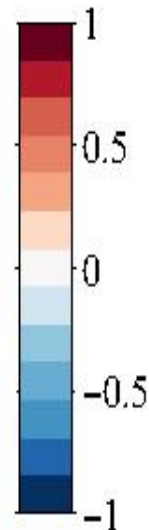


Fennoscandia HR Correlations

Growing Season

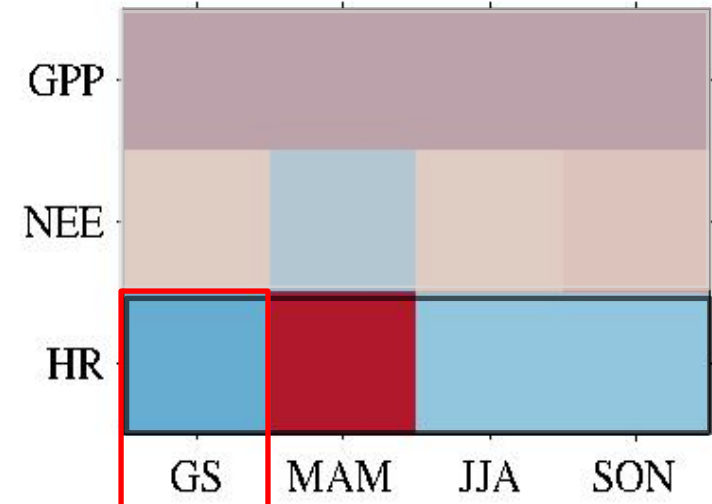


Correlation Coefficient

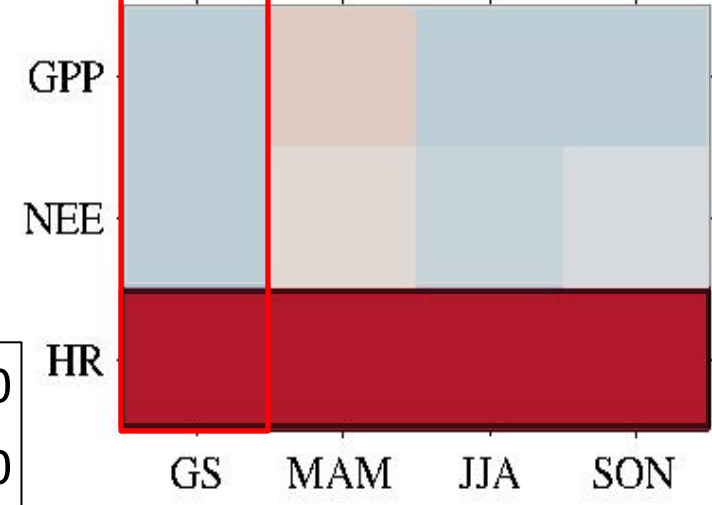


2251—2300

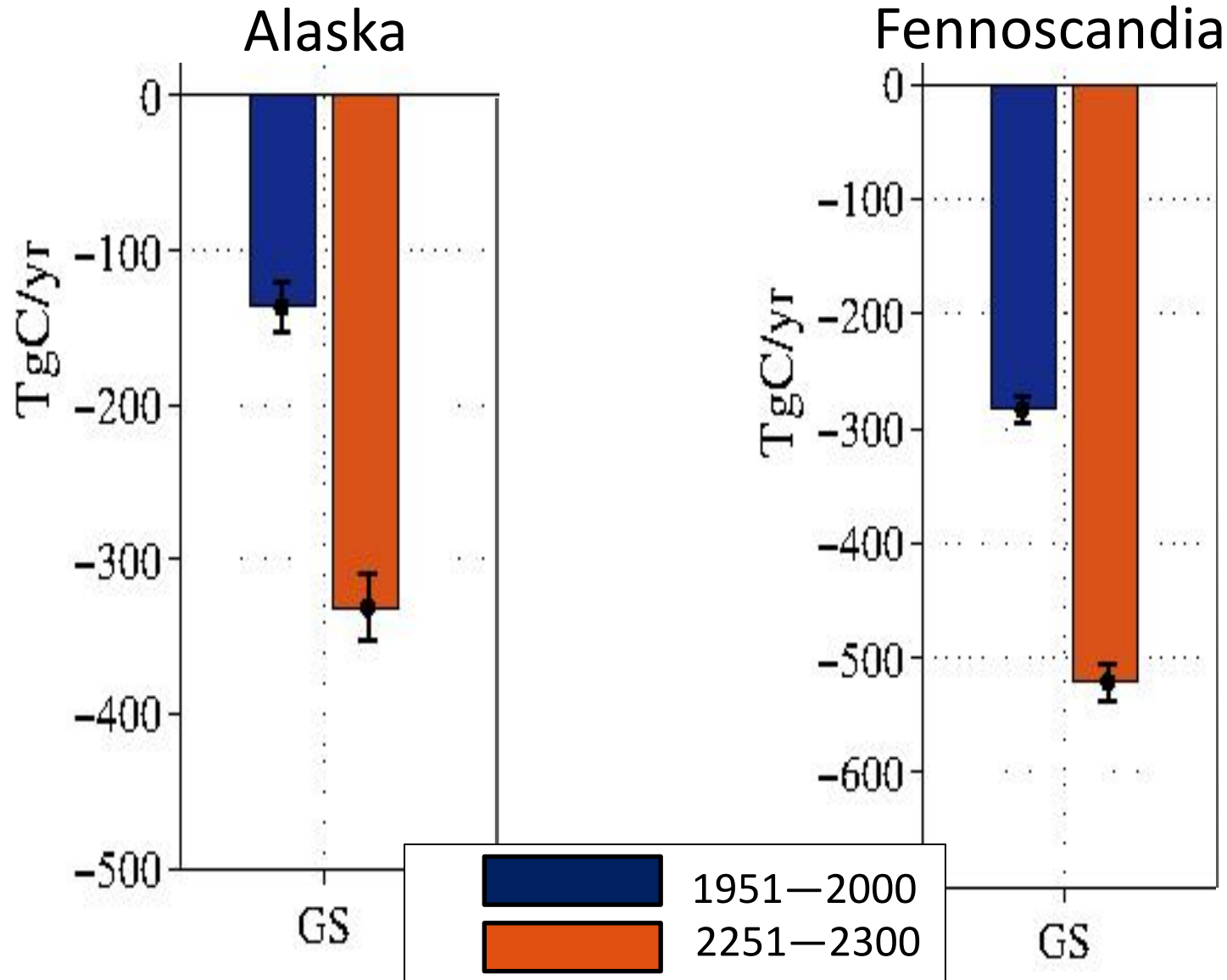
Temperature



Precipitation

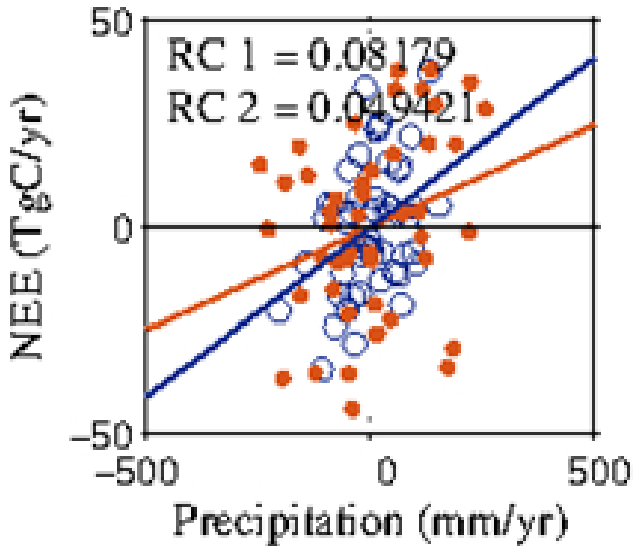
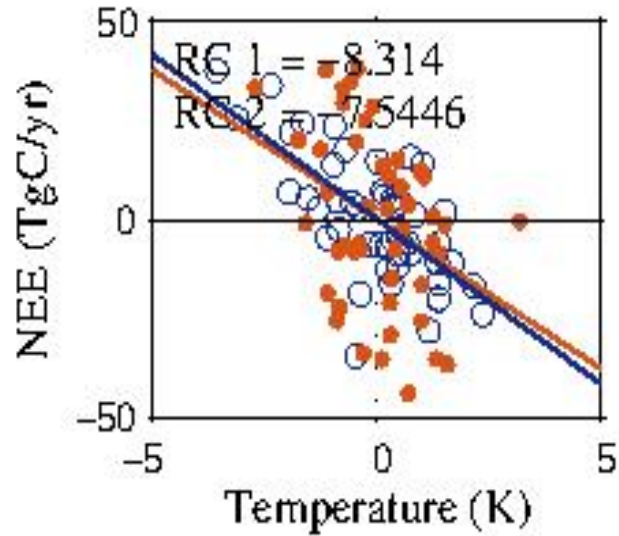


NEE Growing Season Means and Standard Deviations

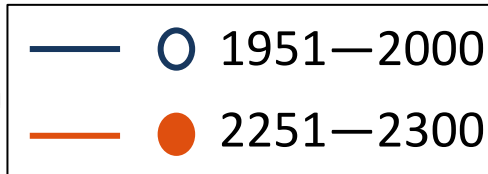
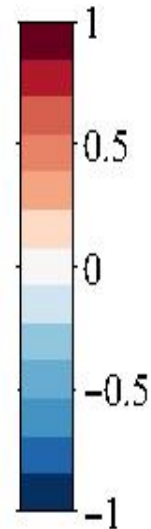


Alaska NEE Correlations

Growing Season

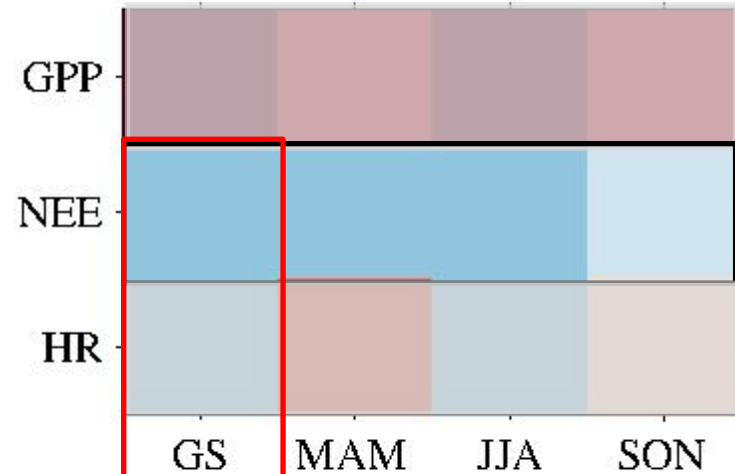


Correlation Coefficient

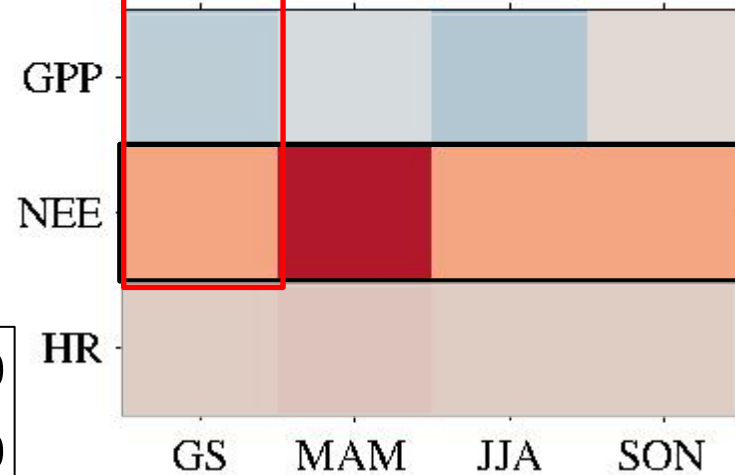


2251—2300

Temperature



Precipitation

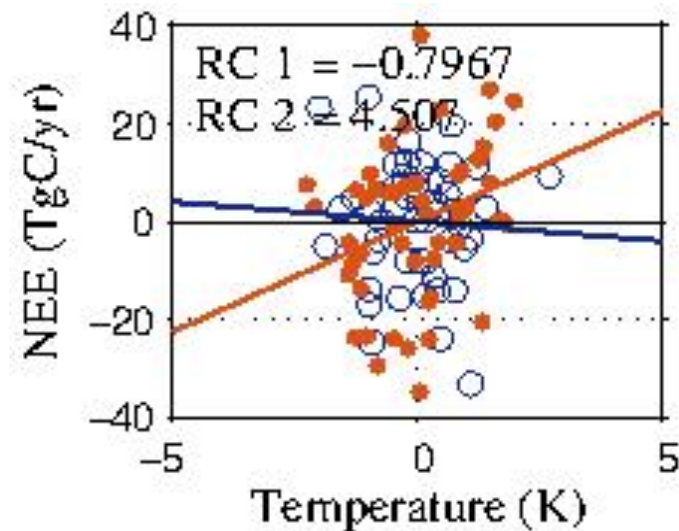


Fennoscandia NEE Correlations

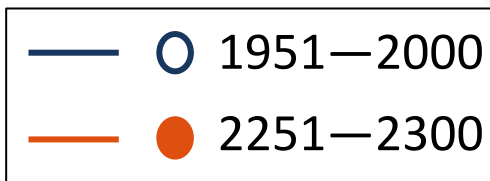
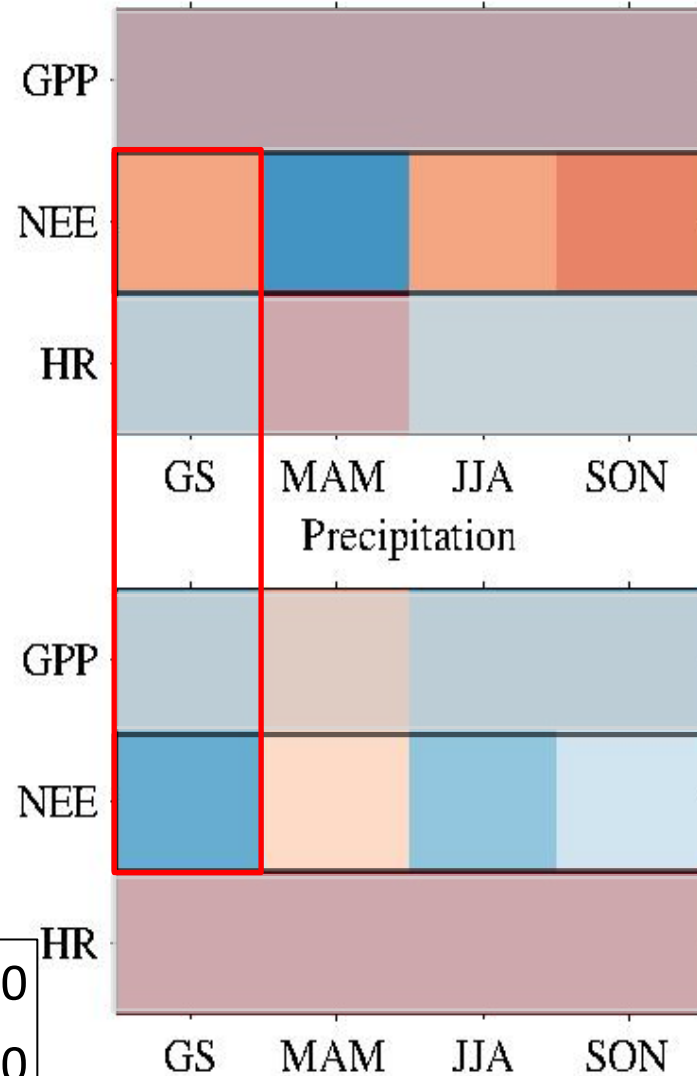
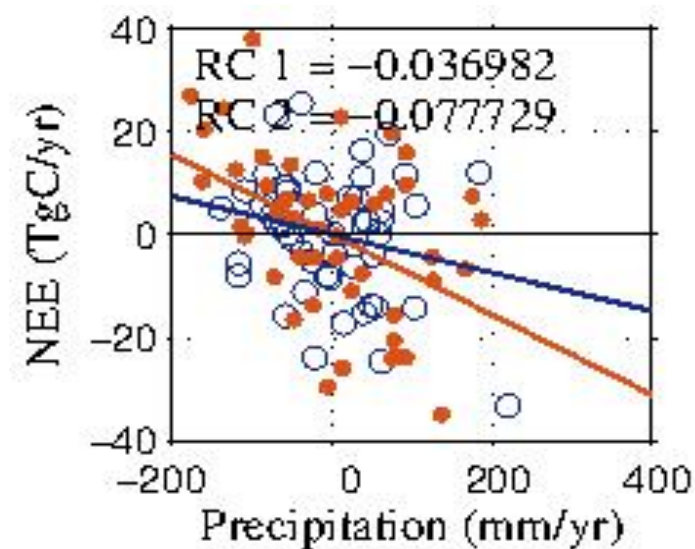
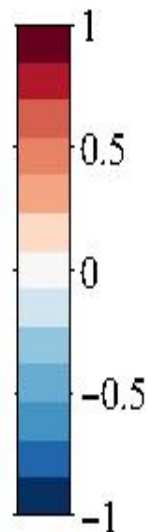
Growing Season

2251—2300

Temperature



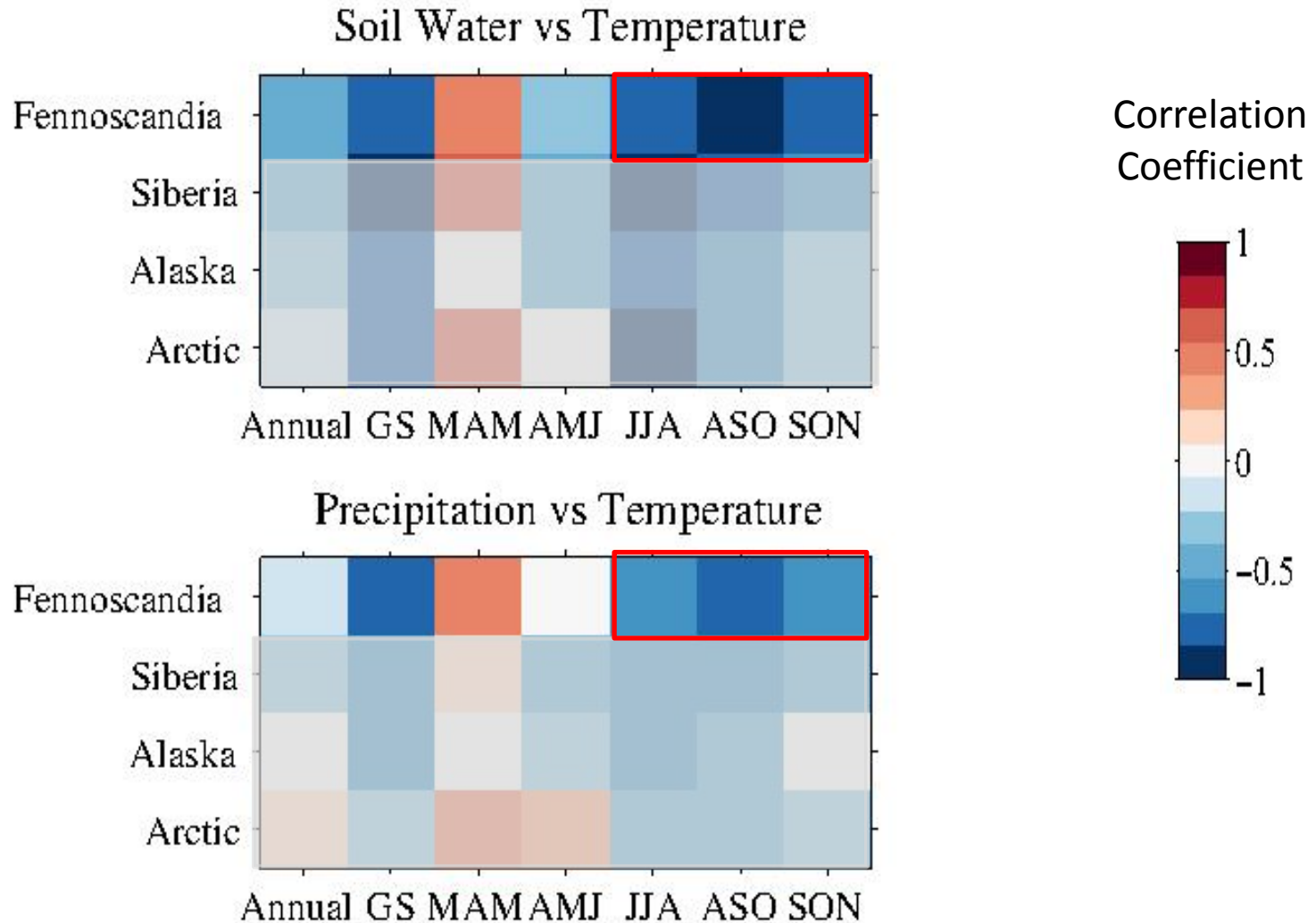
Correlation Coefficient



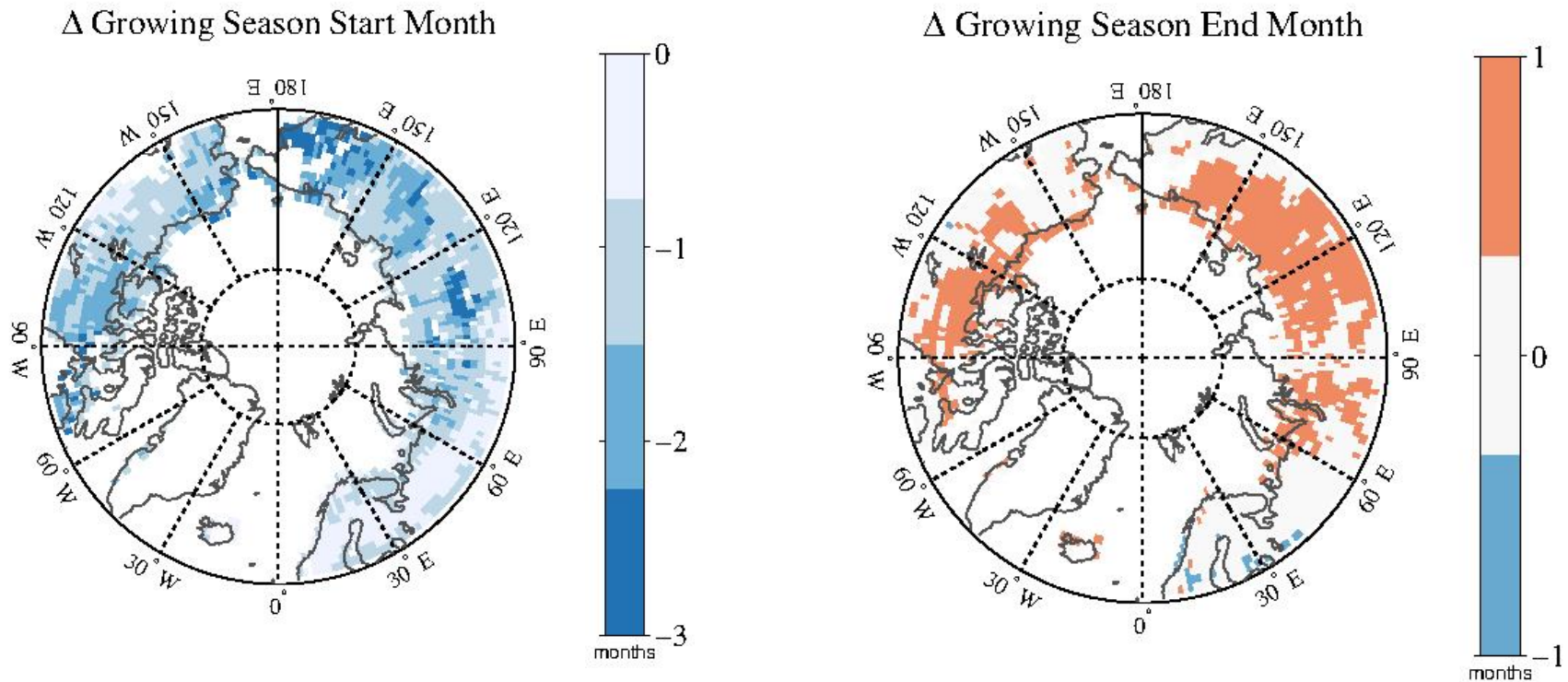
Summary & Conclusions

- Arctic climate reaches a warmer equilibrium in the 23rd century following reduced CO₂ emissions in the fully-coupled CESM
- Precipitation changes vary regionally
 - Growing season precip increases over Alaska
 - Shoulder season precip increases over Fennoscandia, while summer precip decreases
- Interannual variability of growing season net terrestrial C exchange is not driven by precipitation

Warmer Years Tend to be Drier Years



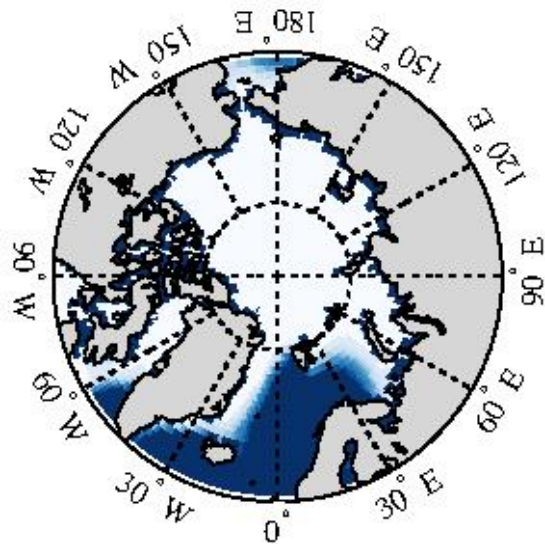
The Growing Season Lengthens over most of the Arctic



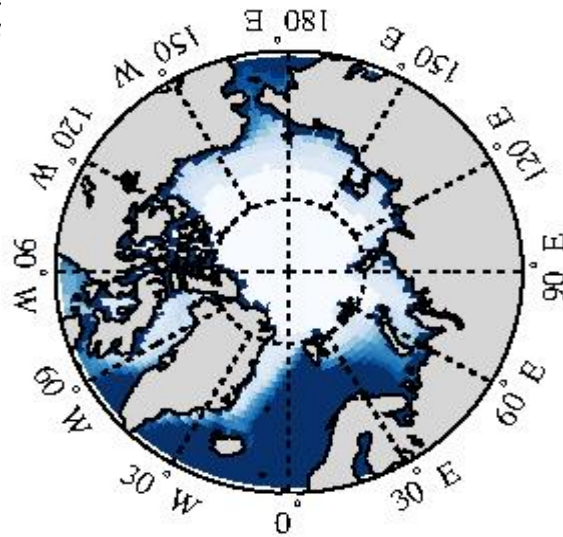
Months with average NEE < 0 (net C uptake) define growing seasons in 1951—2000 and 2251—2300

T and P changes are tied to sea ice loss

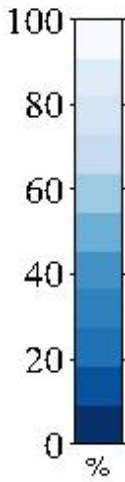
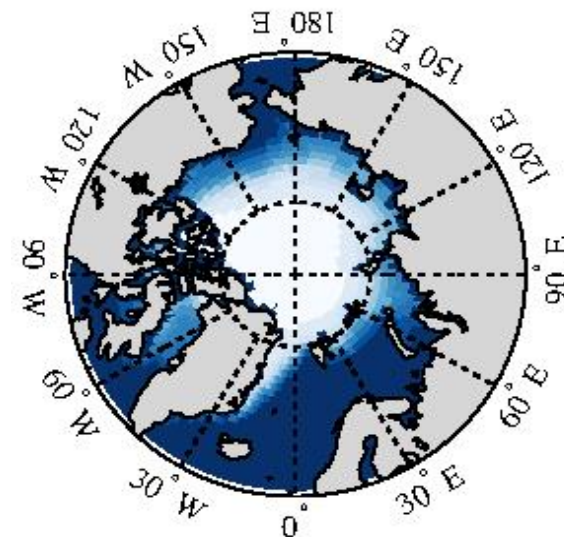
MAM



JJA

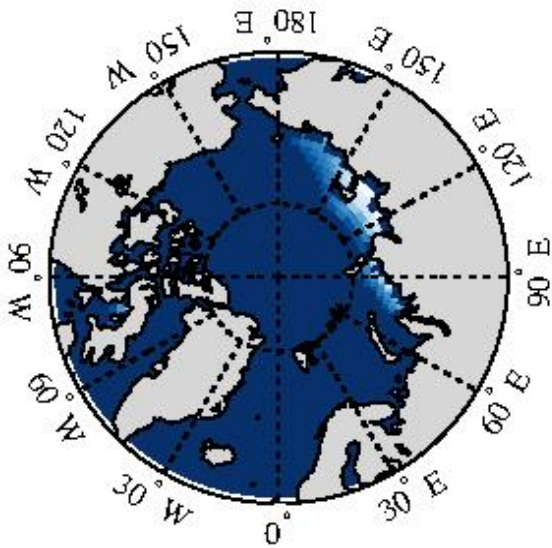


SON

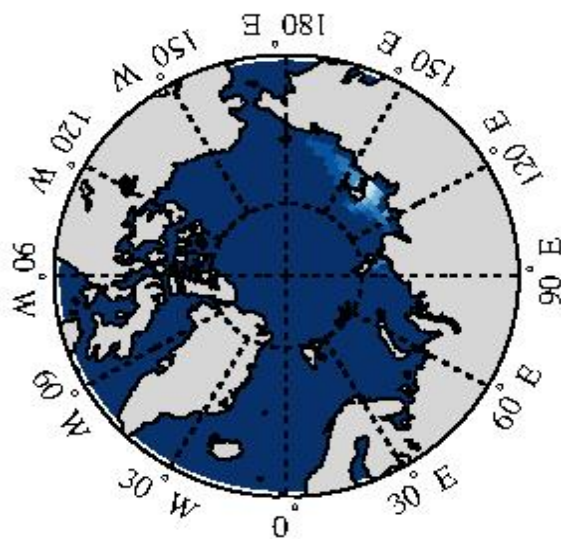


T and P changes are tied to sea ice loss

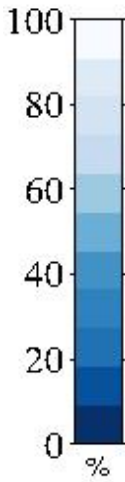
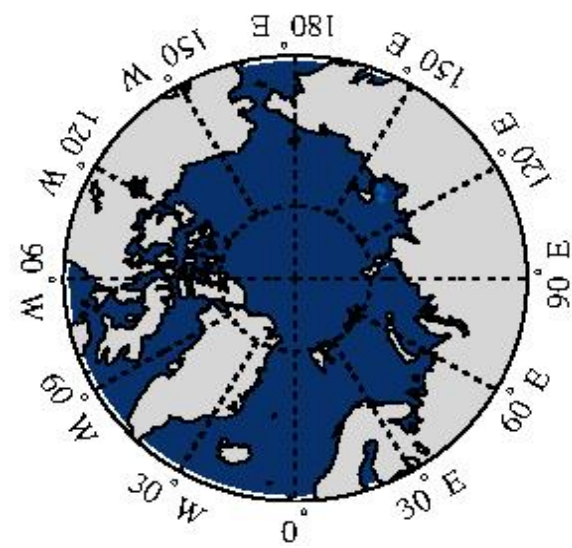
MAM



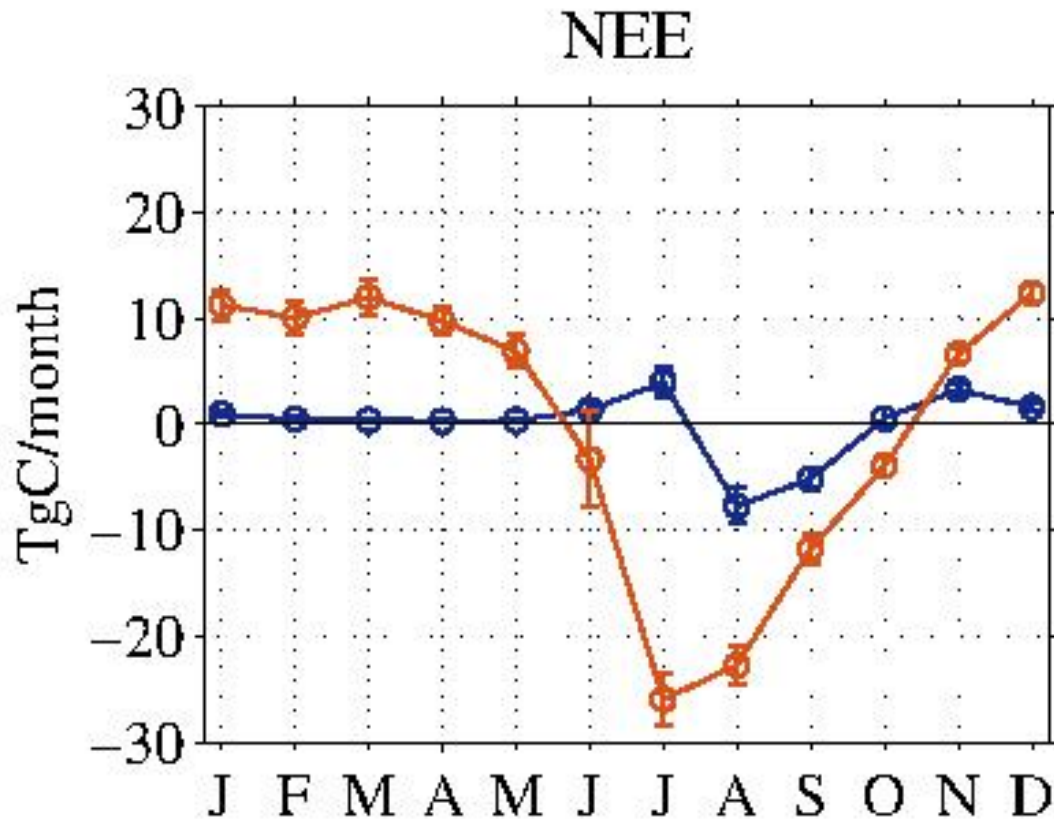
JJA



SON



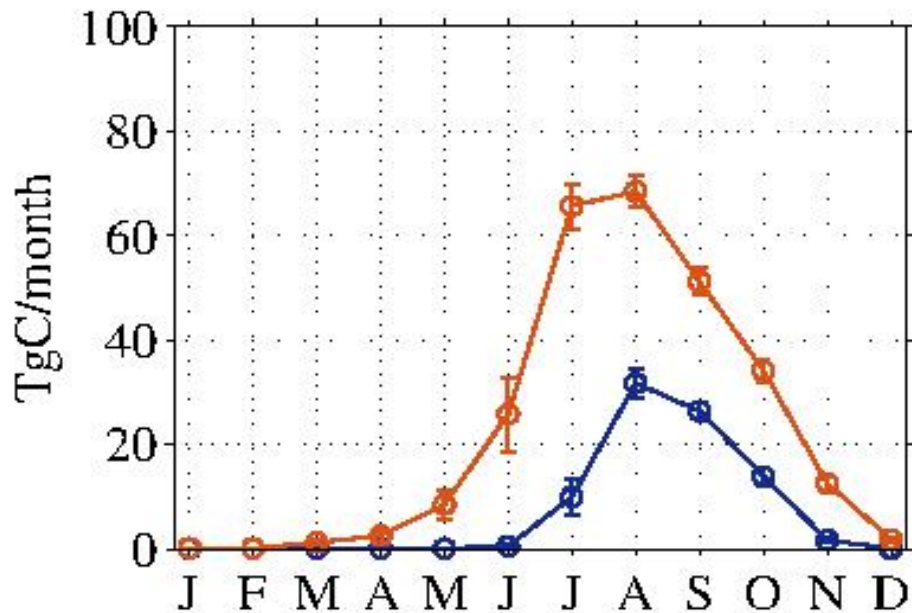
Siberia: Shifts in Growing Season



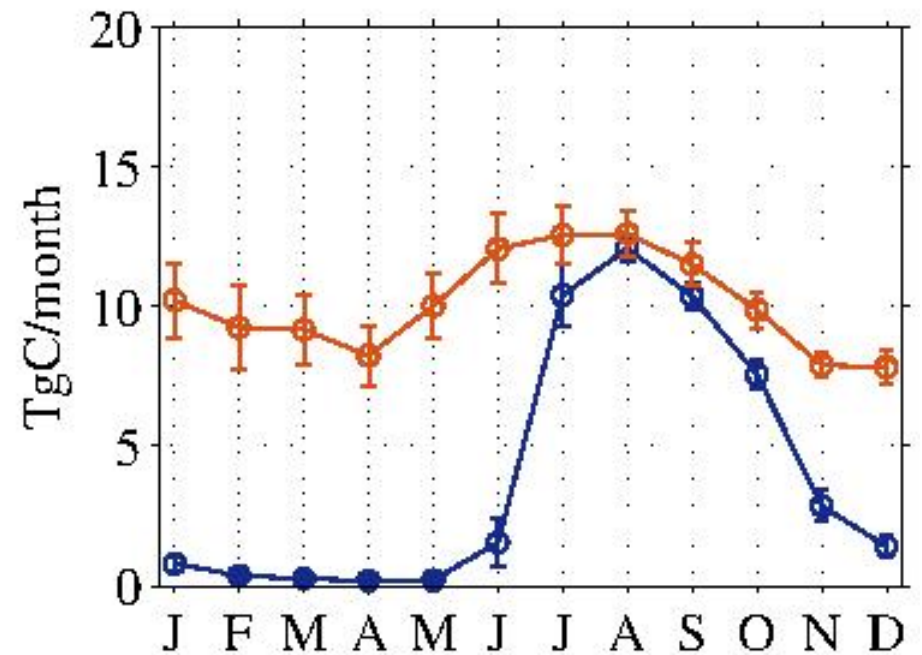
Siberia

Change in annual cycles of GPP and HR

GPP



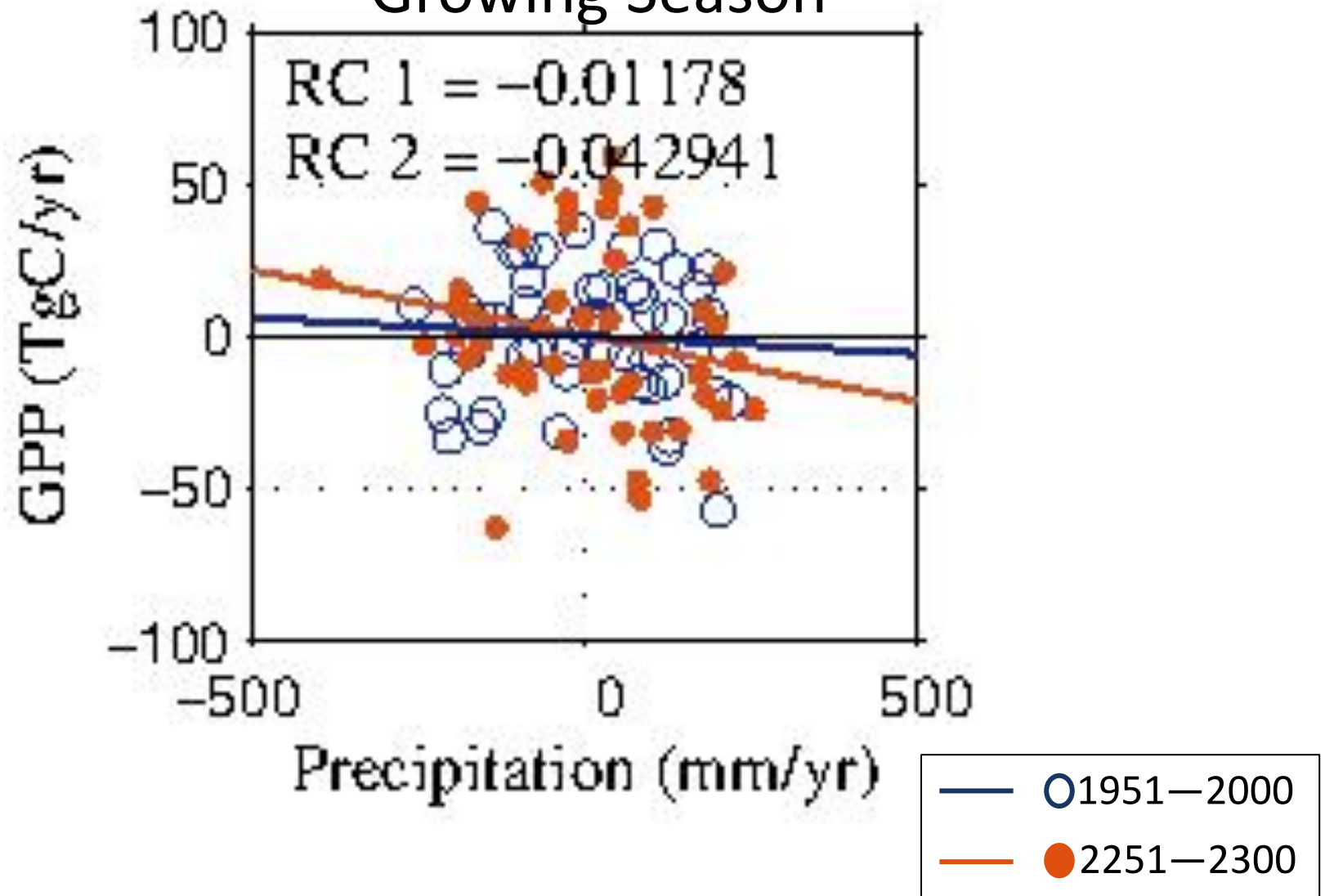
HR



GPP vs P

Siberia

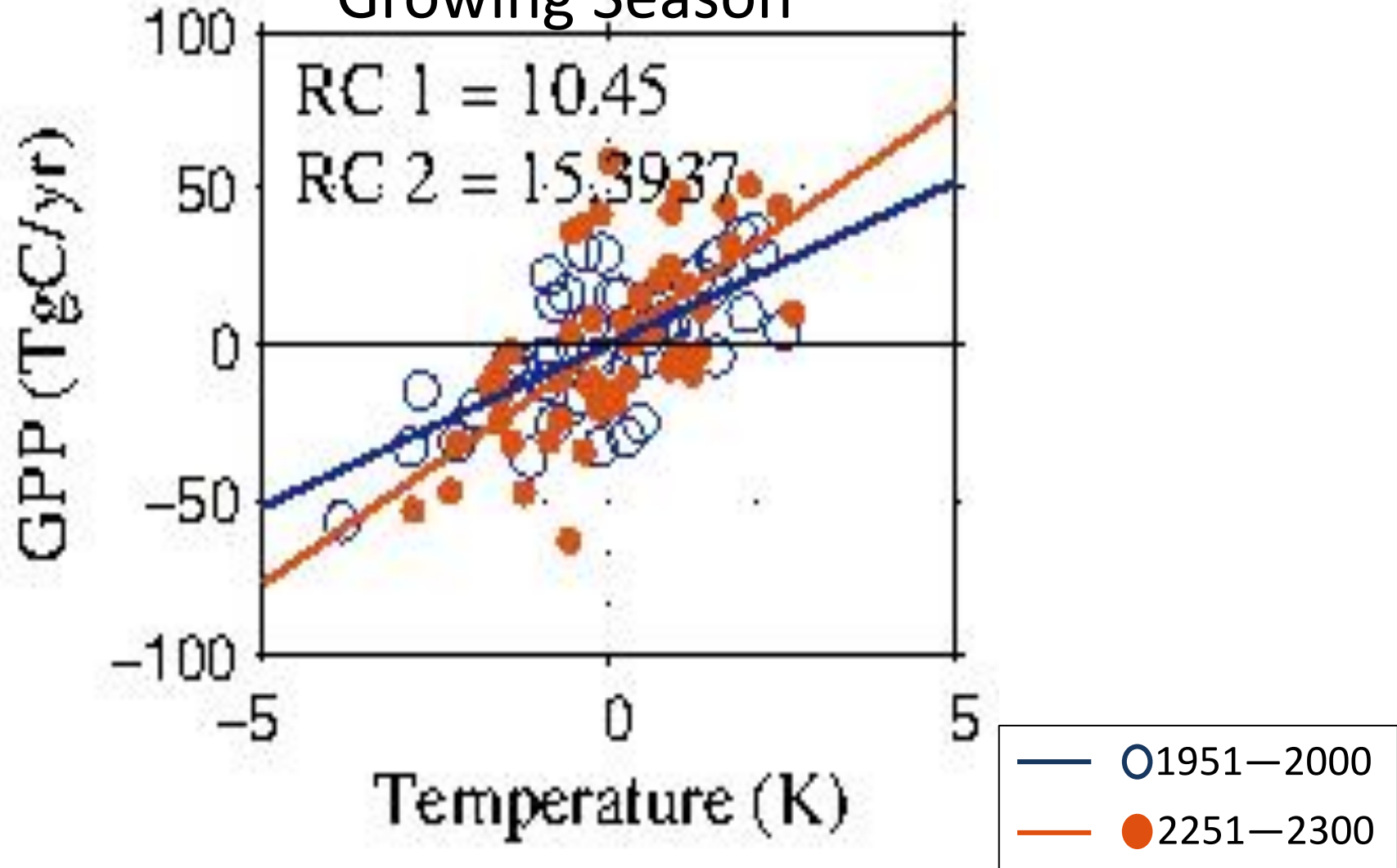
Growing Season



GPP vs T

Siberia

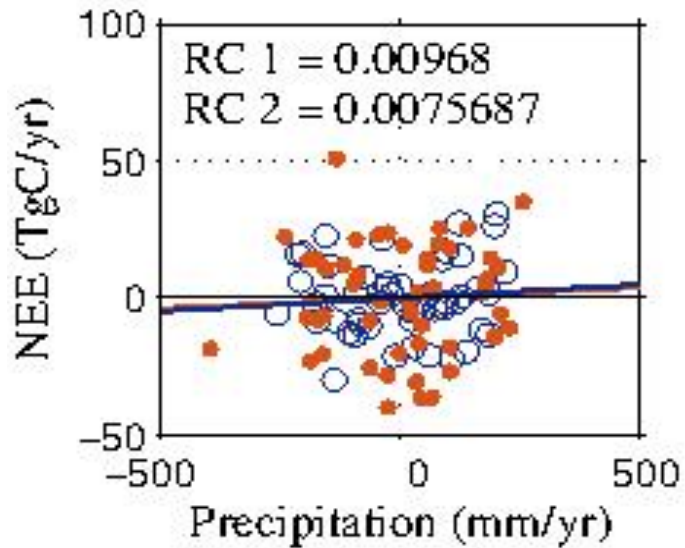
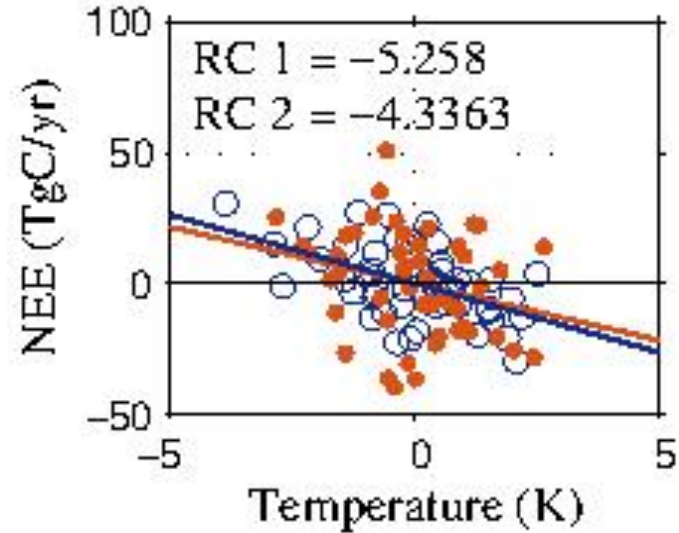
Growing Season



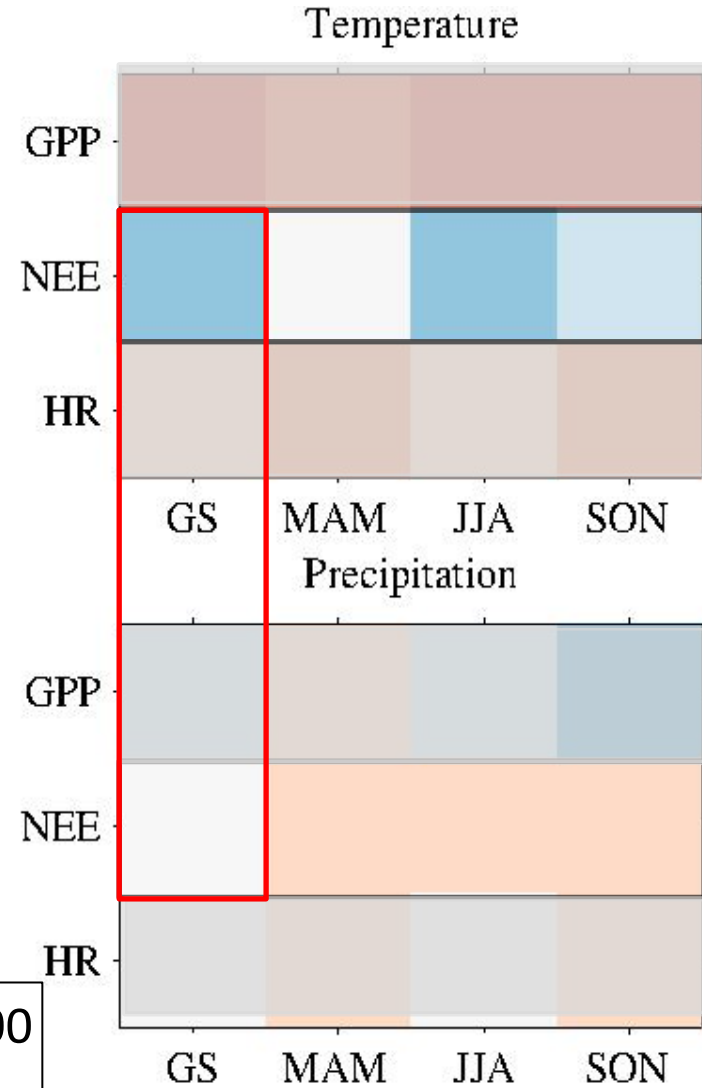
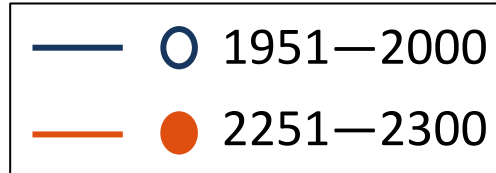
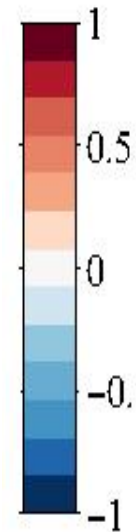
Siberia NEE Correlations

Growing Season

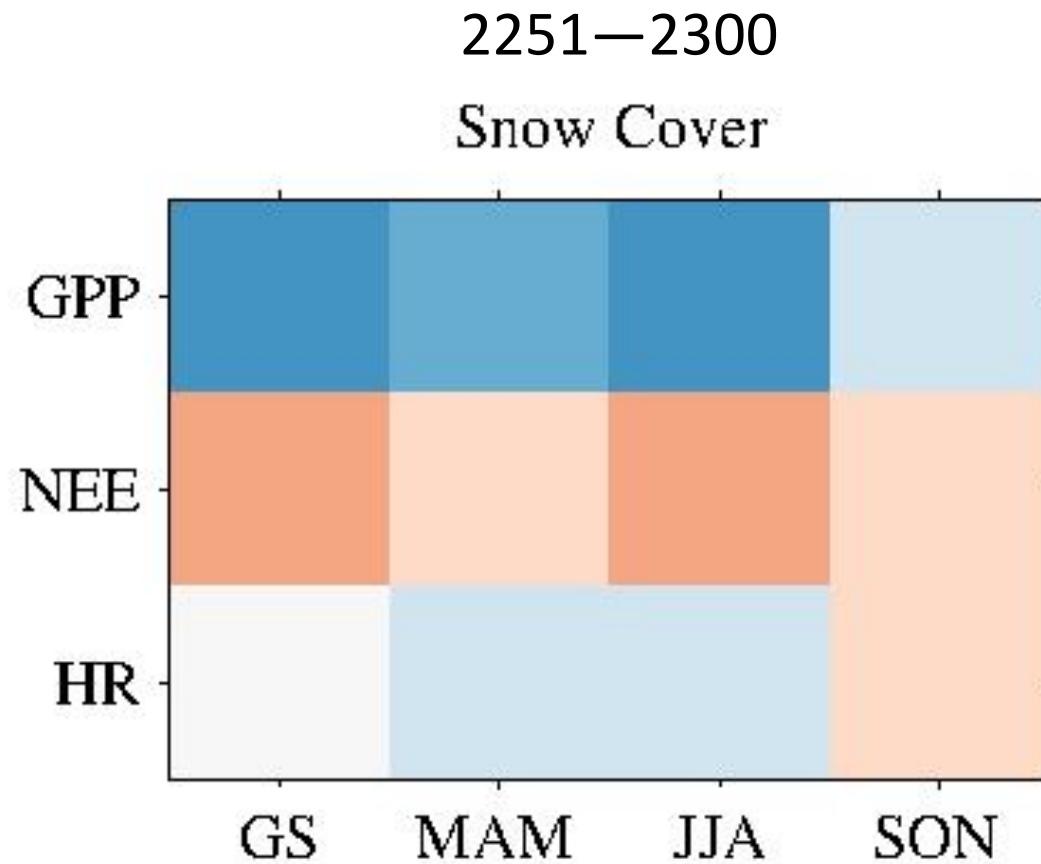
2251—2300



Correlation Coefficient

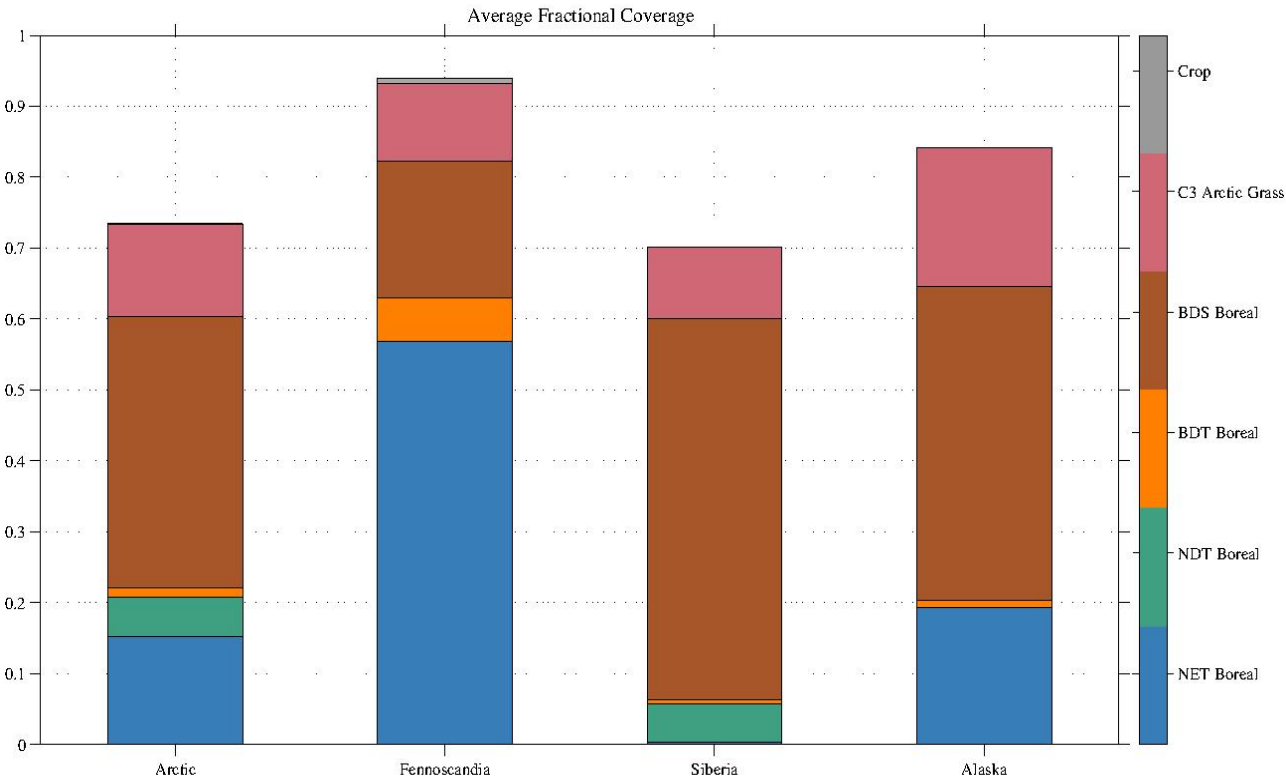
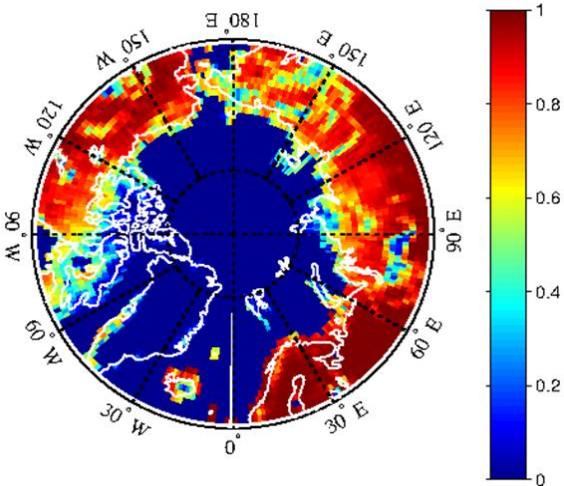


Siberia: Snow Cover Correlations



Vegetation Cover

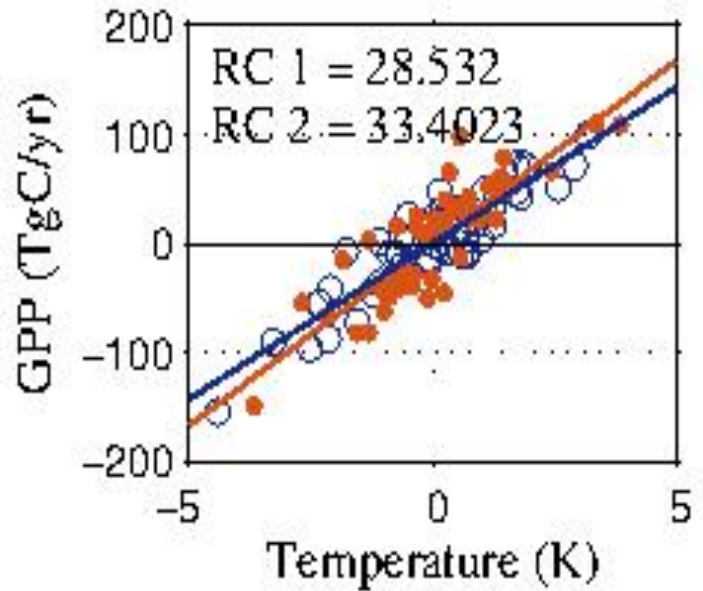
Total Vegetation Cover (all PFTs except bare soil)



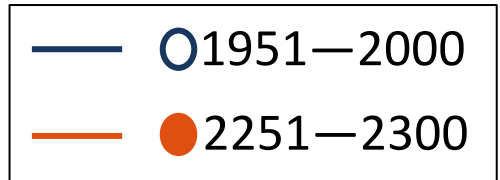
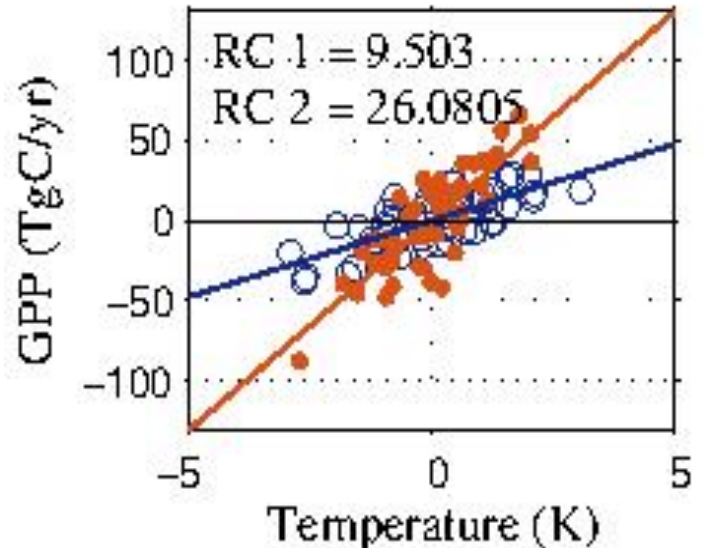
GPP vs T

Alaska

JJA

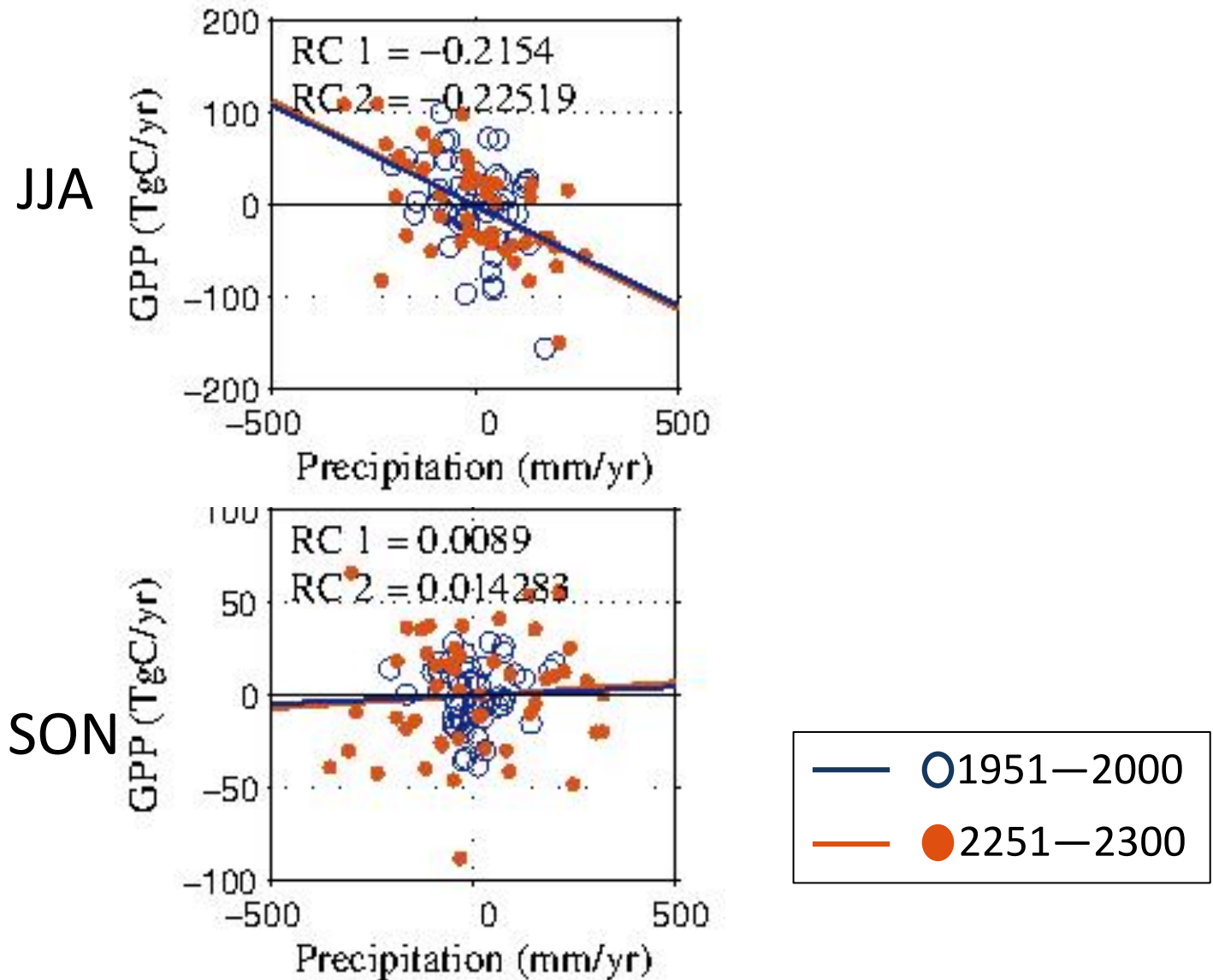


SON



GPP vs P

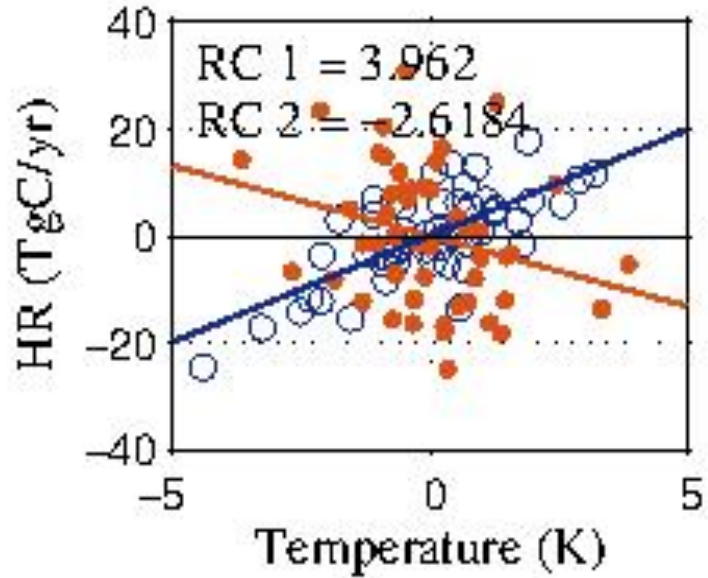
Alaska



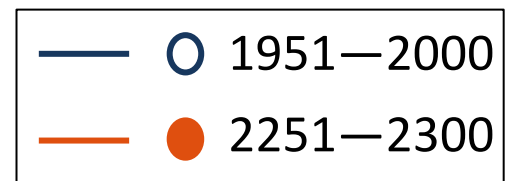
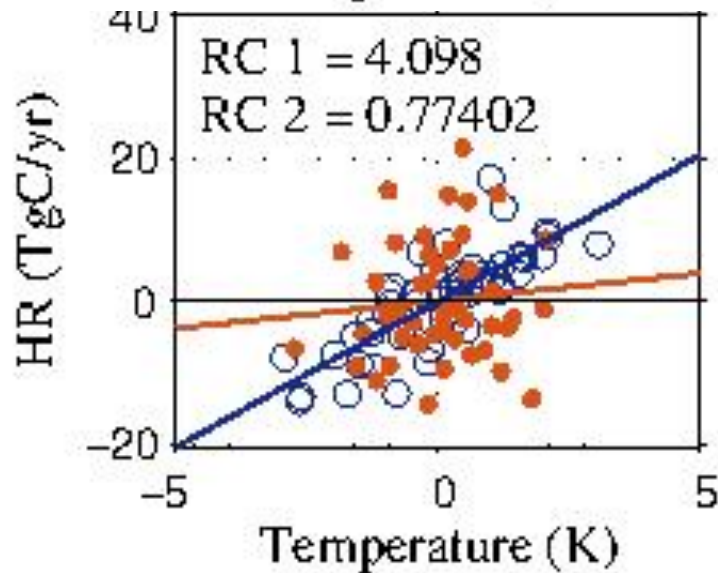
HR vs T

Alaska

JJA



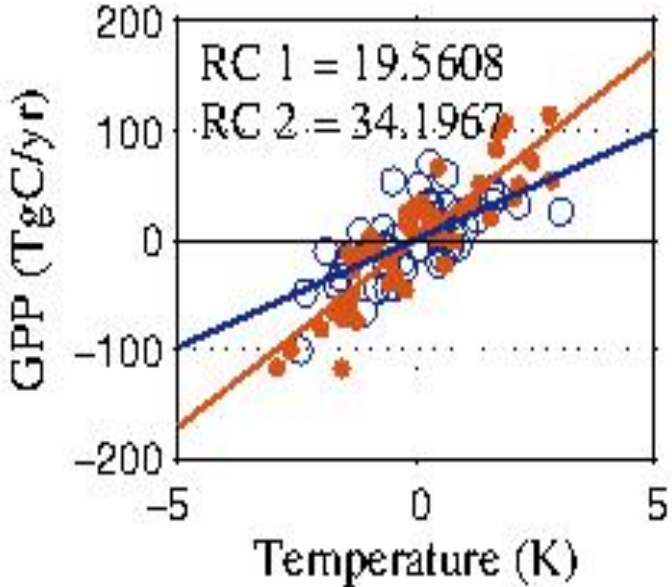
SON



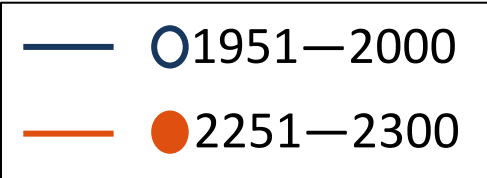
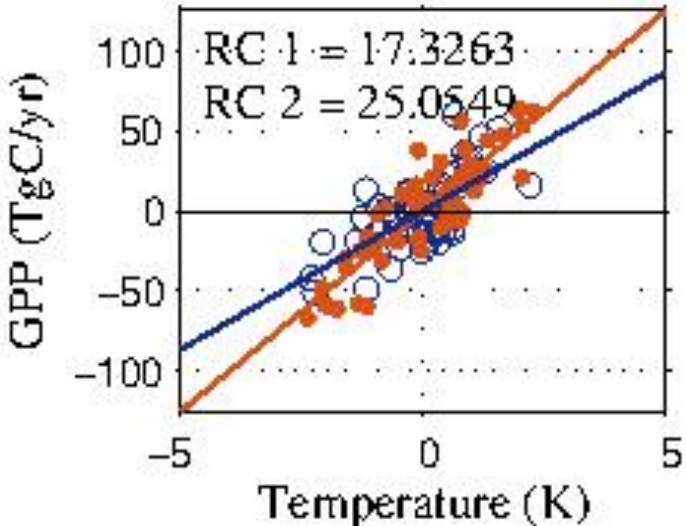
GPP vs T

Fennoscandia

JJA

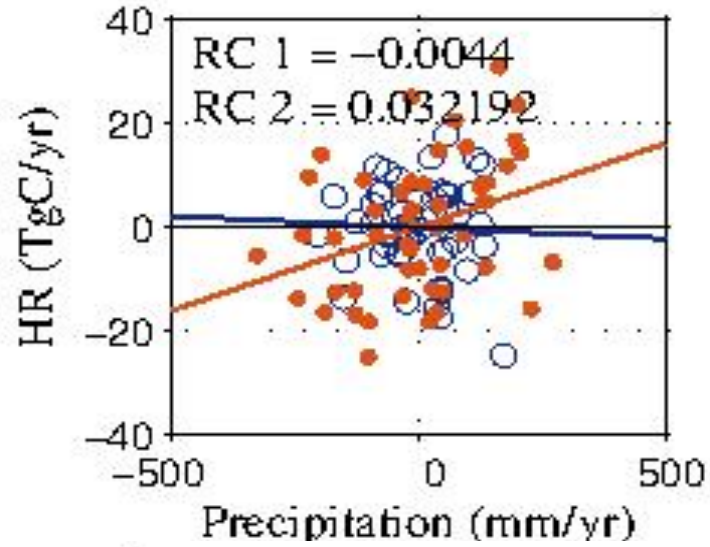


SON

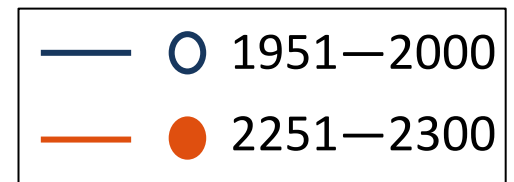
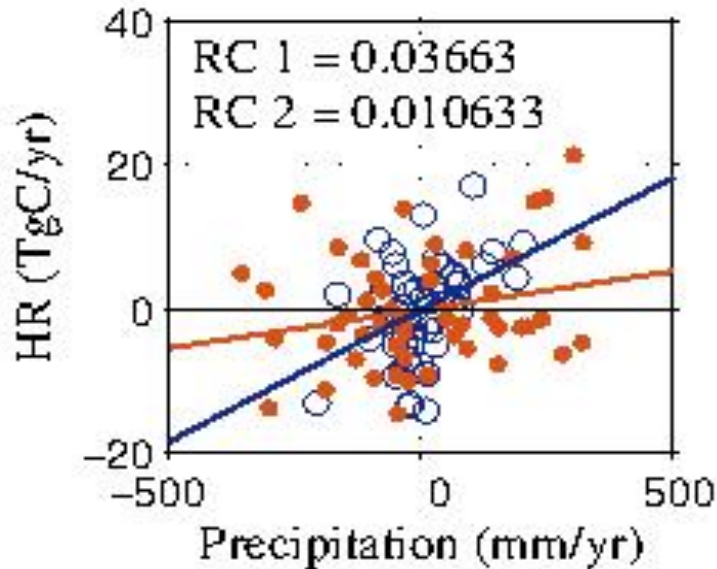


HR vs P Alaska

JJA



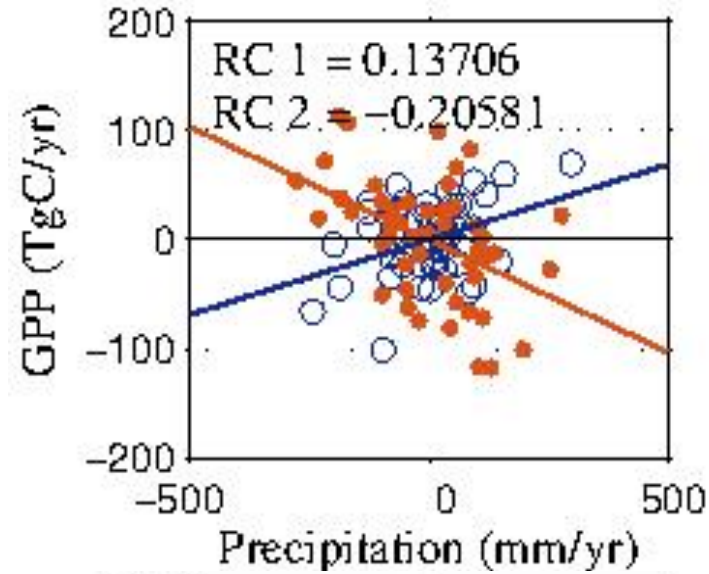
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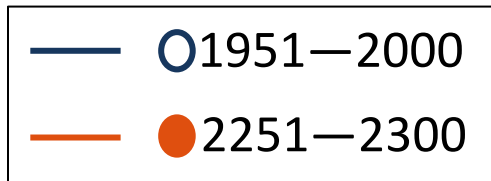
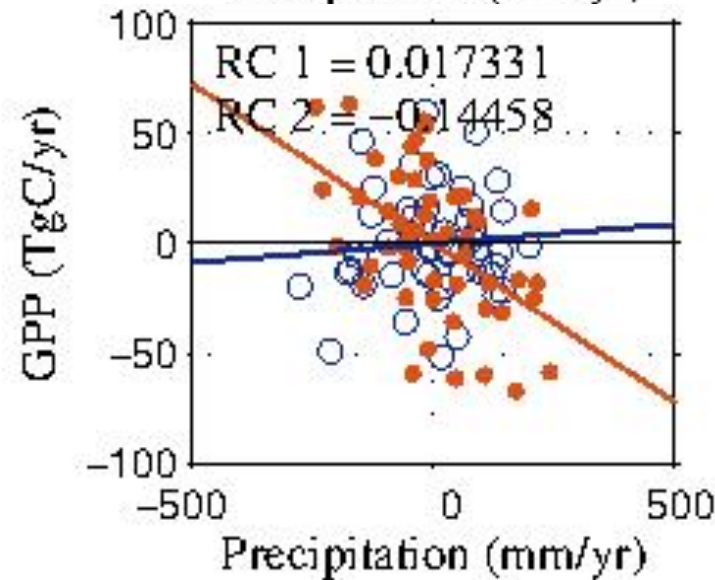
GPP vs P

Fennoscandia

JJA



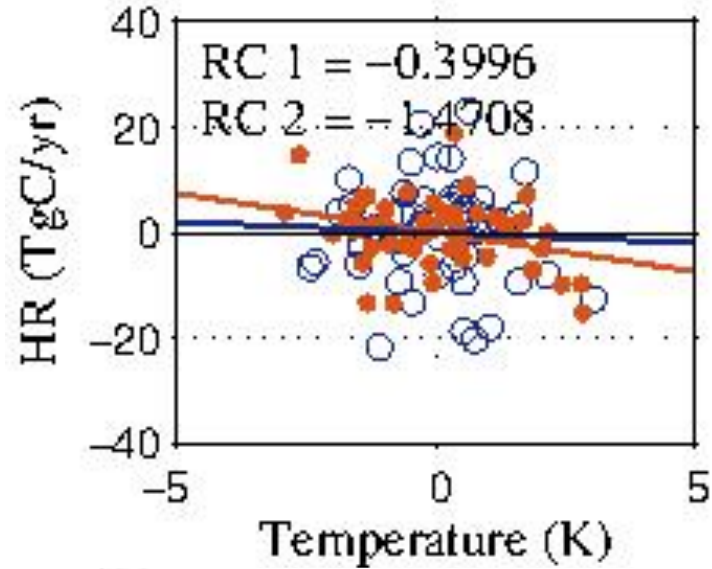
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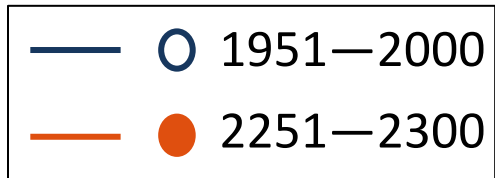
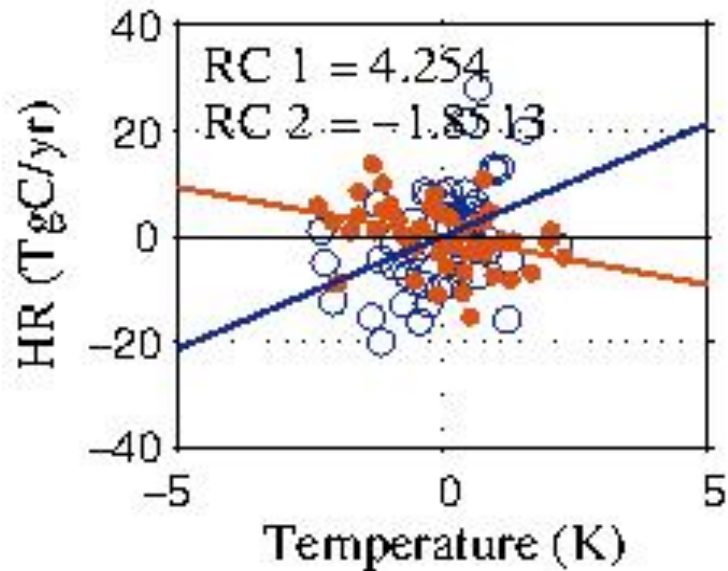
HR vs T

Fennoscandia

JJA



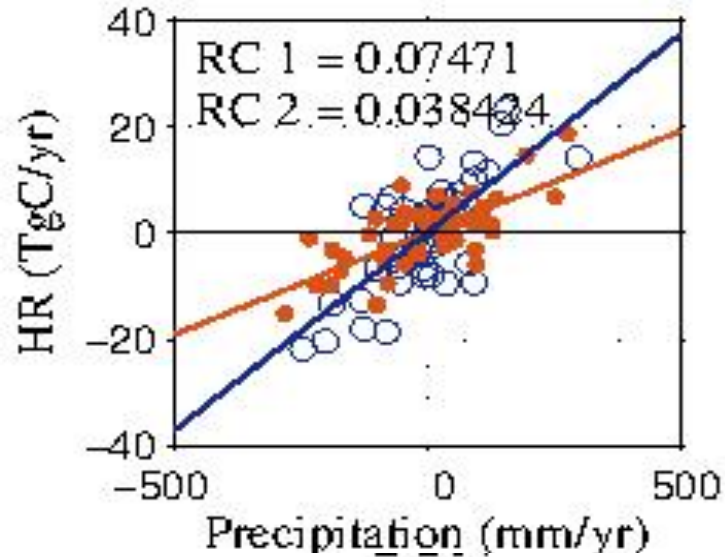
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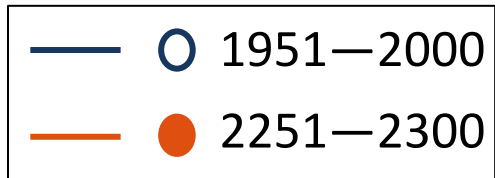
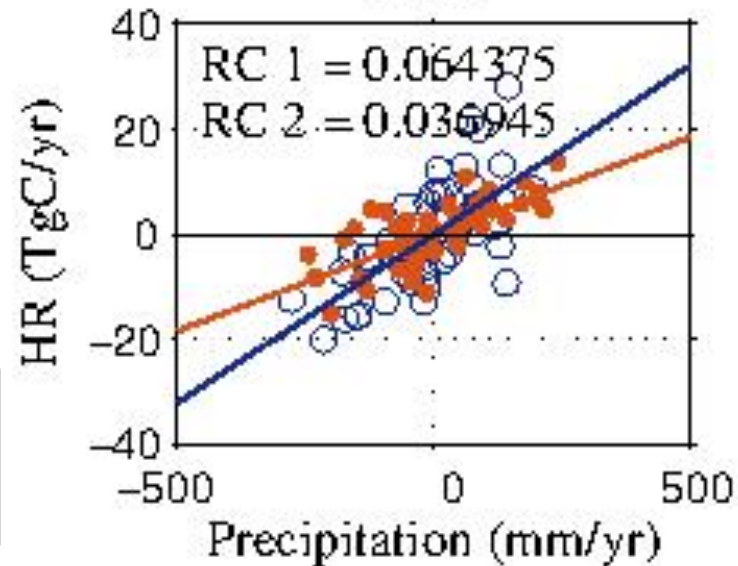
HR vs P

Fennoscandia

JJA



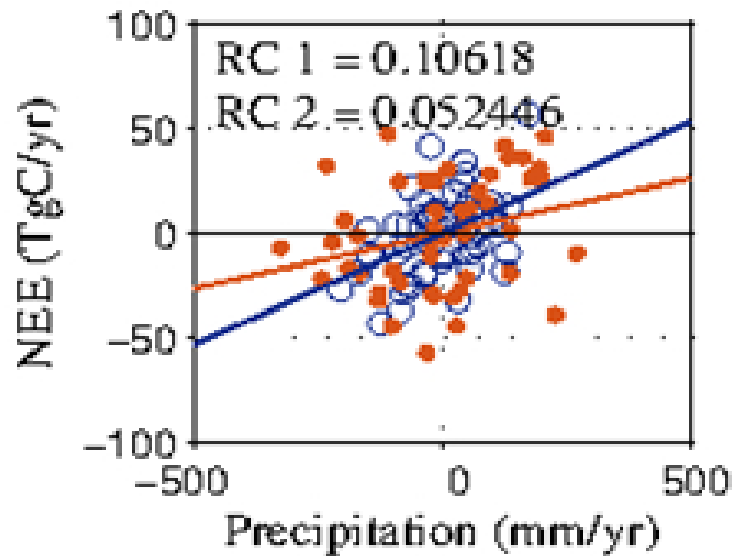
SON



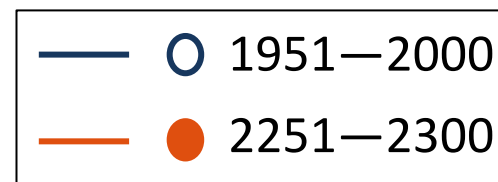
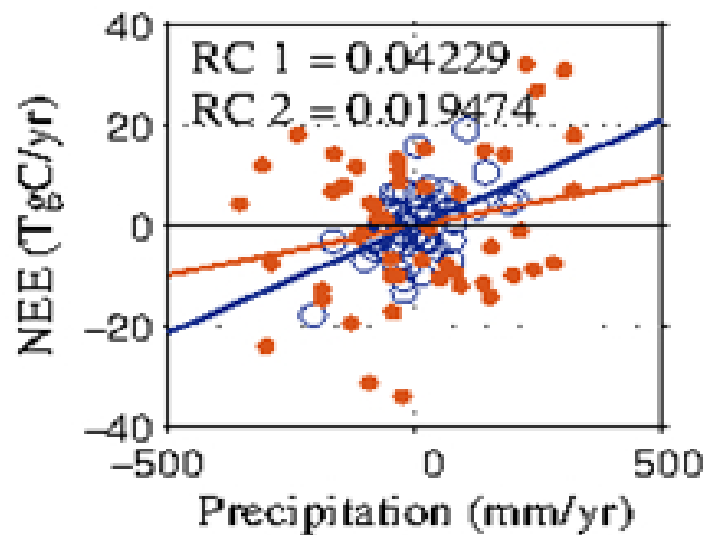
NEE vs P

Alaska

JJA

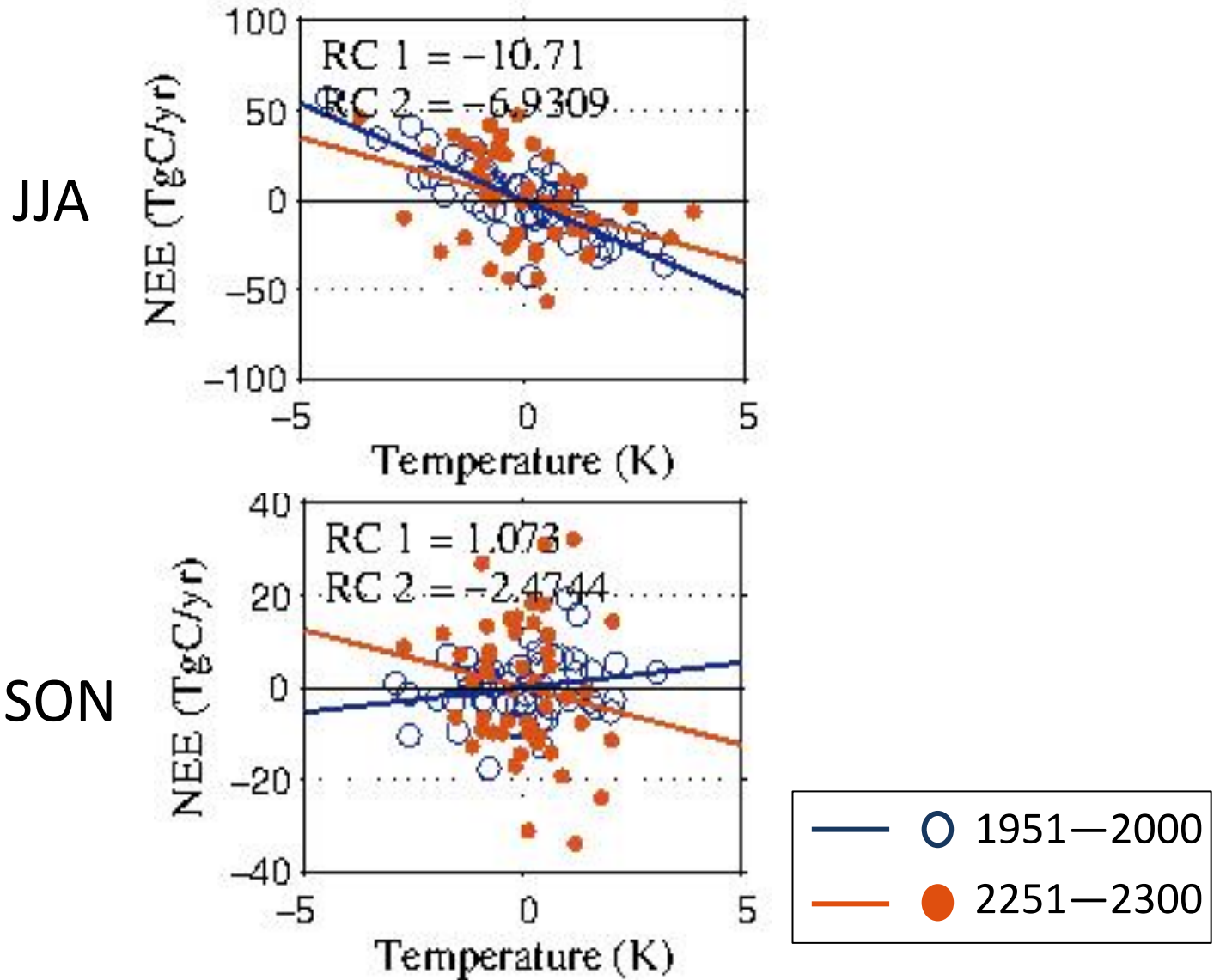


SON



NEE vs T

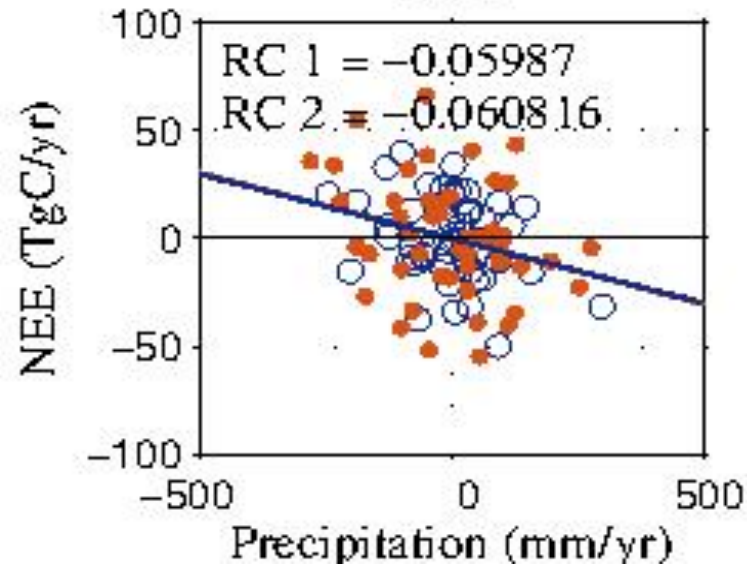
Alaska



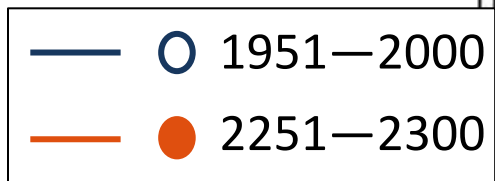
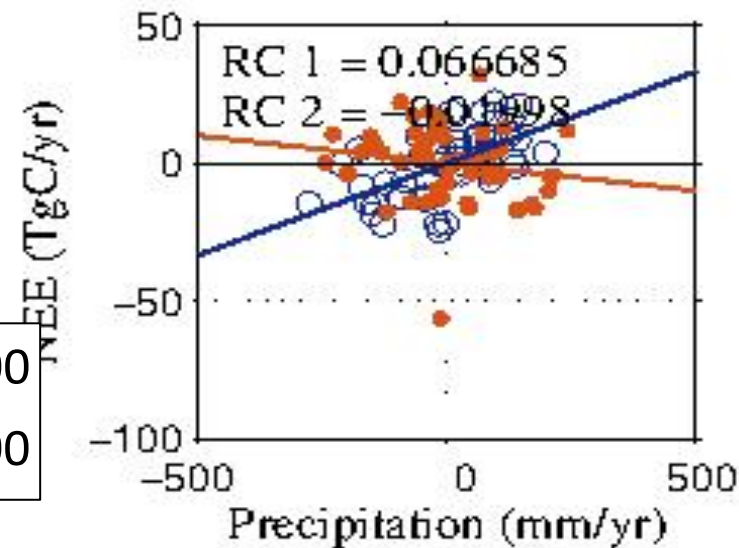
NEE vs P

Fennoscandia

JJA



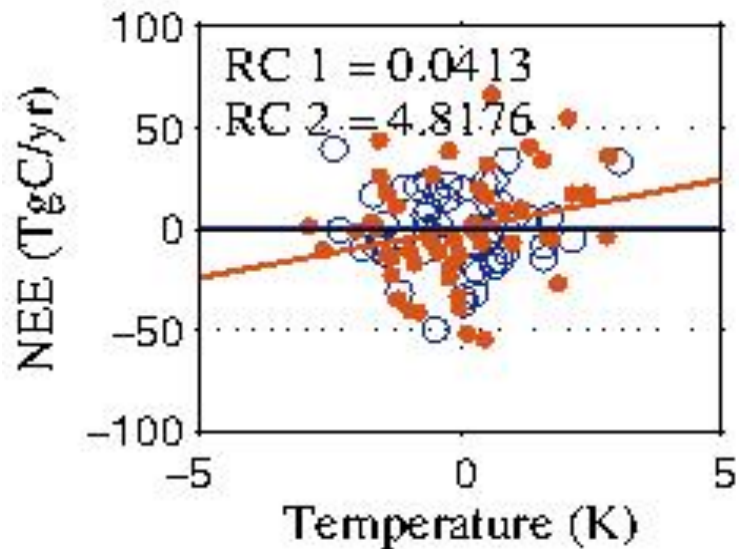
SON



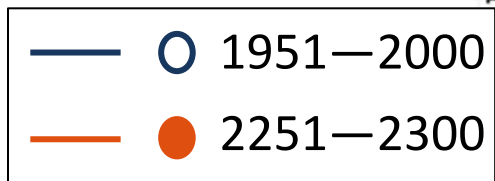
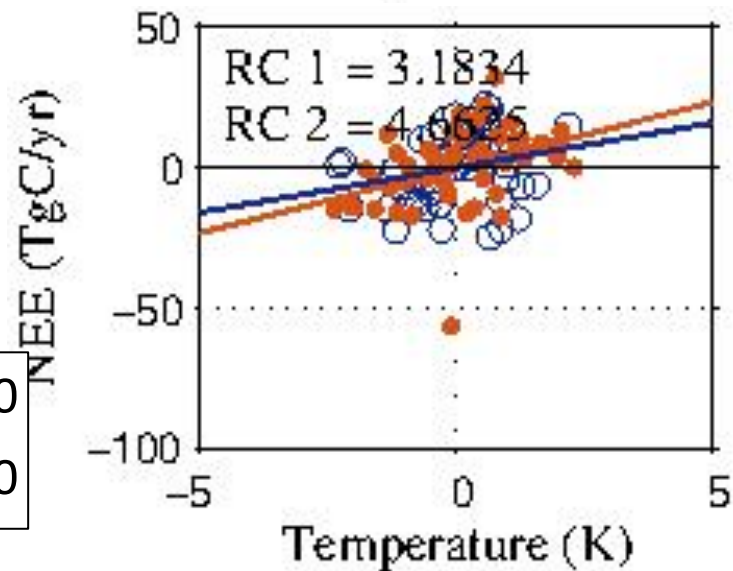
NEE vs T

Fennoscandia

JJA

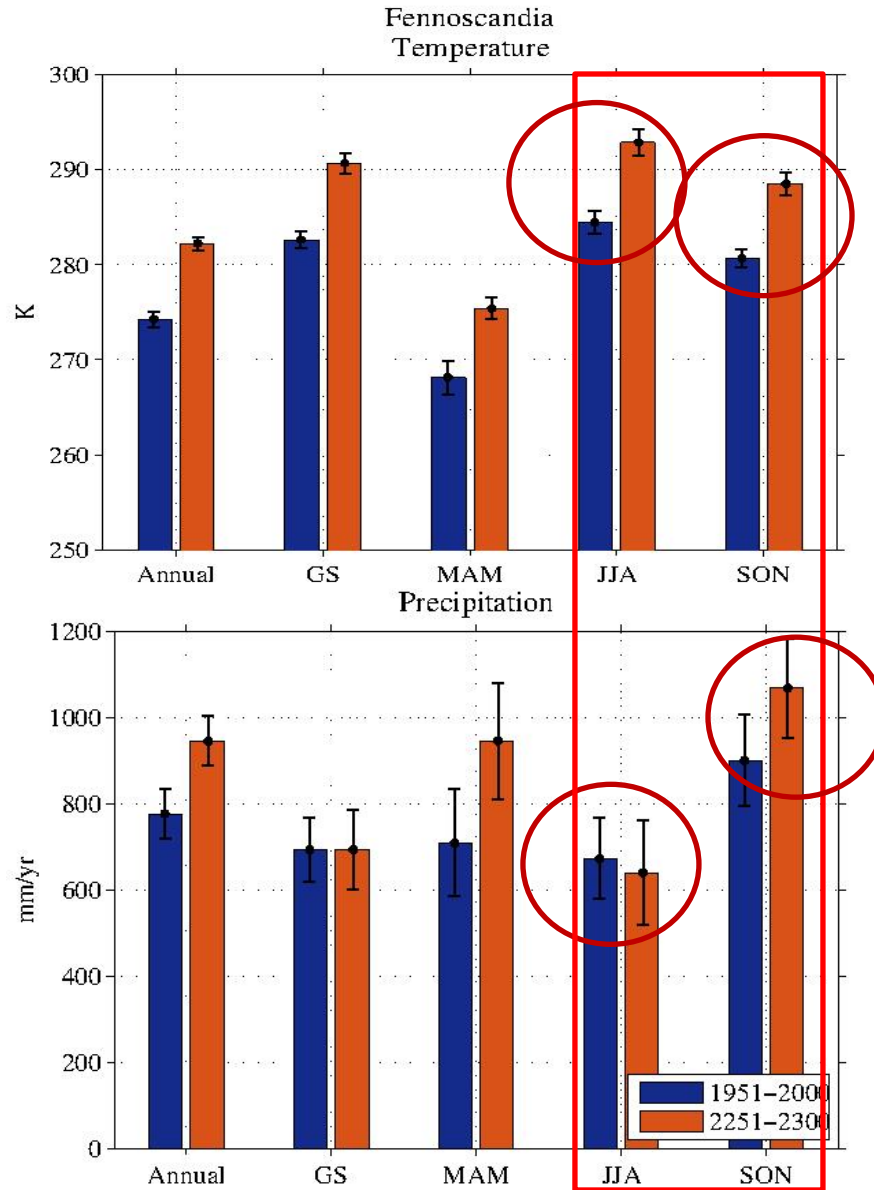


SON



Fennoscandia

Mean and SD of Temperature and Precipitation

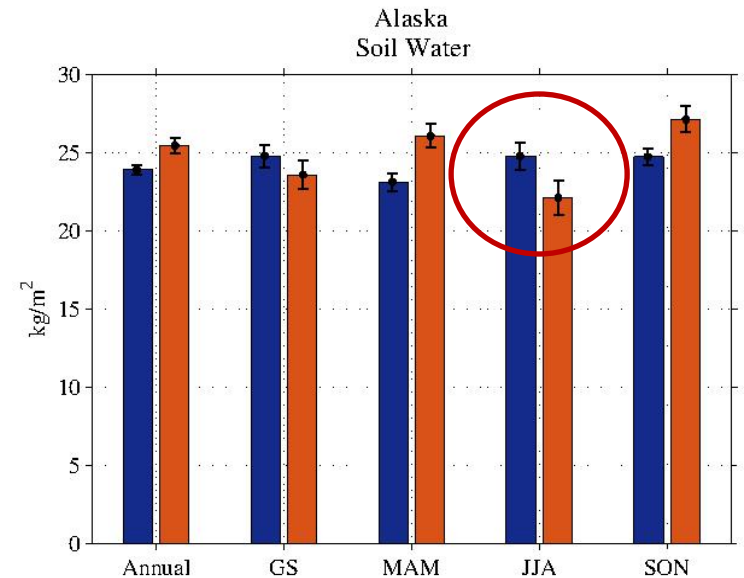
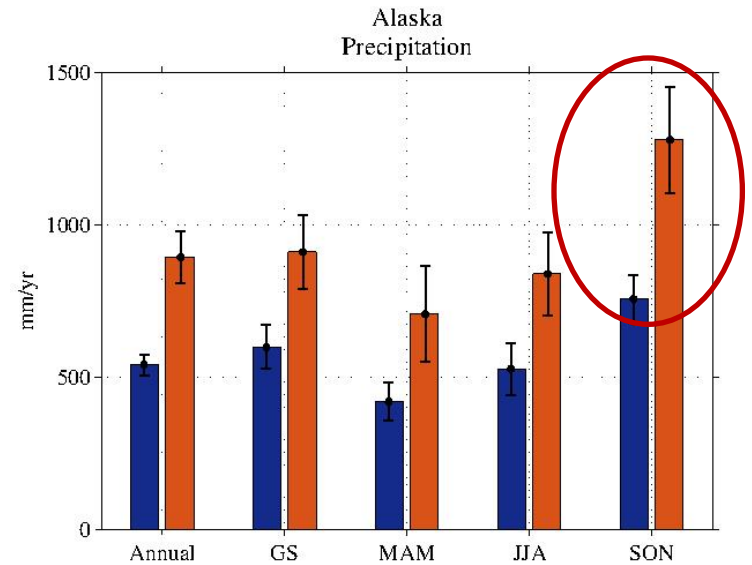
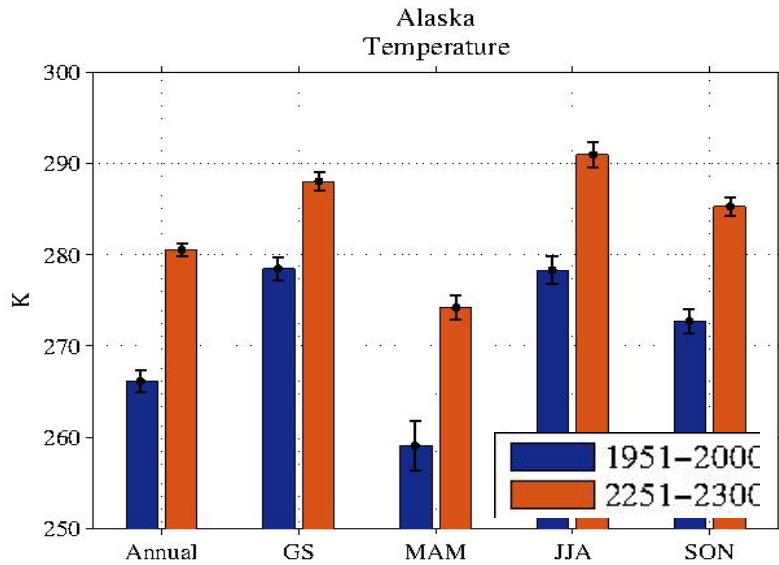


T varies a little more

P varies a lot more

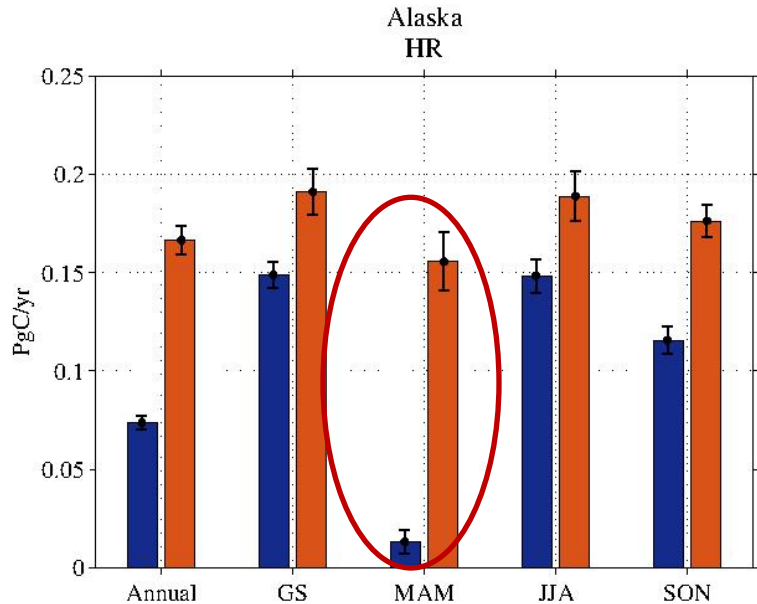
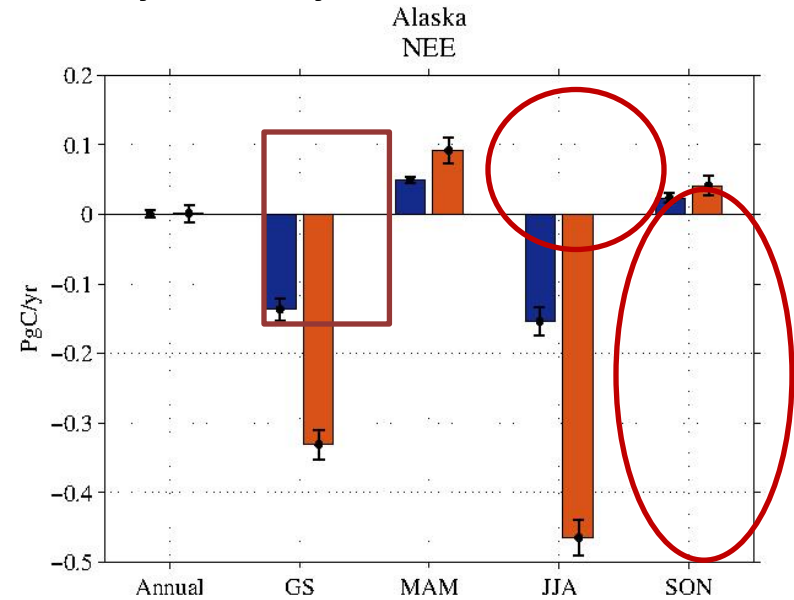
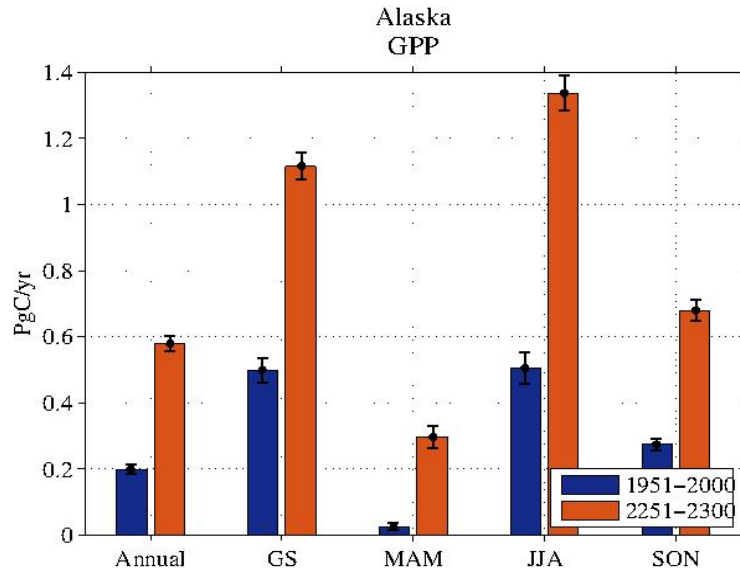
Alaska

Mean and SD of Temperature, Precipitation and Soil Water



Alaska

Mean and SD of GPP, HR, and NEE

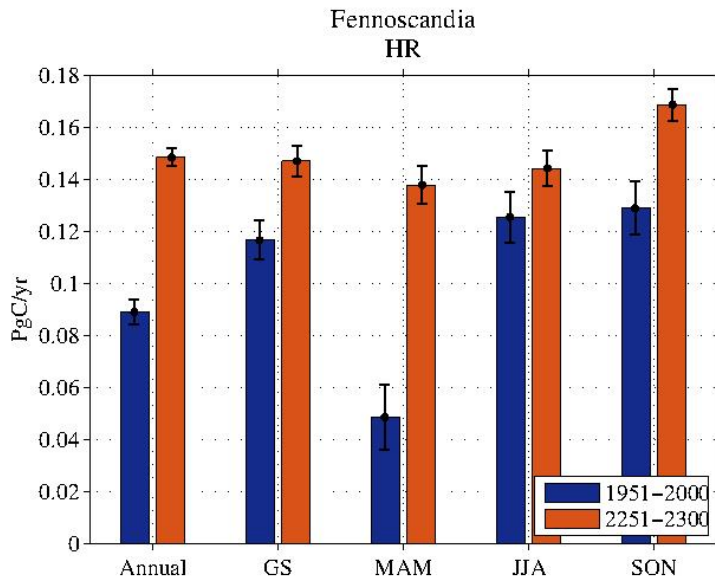
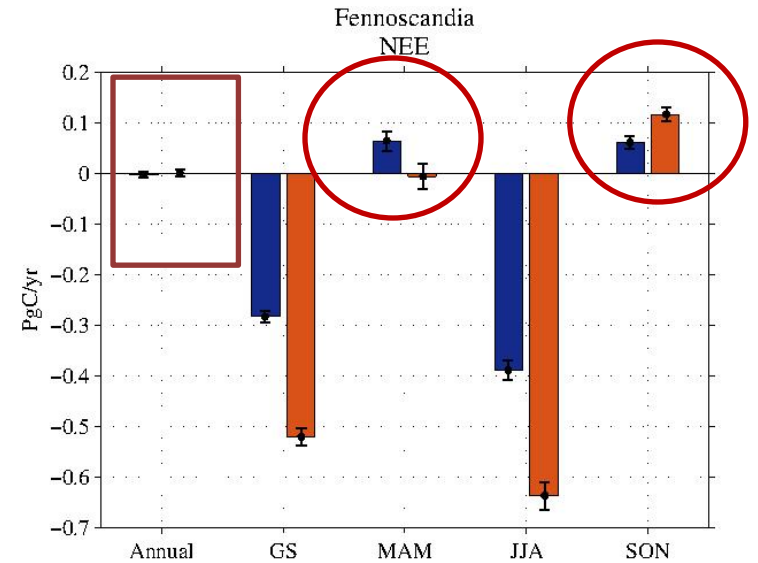
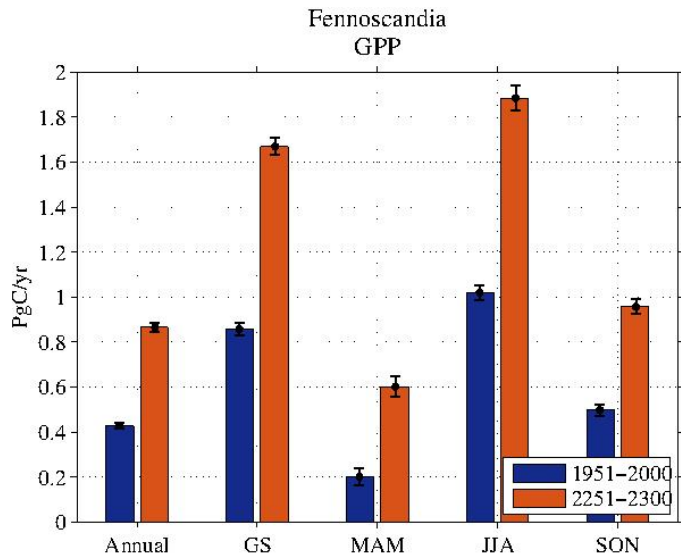


Spring C loss reflects enhanced HR

Summer C uptake nearly 3x larger!

Fennoscandia

Mean and SD of GPP, HR, and NEE

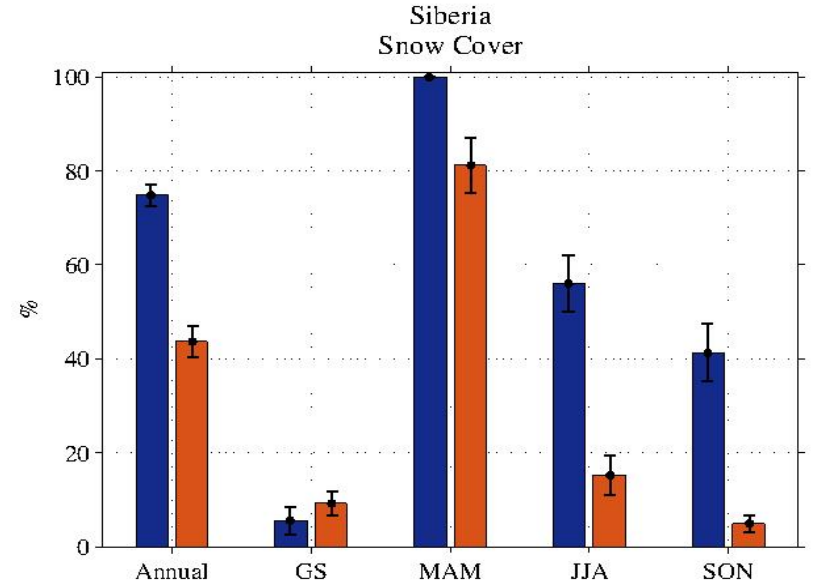
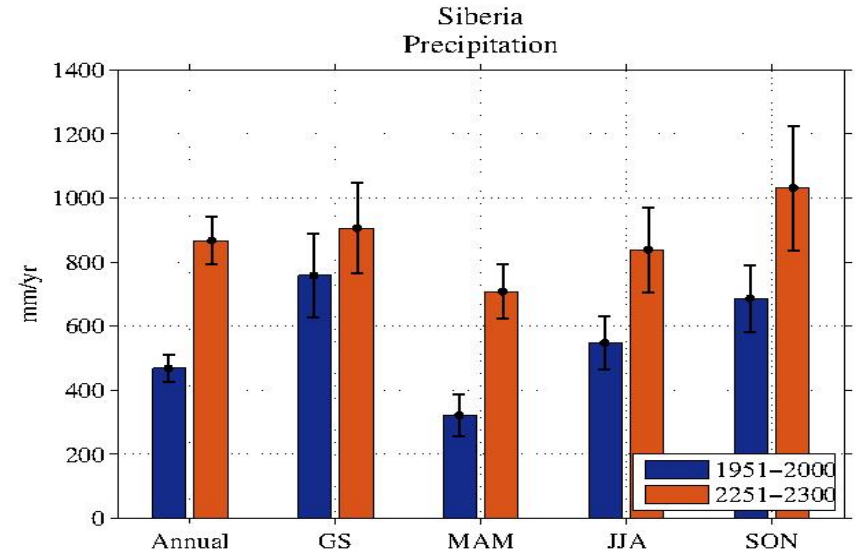
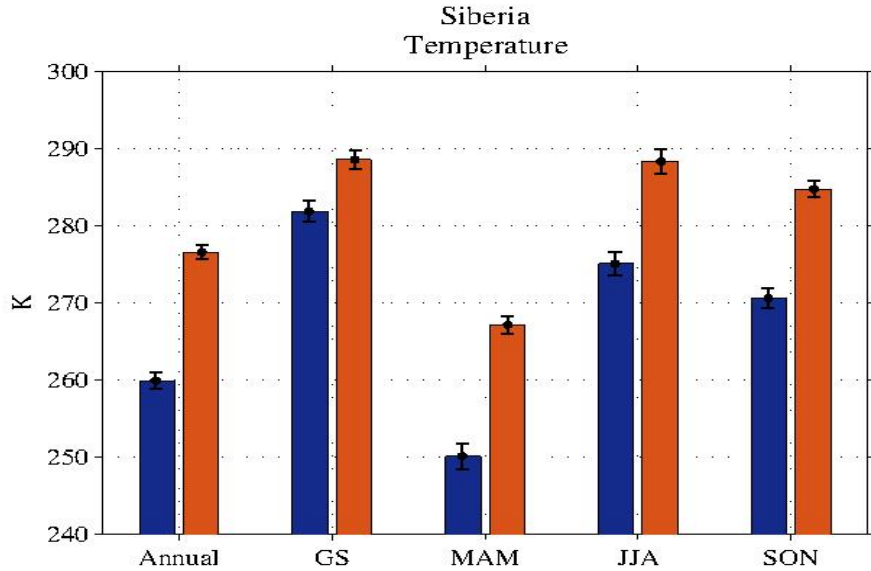


Switch from net C loss to small gain in spring b/c GPP increase > HR increase; NEE varies more

Fall C loss larger, NEE more variable

Siberia

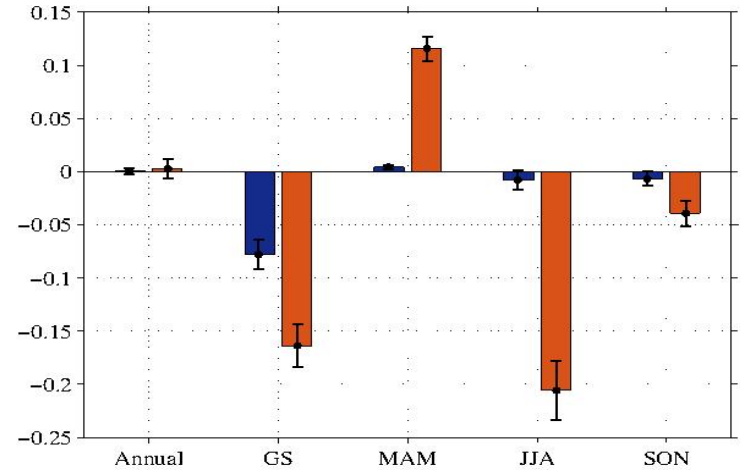
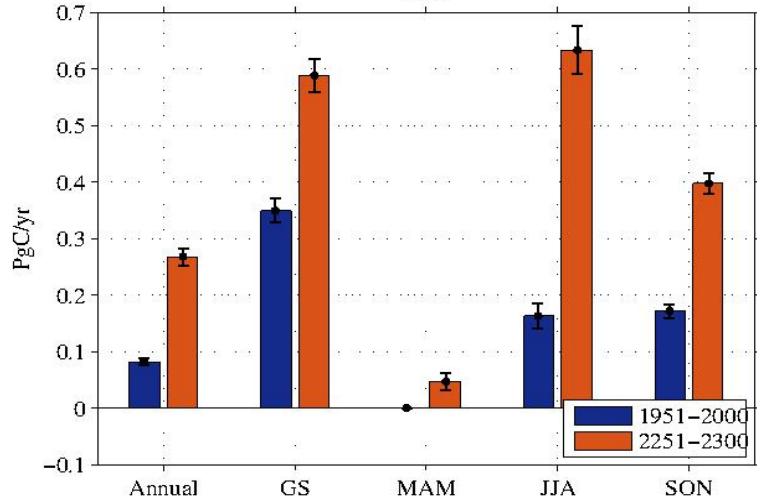
Mean and SD of Temperature, Precipitation, and Snow Cover



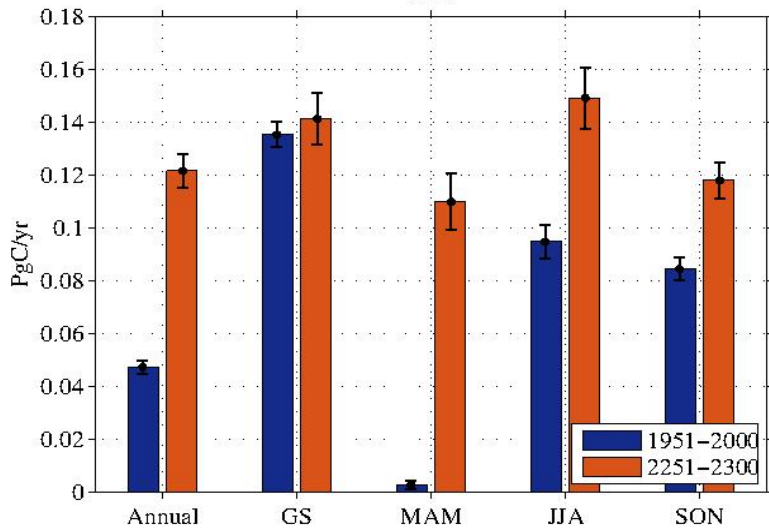
Siberia

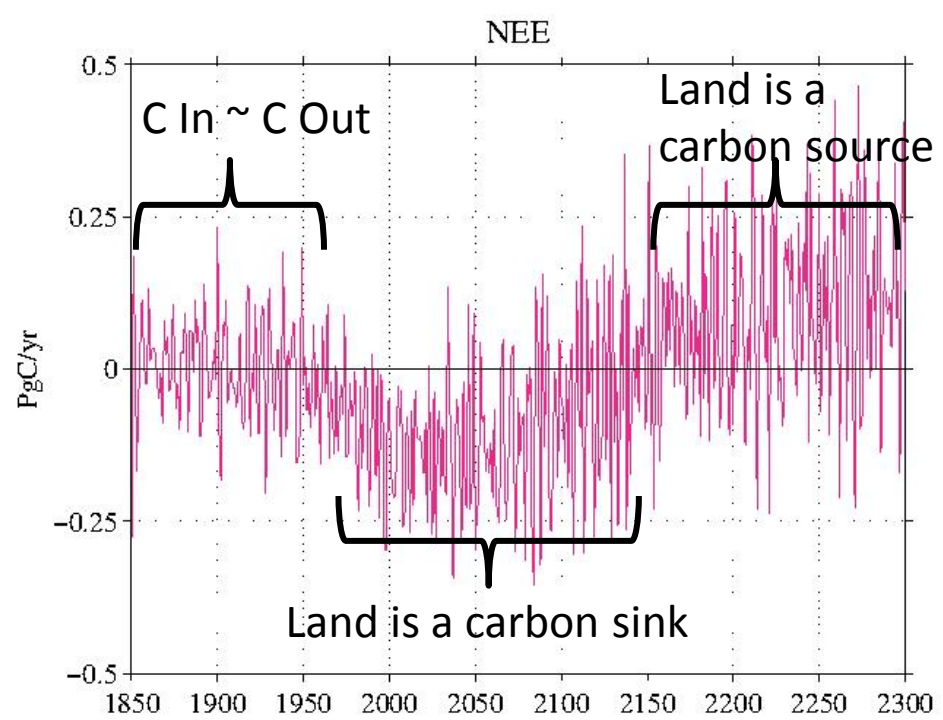
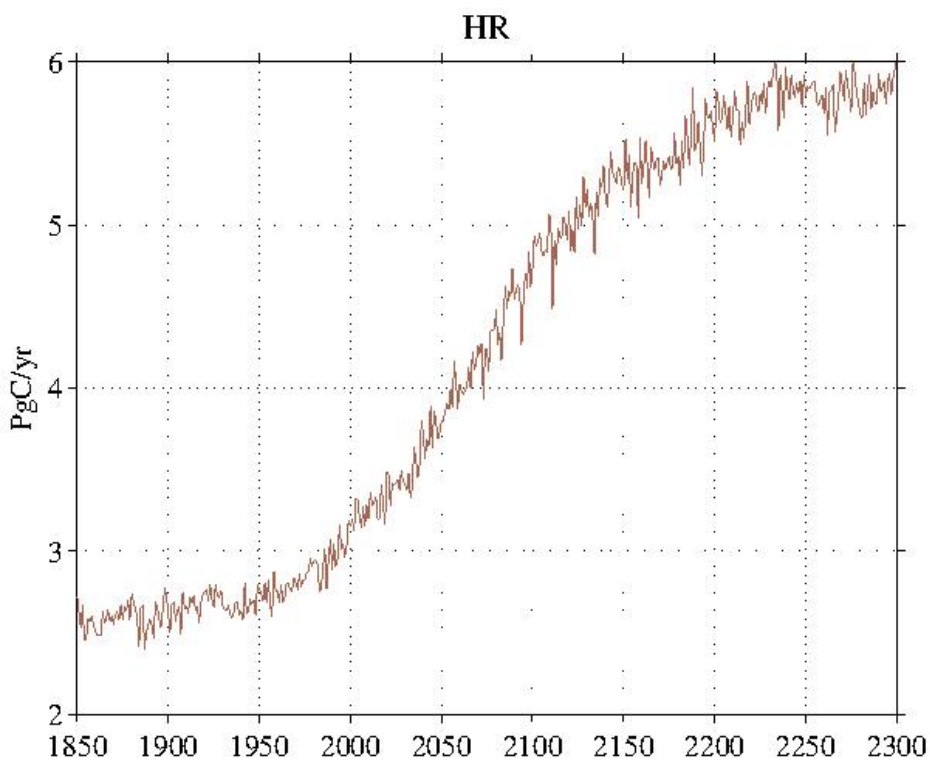
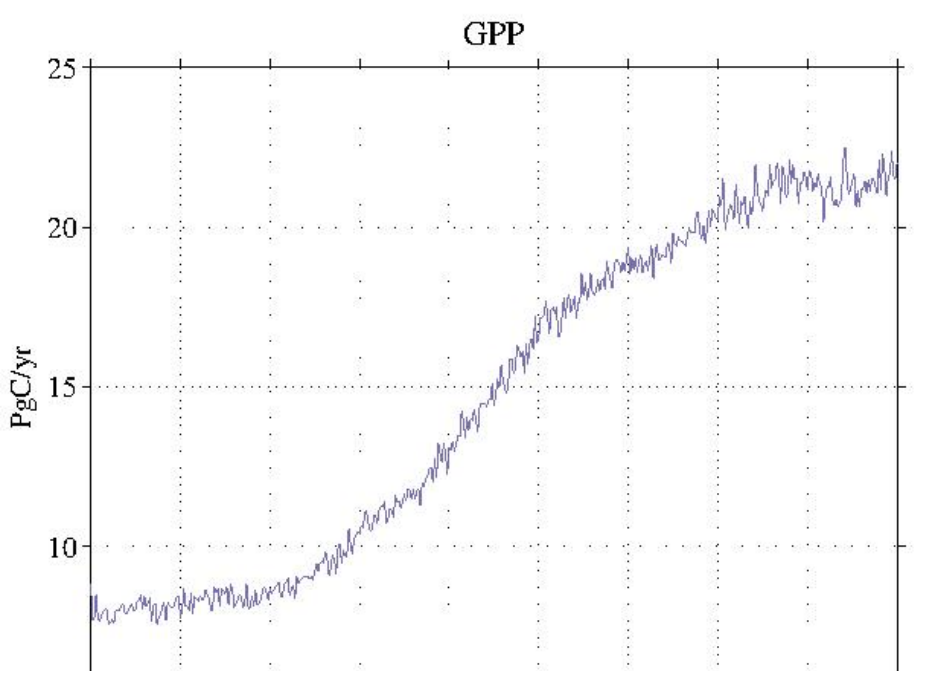
Mean and SD of GPP, HR, and NEE

Siberia
GPP



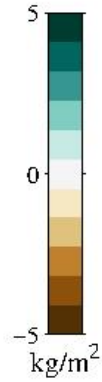
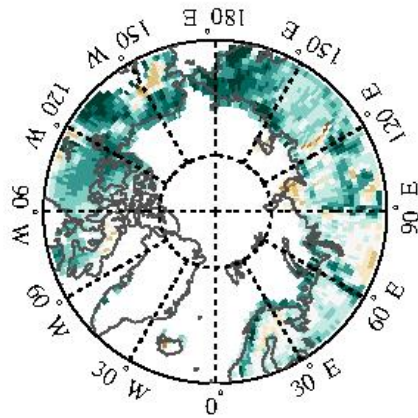
Siberia
HR



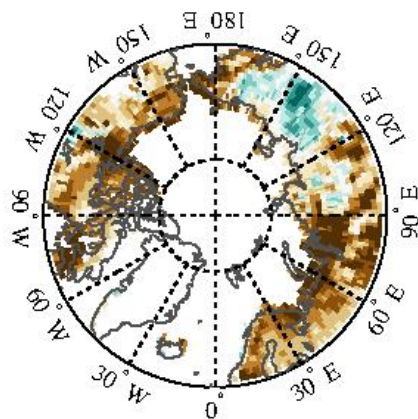


Soil Water: 2251–2300 – 1951–2000

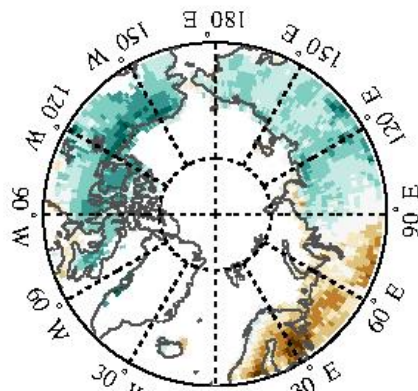
MAM



JJA

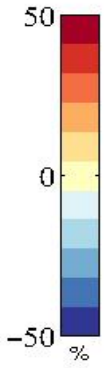
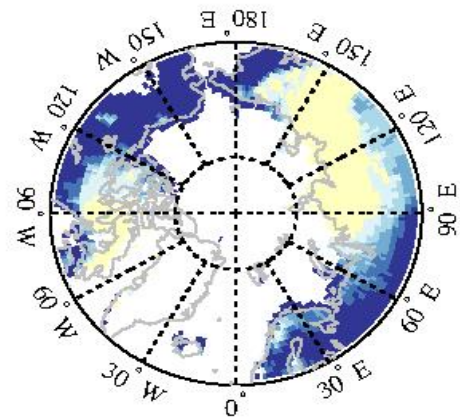


SON

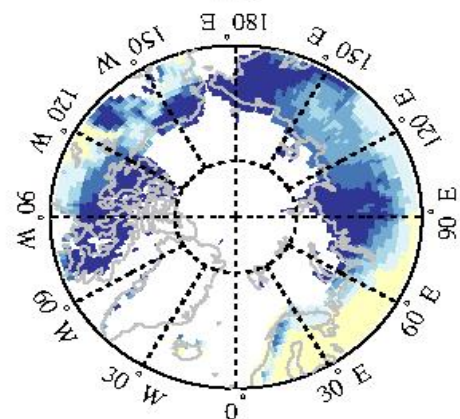


Snow Cover: 2251–2300 – 1951–2000

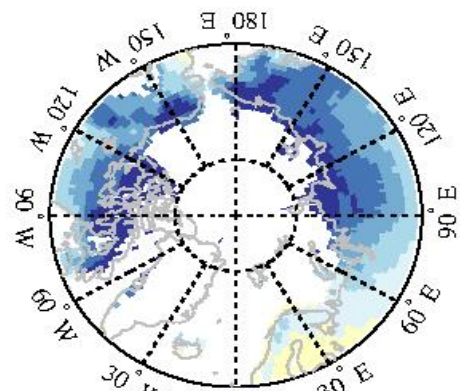
MAM



JJA

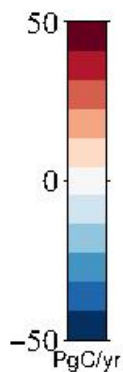
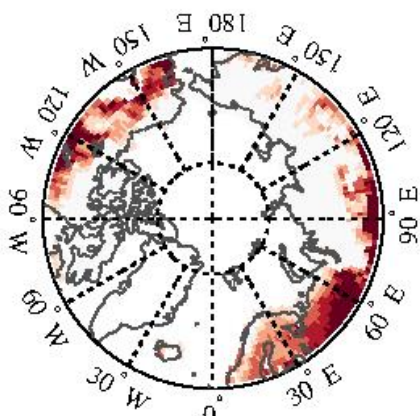


SON



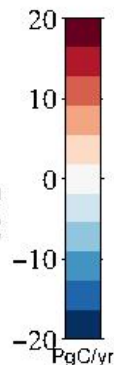
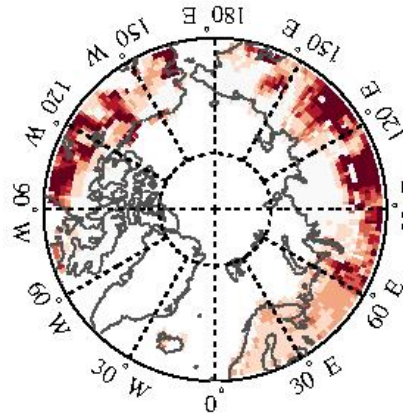
GPP: 2251-2300 - 1951-2000

MAM



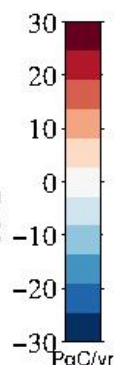
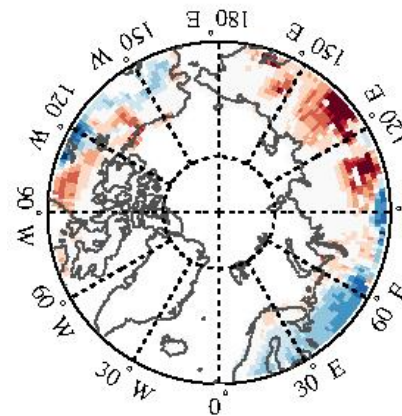
HR: 2251-2300 - 1951-2000

MAM

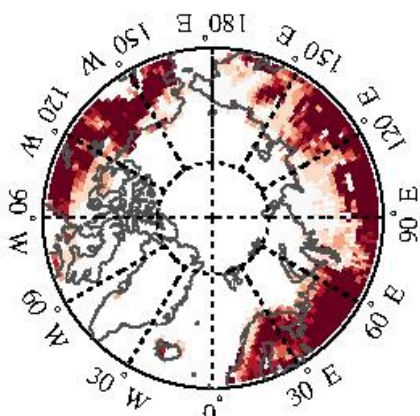


NEE: 2251-2300 - 1951-2000

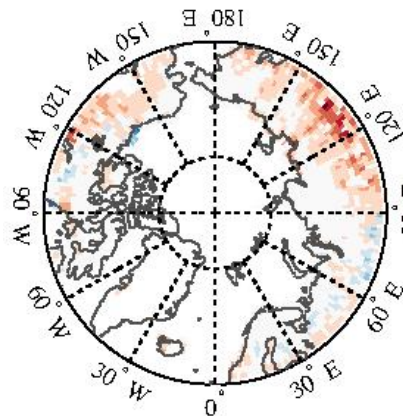
MAM



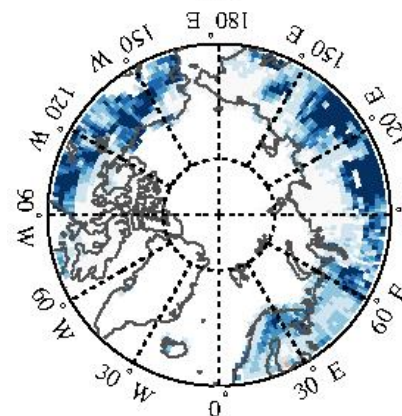
JJA



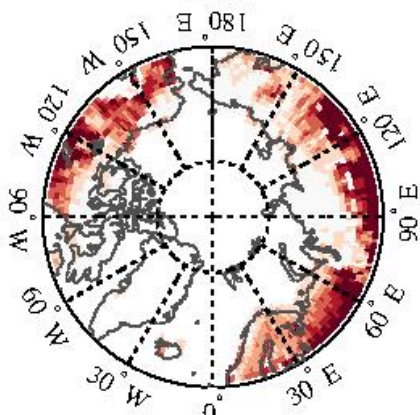
JJA



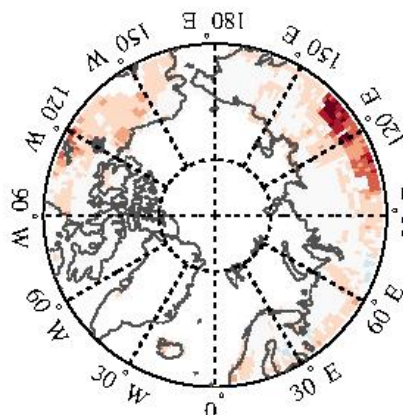
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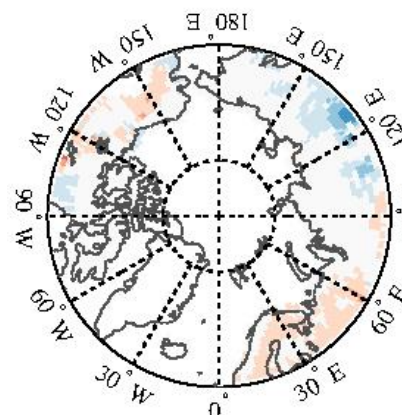
SON



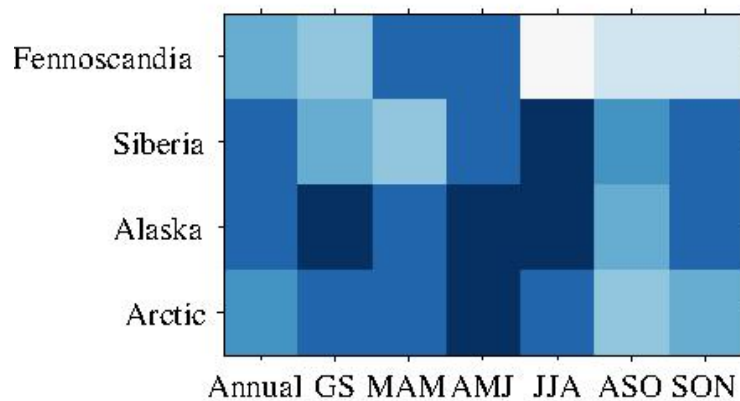
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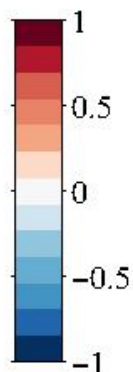
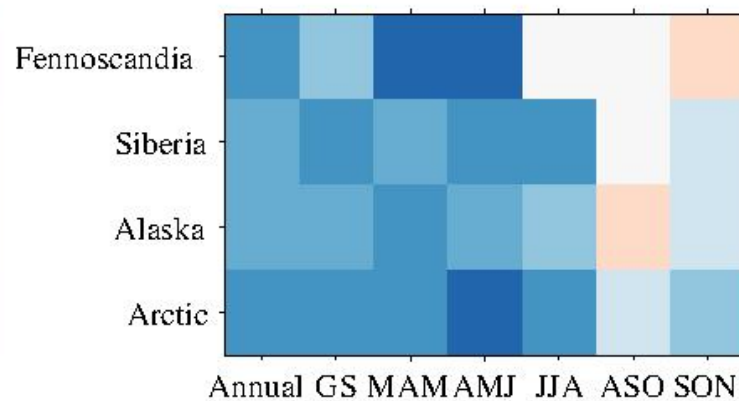
SON



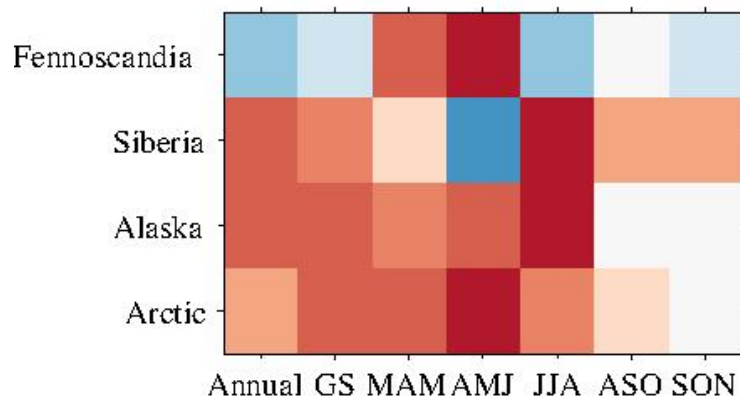
GPP vs Snow
1951–2000



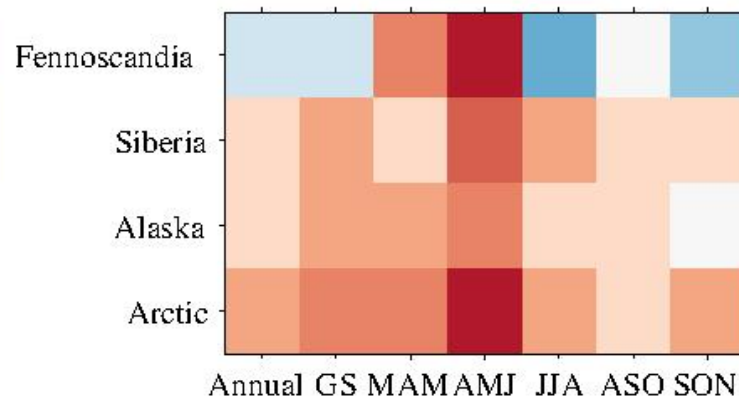
GPP vs Snow
2251–2300



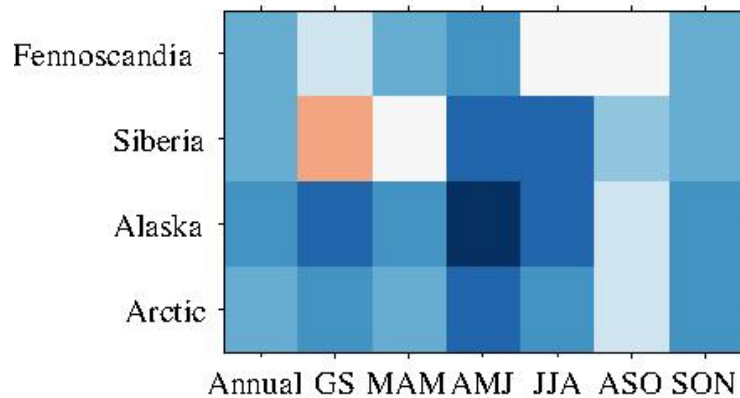
NEE vs Snow



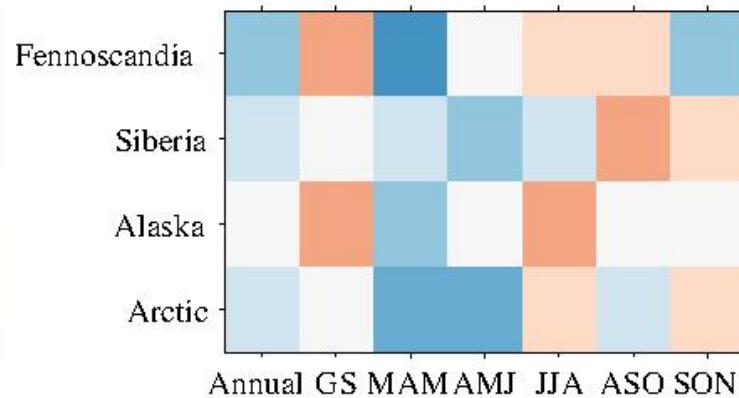
NEE vs Snow



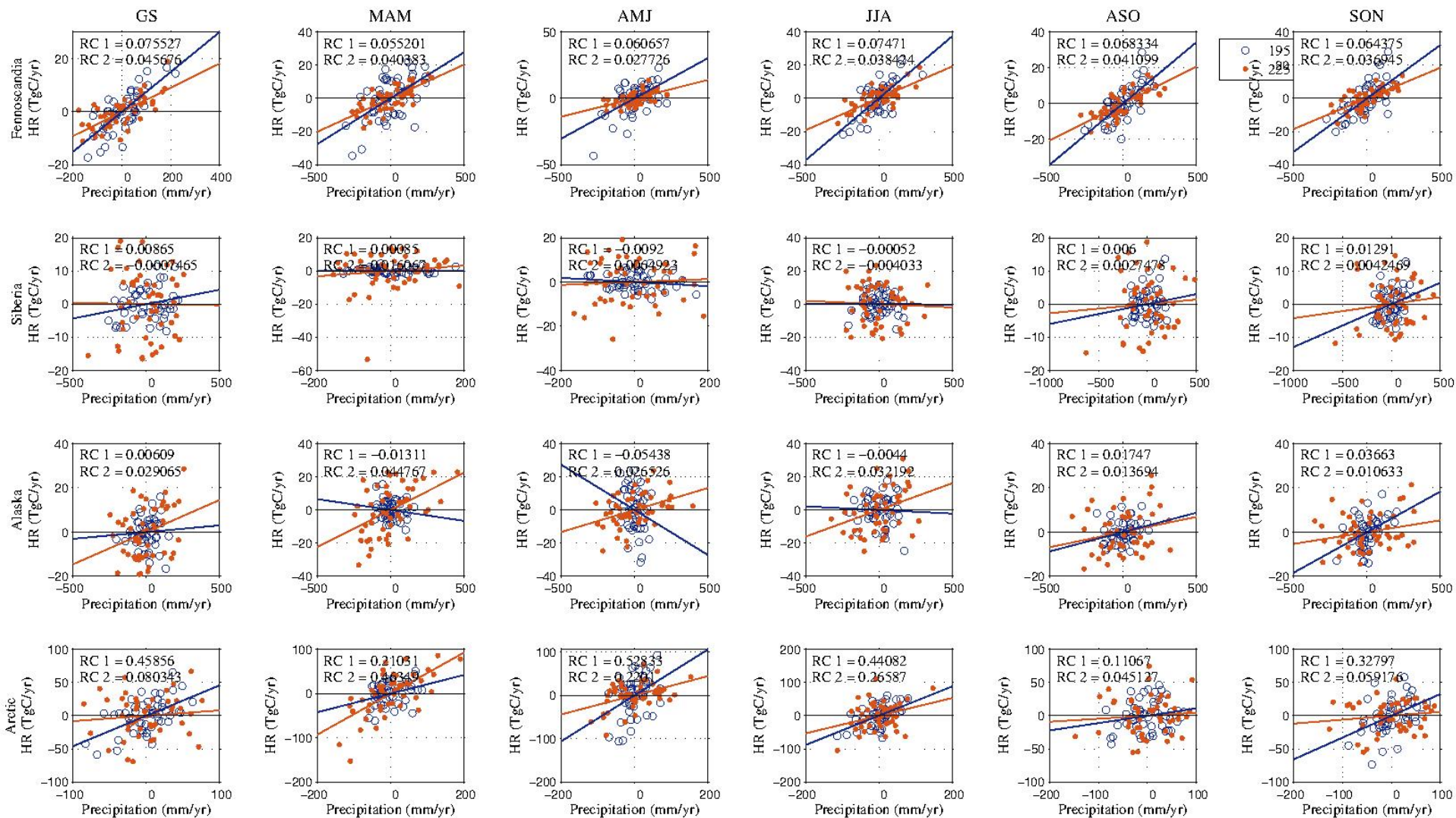
HR vs Snow



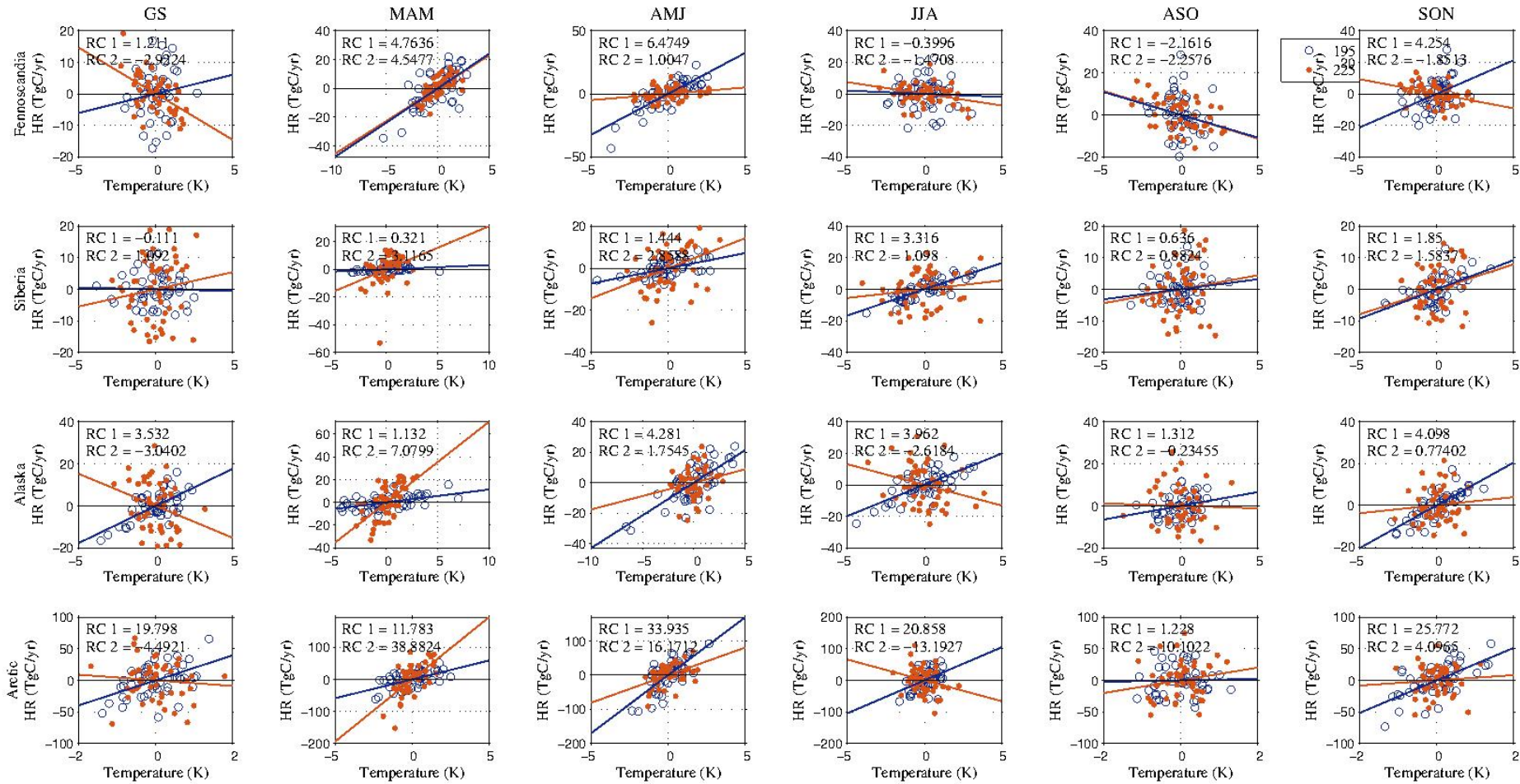
HR vs Snow



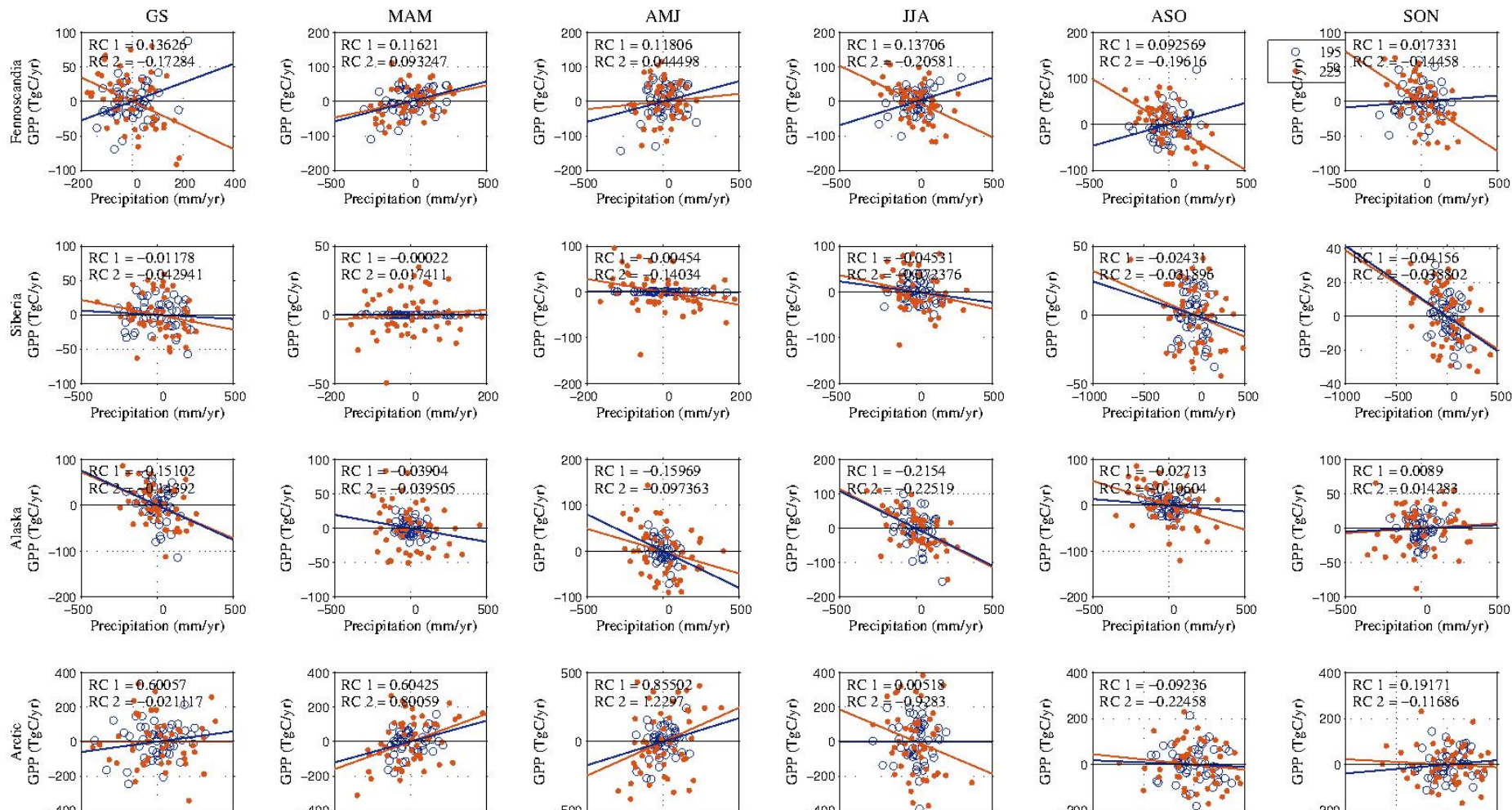
HR vs P



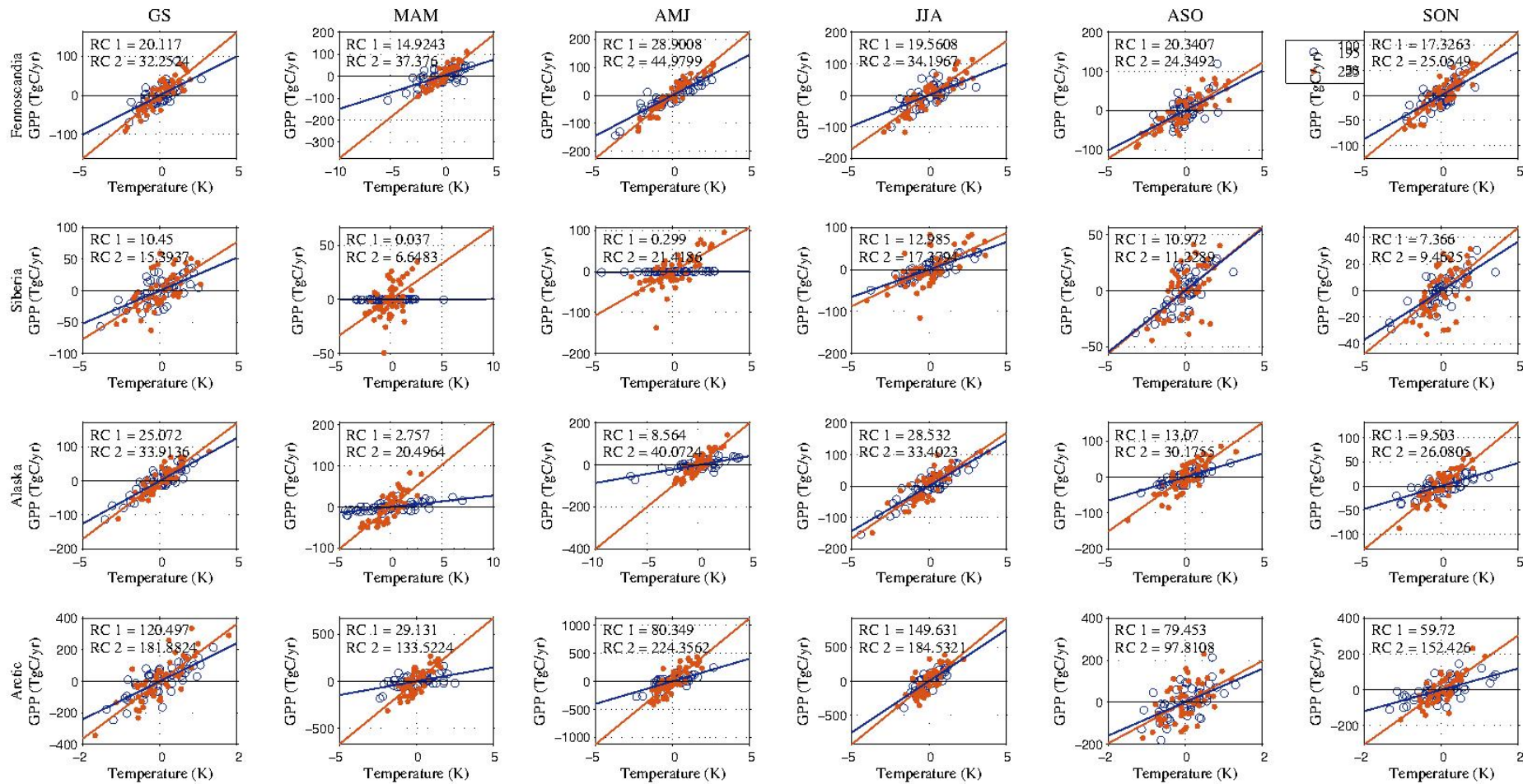
HR vs T



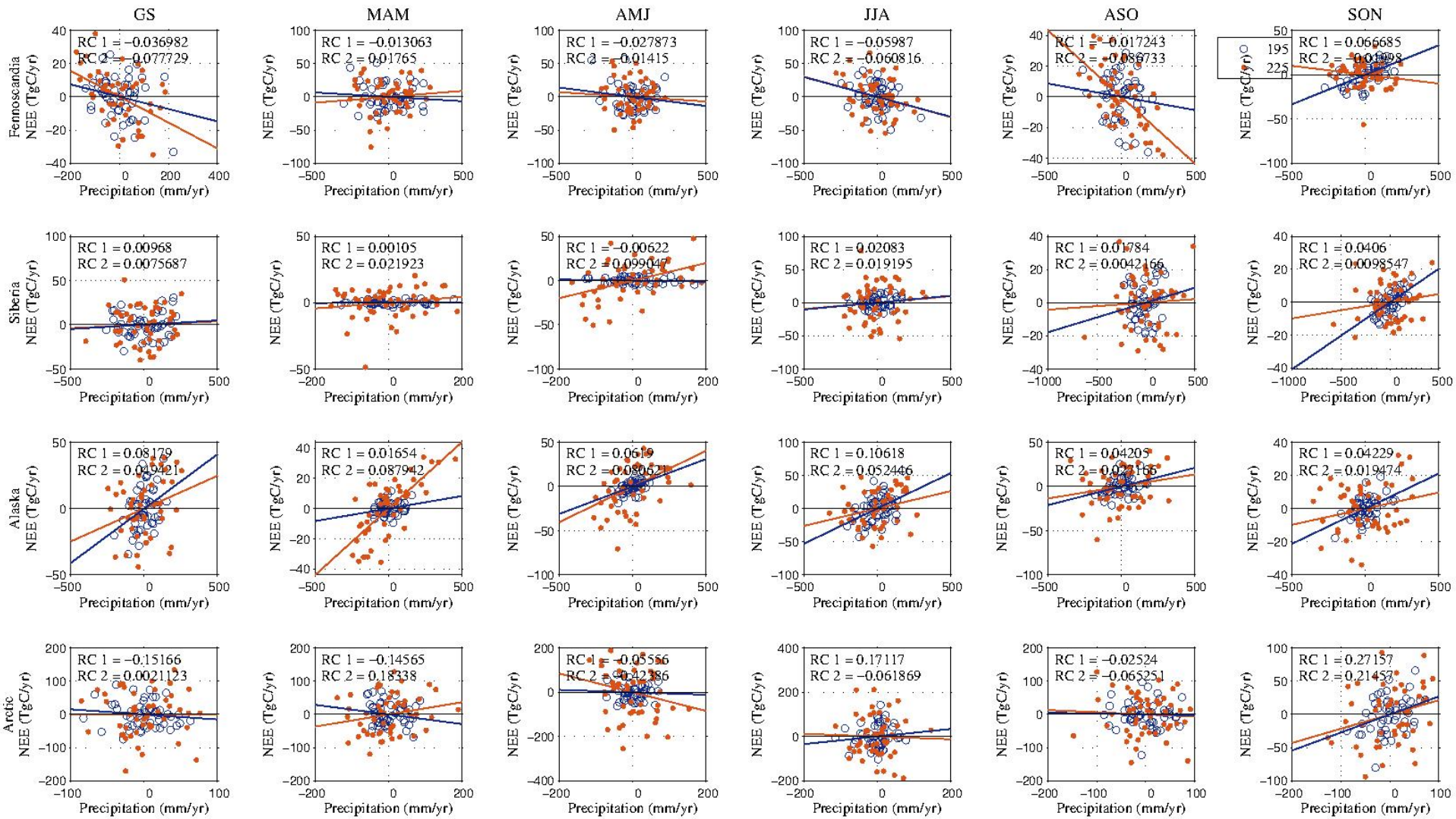
GPP vs Precip



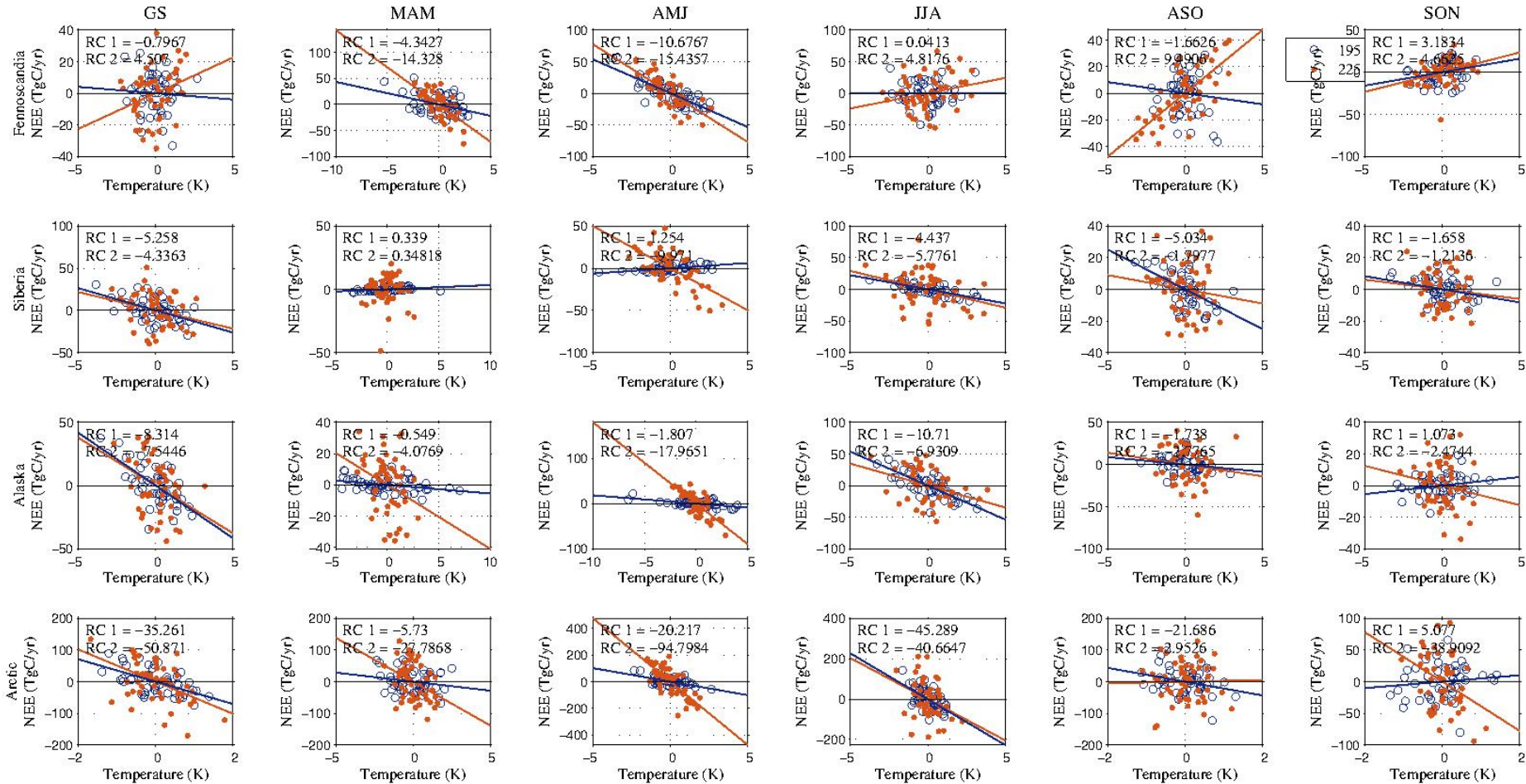
GPP vs T



NEE vs P



NEE vs T



Average 500-mb Height Anomaly

