The Thermal Feedback of Forest to Local and Regional Climate

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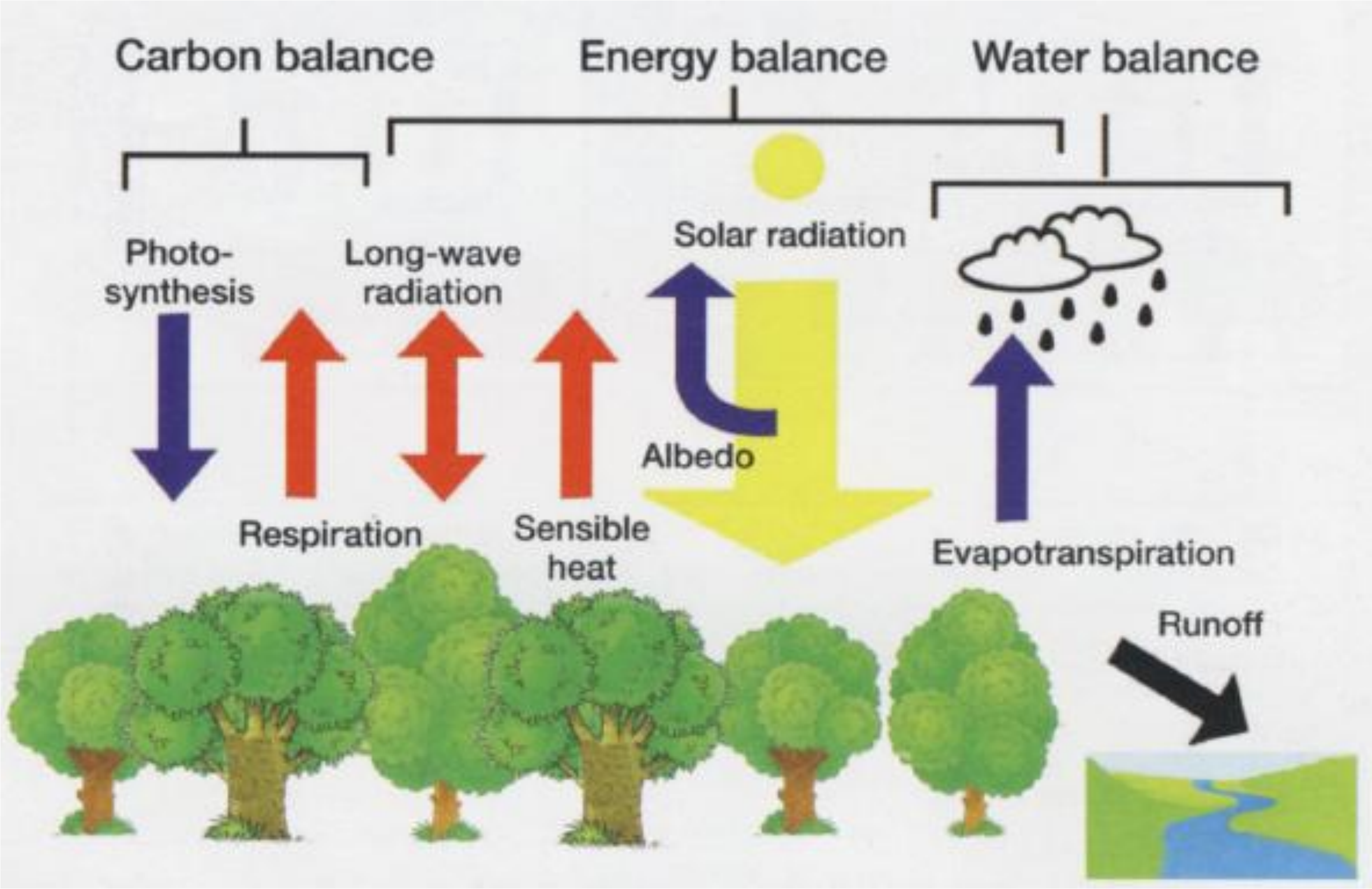
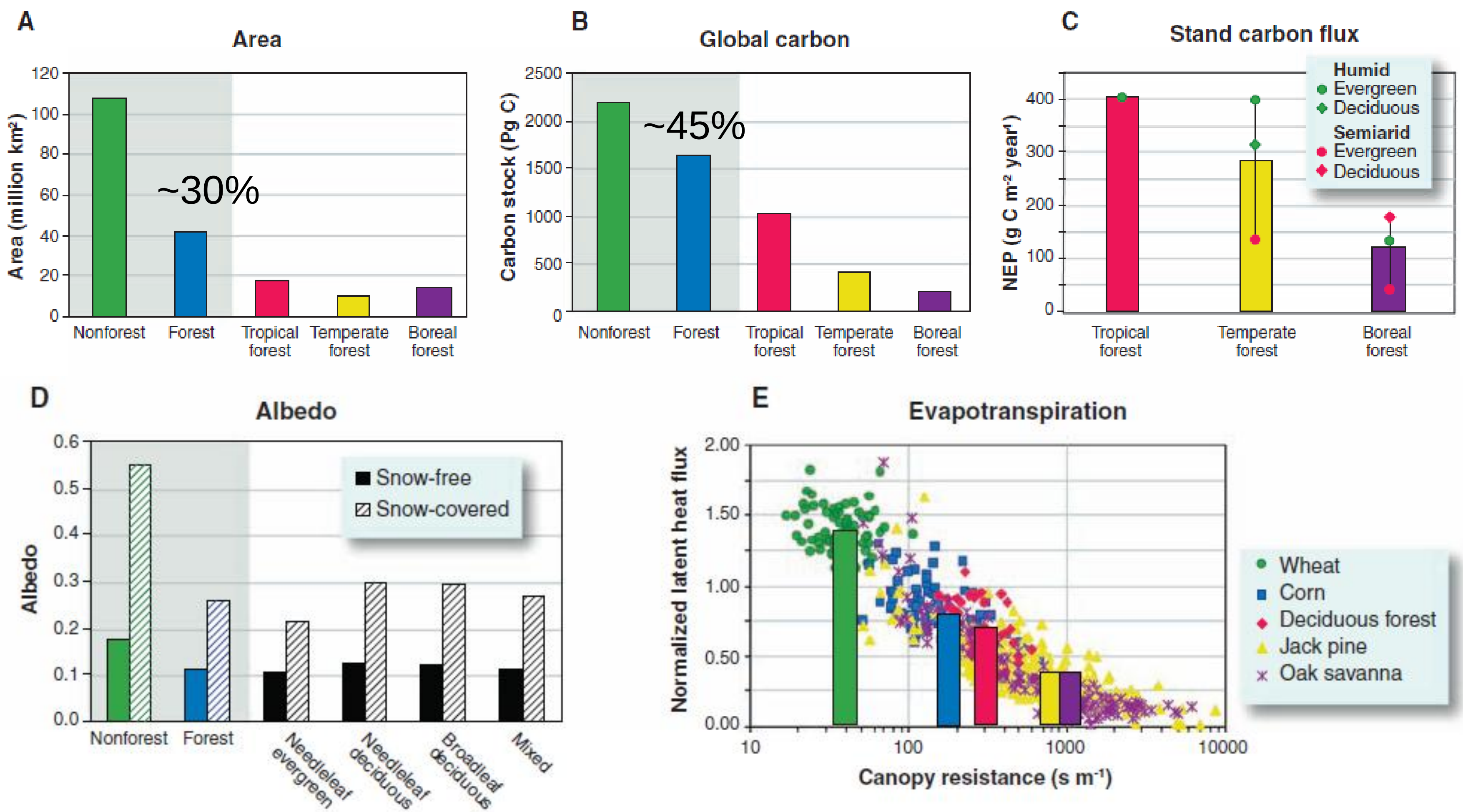
Major pathways of forest's climate feedback.



Chapin et al. (2008)

Other possible factors: clouds, aerosol, N, CH_4, ozone, fire disturbance…

Forest's biophysical and bio-geochemical characteristics



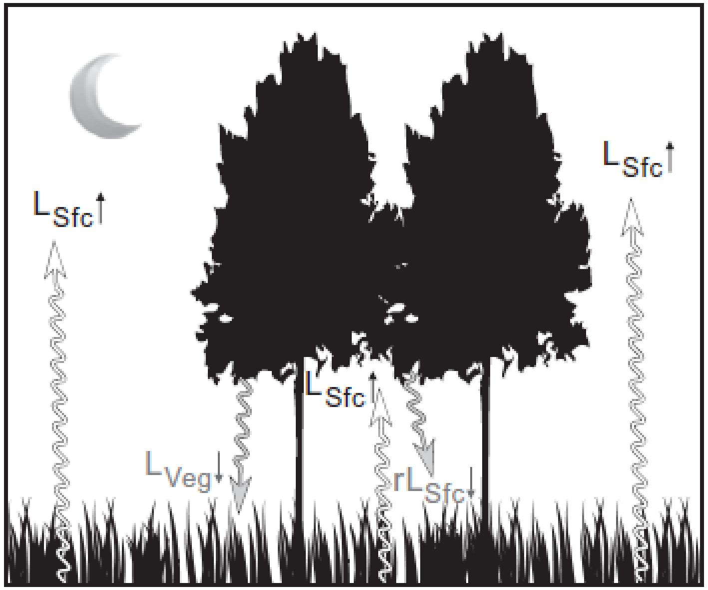
Bonan (2008), Science

Biophysical processes: forest vs. non-forest

- ➢ Solar and long-wave radiation

Forest: high
- Low albedo
- High roughness

Non-forest: low
- High albedo
- Low roughness

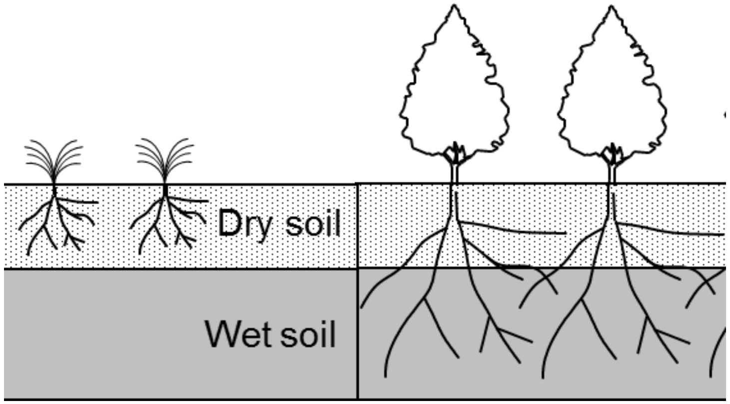


snow cover, surface influence on wind speed and interaction with boundary layer

- ➢ Latent heat flux

Forest: high
- High roughness
- Deep roots

Non-forest: low
- Low roughness
- Shallow roots



water availability, which at the same time also impact corresponding veg distribution.

ET

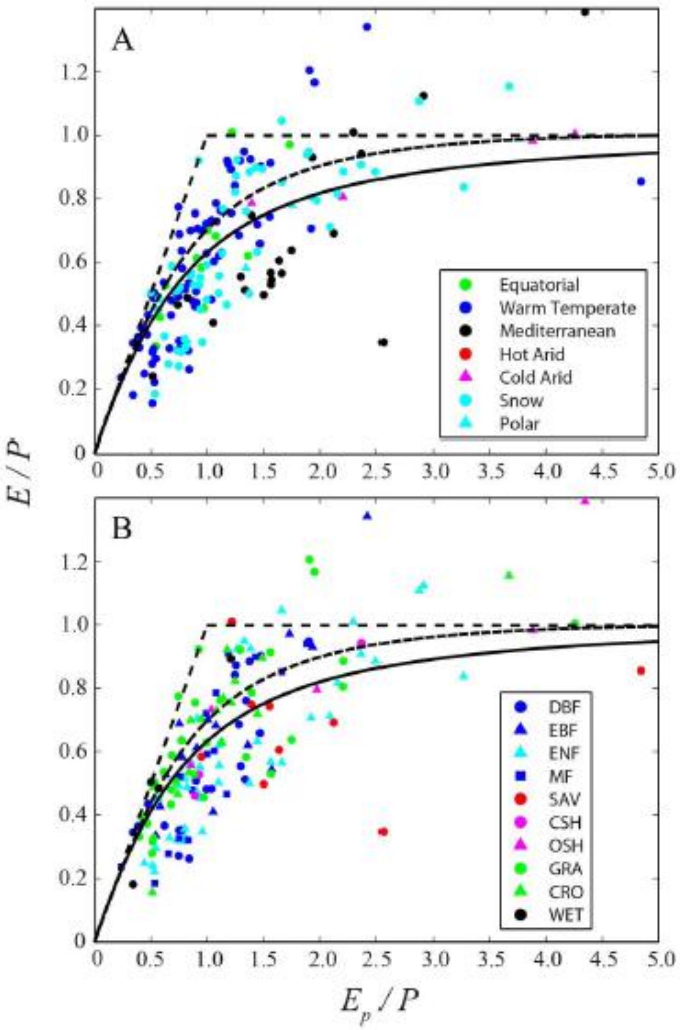


Figure 4. Evaporative index (E/P) versus dryness index (E_p/P) for all FLUXNET sites used in the analysis (one symbol for each) based on annual climatologies. Available

Christopher et al. (2012)

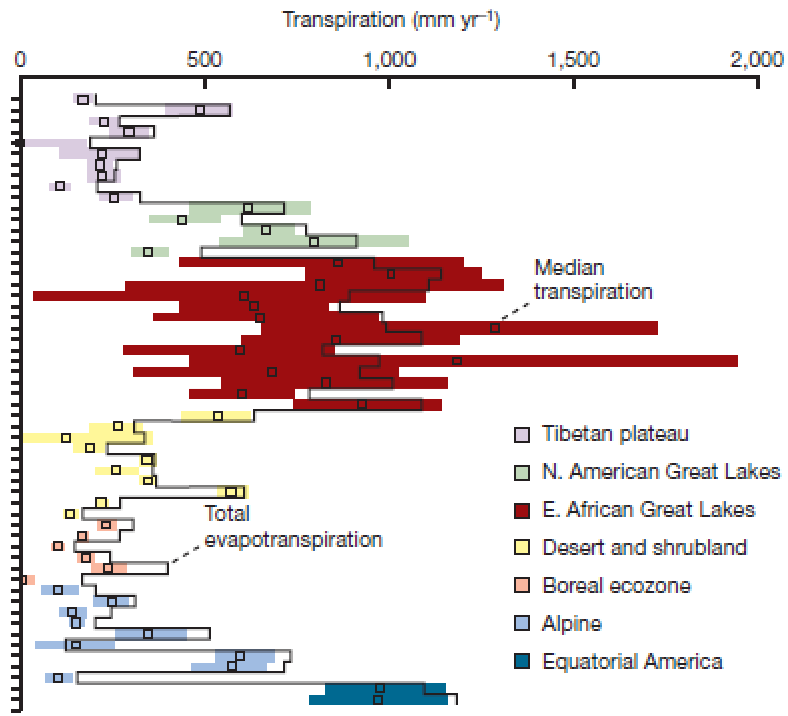
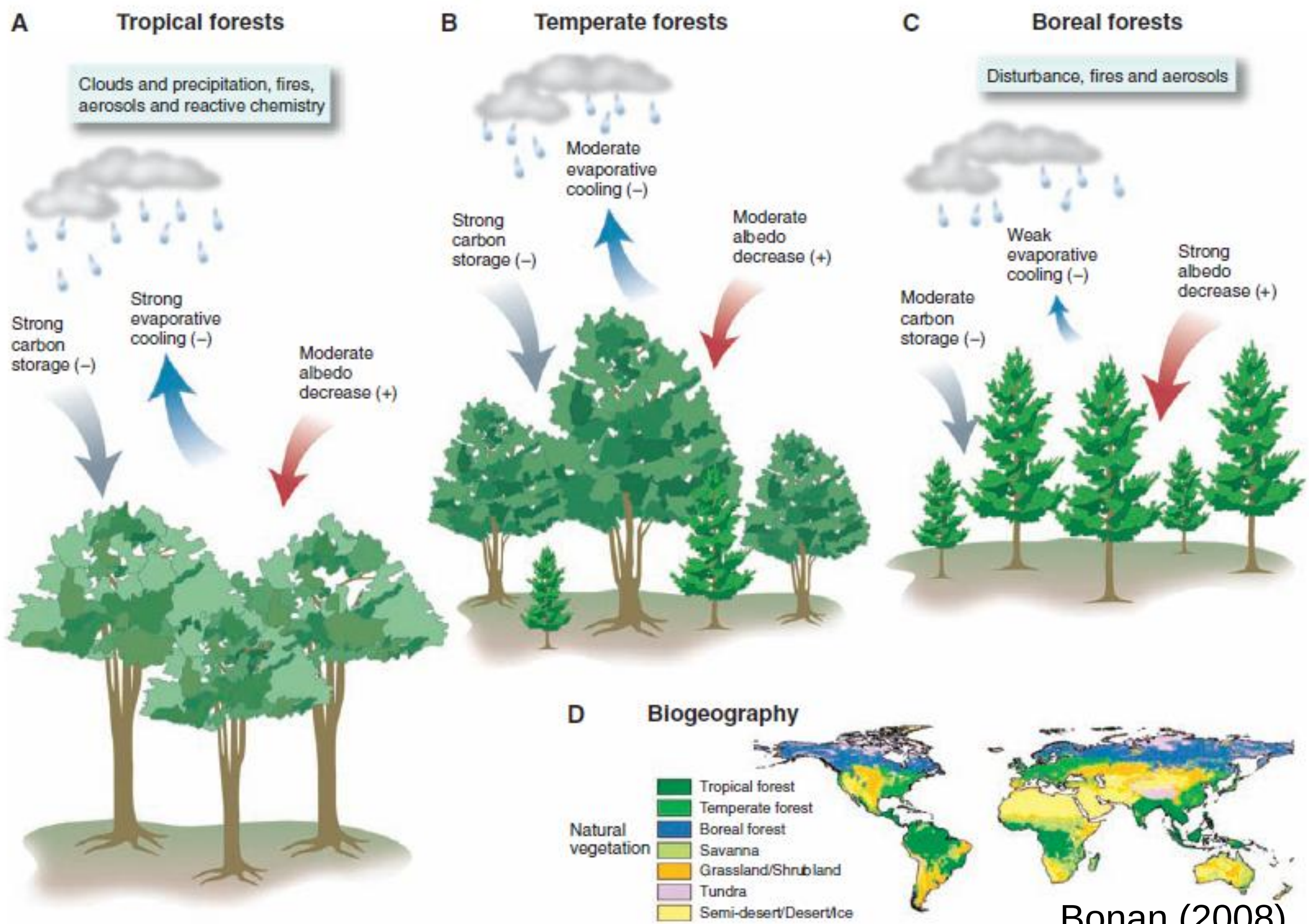


Figure 2 | Transpiration water losses for 56 lake catchments grouped by ecoregion ($^{18}O/^{16}O$-based results). Each coloured bar represents results for a

Jasechko et al. (2013)

Prevailing paradigm:

Climate services in tropical, temperate, and boreal forests



Bonan (2008), Science

Main research methodology for thermal feedback

- **Directly through observations**
  - difficult: spatial comparison (other controls), time series (cause or feedback)
  - limited cases: e.g. nearby site comparison, the effect of leaf emergence on springtime evapotranspiration and air temperature
- **Eddy covariance flux towers and field experiments**
  - local-scale insight to forest atmosphere interactions
- **Remote sensing**
  - aiding extrapolation of local knowledge to larger spatial scales
- **Climate-Earth's land surface models**
  - paired climate simulations, one as control against another with altered vegetation

Discrepancies in the mid-latitude?

❑ **Model simulations for the temperate forest:**

Forest warms temperatures	
Otterman et al. (1984)	Foley et al. (1994)
Bonan (1997)	Hansen et al. (1998)
Bonan (1999)	Brovkin et al. (1999)
Betts (2001)	Claussen et al. (2001)
Bounoua et al. (2002)	Diffenbaugh and Sloan (2002)
Defries et al. (2002)	Matthews et al. (2004)
Brovkin et al. (2004)	Oleson et al. (2004)
Feddema et al. (2005)	Gibbard et al. (2005)
Brovkin et al. (2006)	Shaeffer et al. (2006)
Bala et al. (2007)	Diffenbaugh (2009)
Dallmeyer et al. (2010)	Davin et al. (2010)

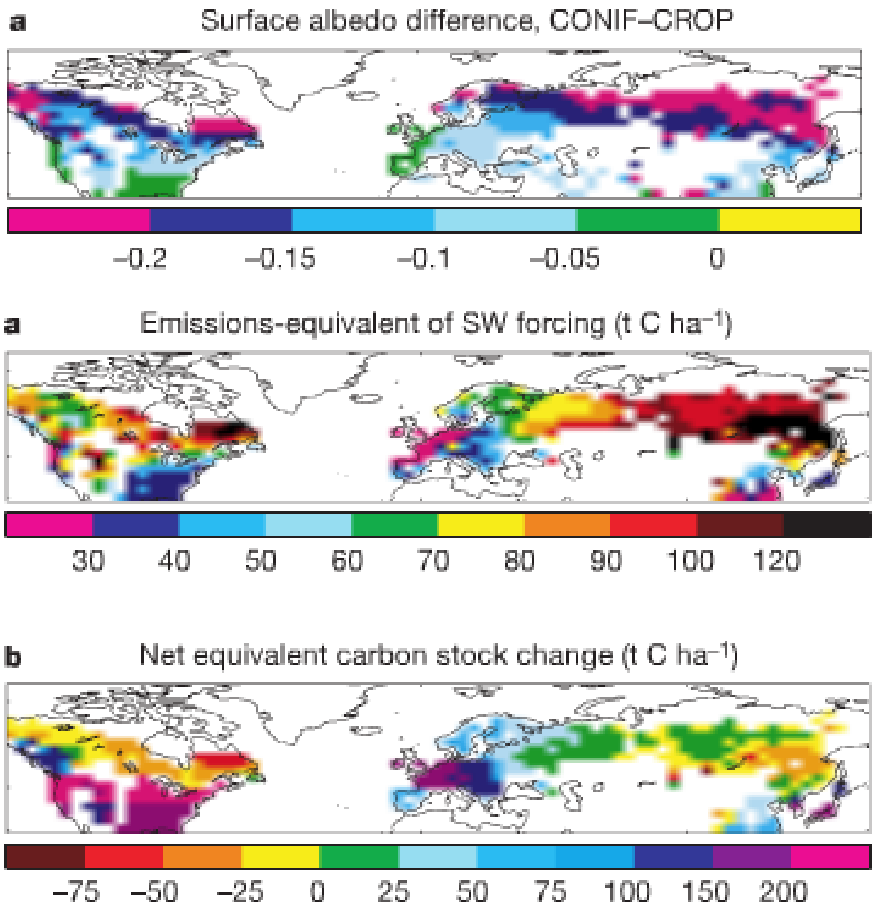
Forest cools temperatures
Betts (2000)
Baidya Roy *et al*. (2003)
Marshall *et al*. (2004)
Jackson *et al*. (2005)
Ramankutty *et al*. (2006)
Arora and Montenegro (2011)

❑ removal of **continental scale** temperate forest will promote cooling.

→ temperate forests are a source of heat relative to other classes of land cover.

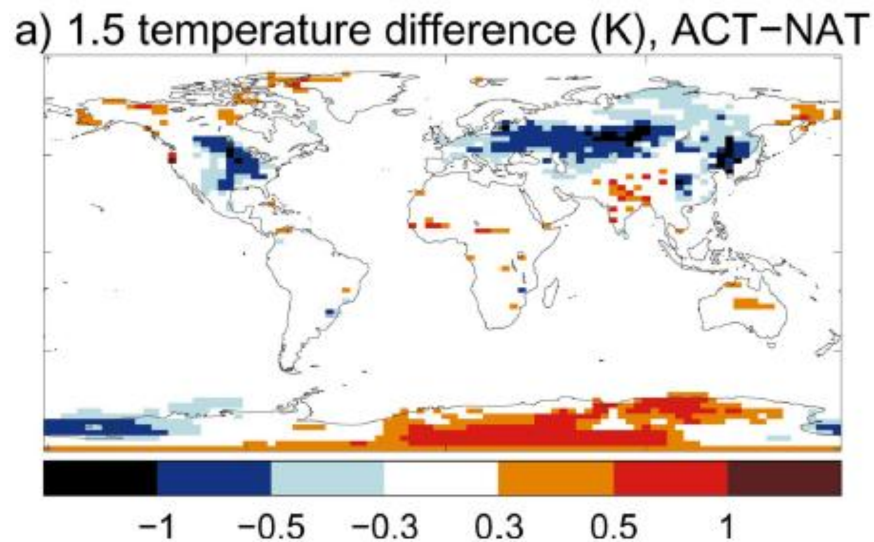
Model simulation: case 1

Coniferous plantations – crop
- HadAM3 for albedo forcing
- Carbon sequestration potential



Betts, (2000), Nature

Actual land cover – natural potential vegetation
- HadAM3 for GCM
- MOSES for land process



Betts (2001), ASL

Model simulation: case 2

Combined climate and carbon-cycle effects of large-scale deforestation

- INCCA (Integrated Climate and Carbon) model: deforestation scenarios - controlled

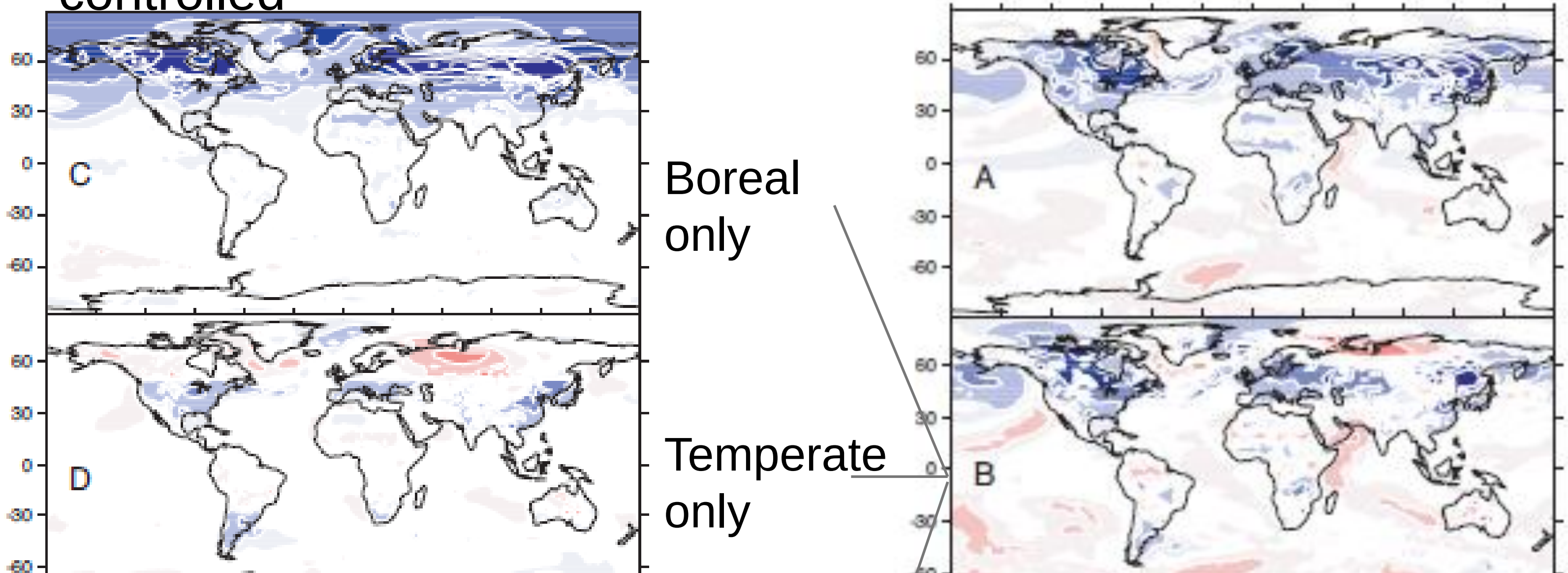


Table 1. Climate variable differences between Global and Standard experiments for the decade centered on year 2100

	Global	Global land	SH mid-latitude land (50°S to 20°S)	Tropical land (20°S to 20°N)	NH mid-latitude land (20°S to 50°N)	NH high-latitude land (50°S to 90°N)
Surface temperature, K	−0.3	−1.0	0.1	−0.4	−1.6	−2.1
Evapotranspiration, %	−2.6	−7.8	−16.7	−5.8	−5.8	−14.6
Surface albedo, %	1.9	5.2	5.0	4.1	4.7	10.7
TOA albedo, %	0.6	1.6	0.5	−0.3	1.7	5.5
Total cloudiness, %	−0.7	−1.7	−4.7	−4.6	−1.2	2.5
Surface SW absorbed, Wm^{-2}	−1.4	−4.3	−1.7	1.2	−5.2	−13.8
Surface downward SW, Wm^{-2}	2.2	5.1	11.3	12.9	3.0	−3.2

Evapotranspiration percentage differences are relative to Standard mean climate for this period. Cloudiness and albedo changes are absolute changes. SH, Southern Hemisphere; NH, Northern Hemisphere; TOA, Top of Atmosphere; SW, shortwave.

Bala et al. (2007)

Model simulation: case 3

Small temperature benefits provided by realistic afforestation

- CanESM1 (Canadian Earth System Model)

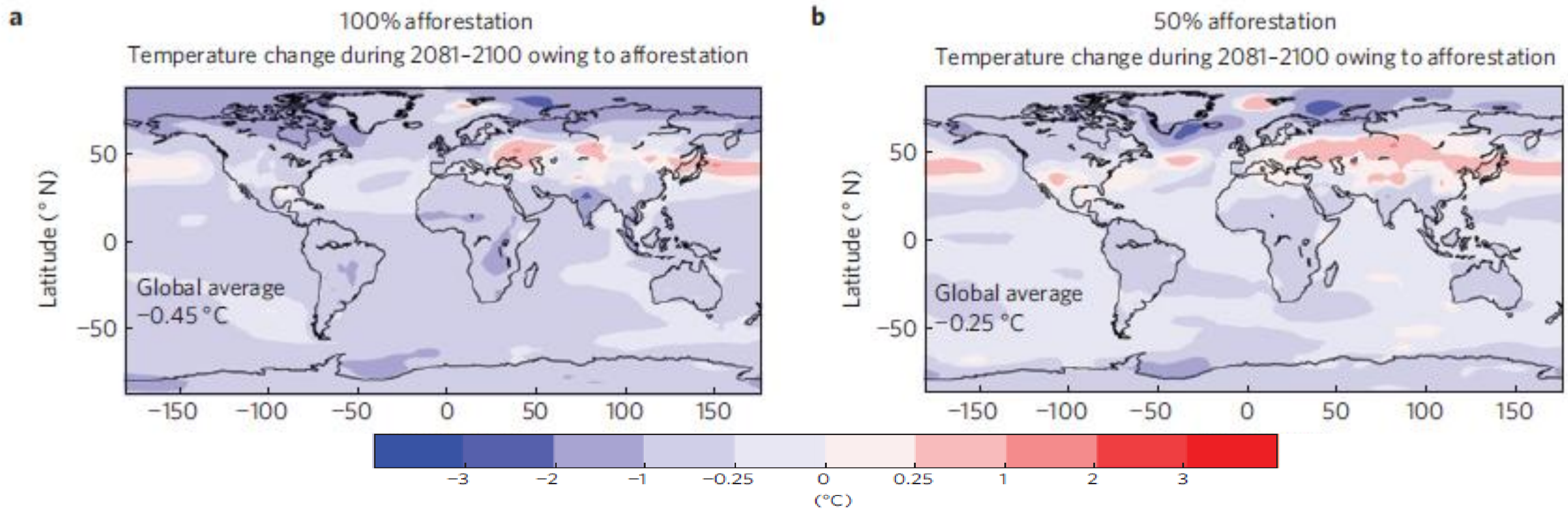


Table 1 | Global and land-only averaged temperature differences between the standard no-LUCC and the five cropland afforestation simulations for the 2081–2100 period.

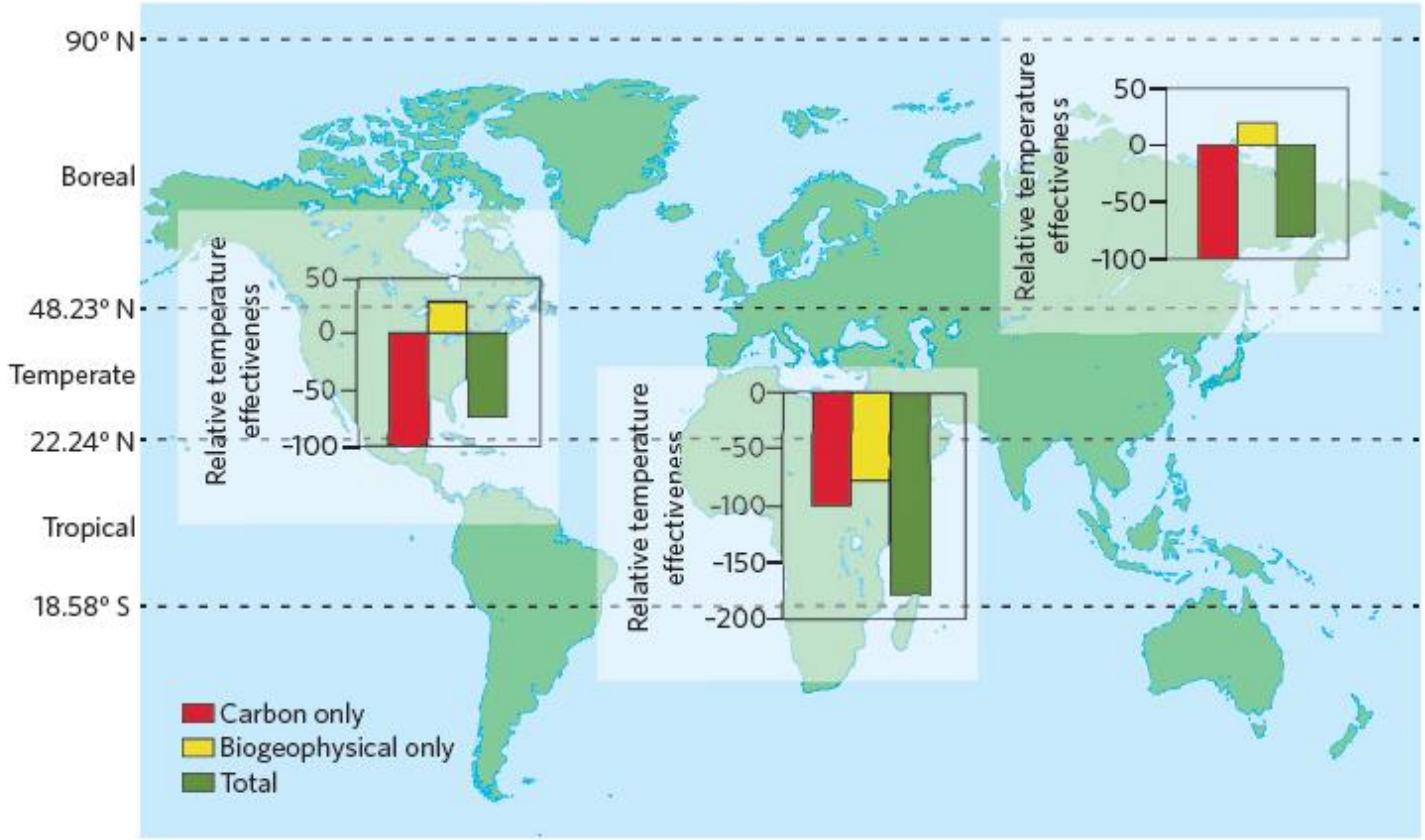
	Simulation	Afforested area (million km²)	Temperature difference compared with the no-afforestation case (°C)		Statistical significance
			Land only	Global	
1.	100% global afforestation	20.2	−0.63	−0.45	$p < 0.01$
2.	50% global afforestation	10.1	−0.31	−0.25	$p < 0.01$
3.	50% boreal afforestation	2.0	0.01	−0.04	$p > 0.25$
4.	50% northern temperate afforestation	4.7	−0.16	−0.11	$p > 0.05$
5.	50% tropical afforestation	2.7	−0.25	−0.16	$p < 0.01$

The statistical significance of global temperature differences is also shown on the basis of the unequal-variance Student t-test. Afforested areas in different simulations are also shown.

Arora (2011)

Model simulation: case 3

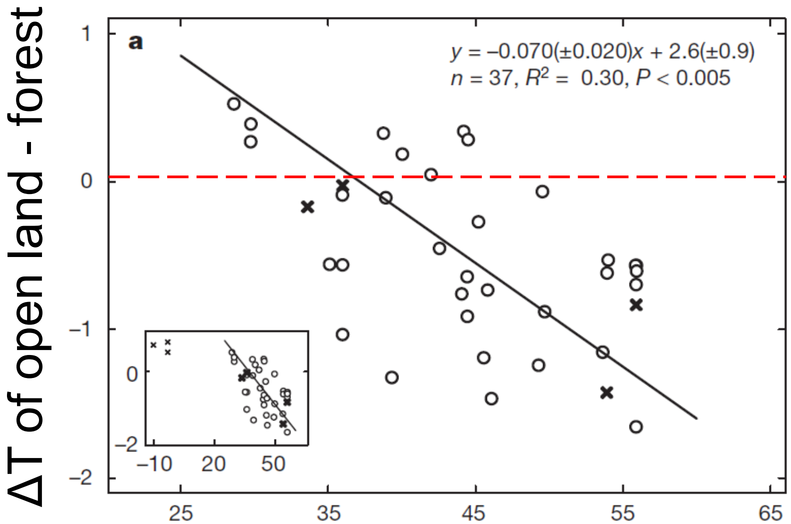
Afforestation cools more or less



Betts (2011), review of Arora (2011)

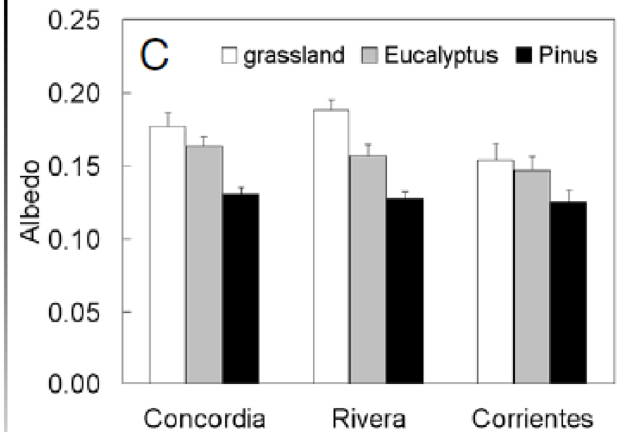
Discrepancies in the mid-latitude?

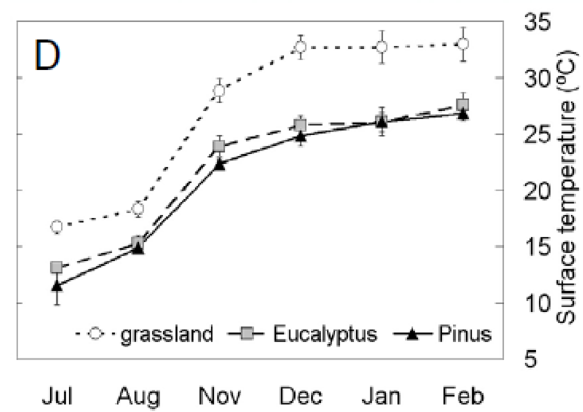
❑ Observations/remote sensing



Lee et al. (2011)

Forest warms surface air temperature





Jackson (2008)

Table 2. Annual mean values (6 years) of radiation fluxes, albedo, and surface (skin) temperature in the semi-arid forest (Yatir) and in the shrubland background.

Variable	Forest	Shrubland
Global radiation (E_g, W m^{-2})	238	238
Albedo (unit-less)	0.11	0.21
Net solar radiation (S_n, W m^{-2})	212	188
Net longwave radiation (L_n, W m^{-2})	−96	−121
Net radiation ($R_n = S_n + L_n$, W m^{-2})	115	67
Skin temperature (°C)	19	24*

*(27)

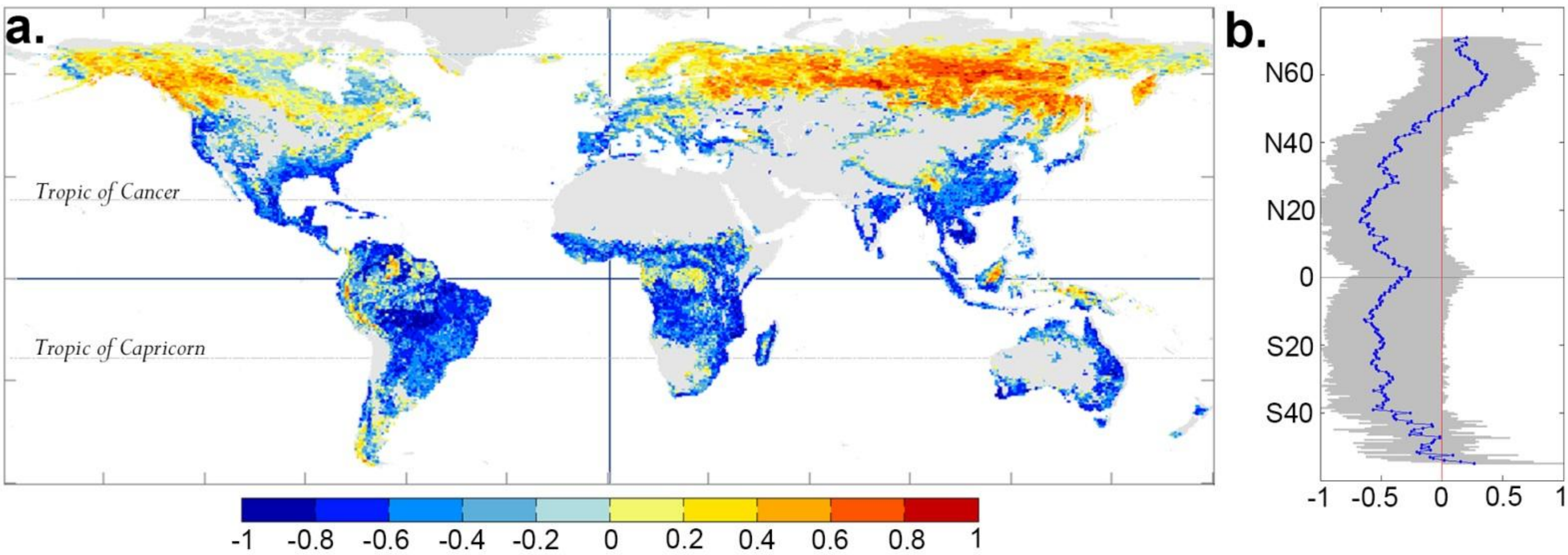
Rotenberg (2010)

Desertification contributed negative forcing (cooling)

Question

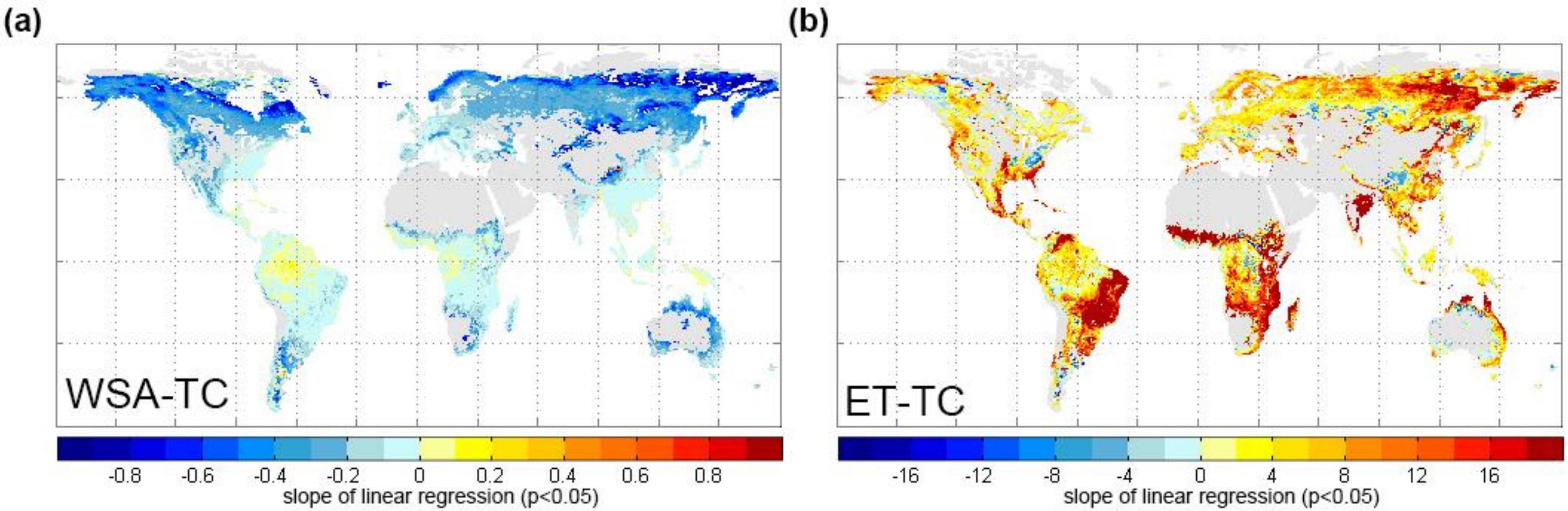
1. **How will current forest influence land surface temperature?**
   - Hypothesis: In a relatively similar climate/geographical background, if patches of higher forest coverage are associated with higher surface temperature, forest tends to be a source of heat relative to other land-cover types at the land surface.
2. **How will this thermal effect change across season and what might the implication for seasonality be like?**
   - Hypothesis: As albedo and evapotranspiration have both seasonal change, the thermal influence mainly regulated by these two processes should thus have seasonal pulse, which might be important beyond the overall annual impact.

Partial correlation between LST and Tree cover



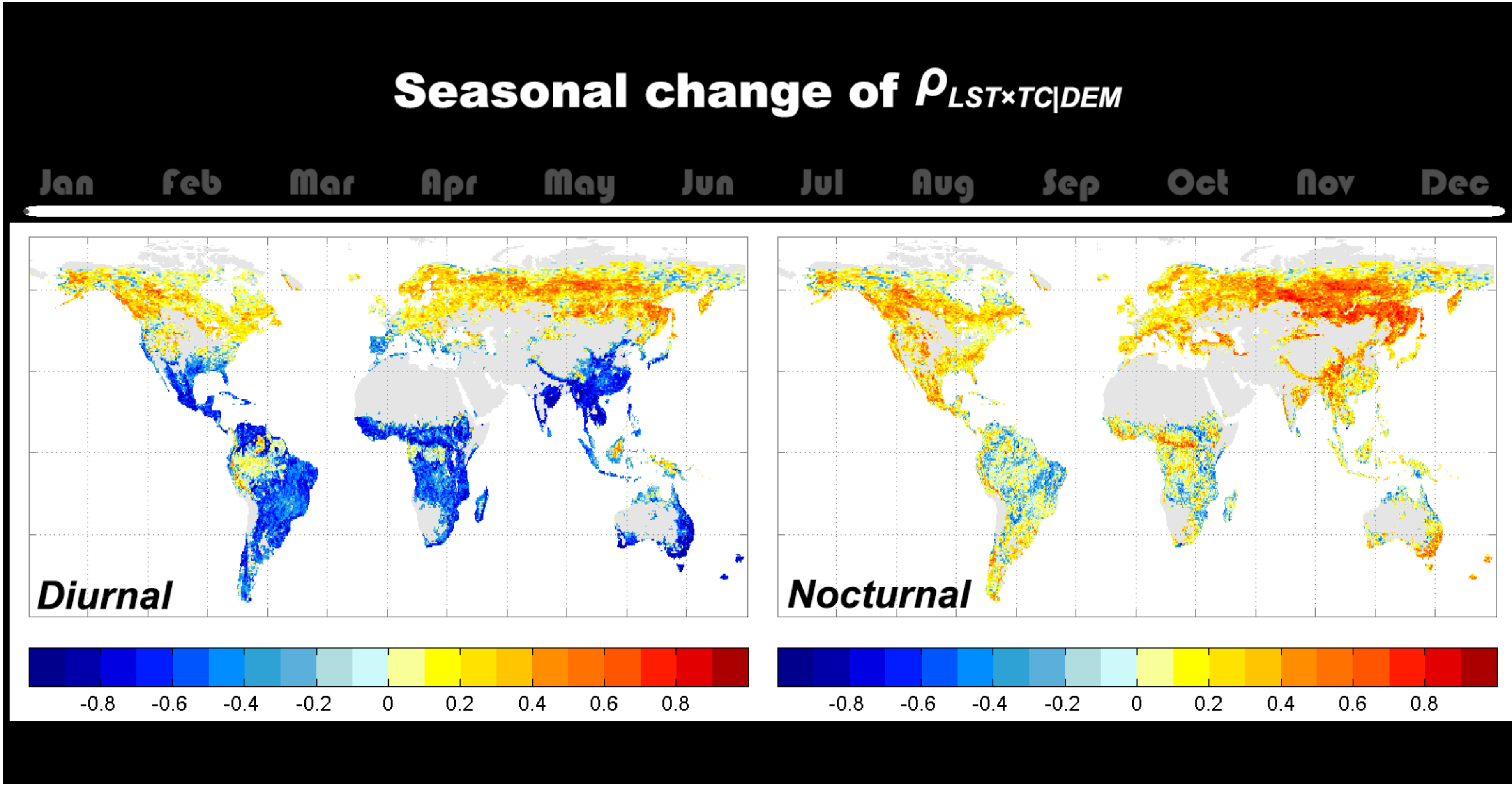
Partial correlation coefficient between mean annual LST (Land Surface Temperature) and tree cover in each 60 km bin (~0.5 degree longitudinally) with the effect of elevation controlled ($\rho_{(LST*TREE/DEM)}$)

Correlation between Albedo/ET with Tree Cover

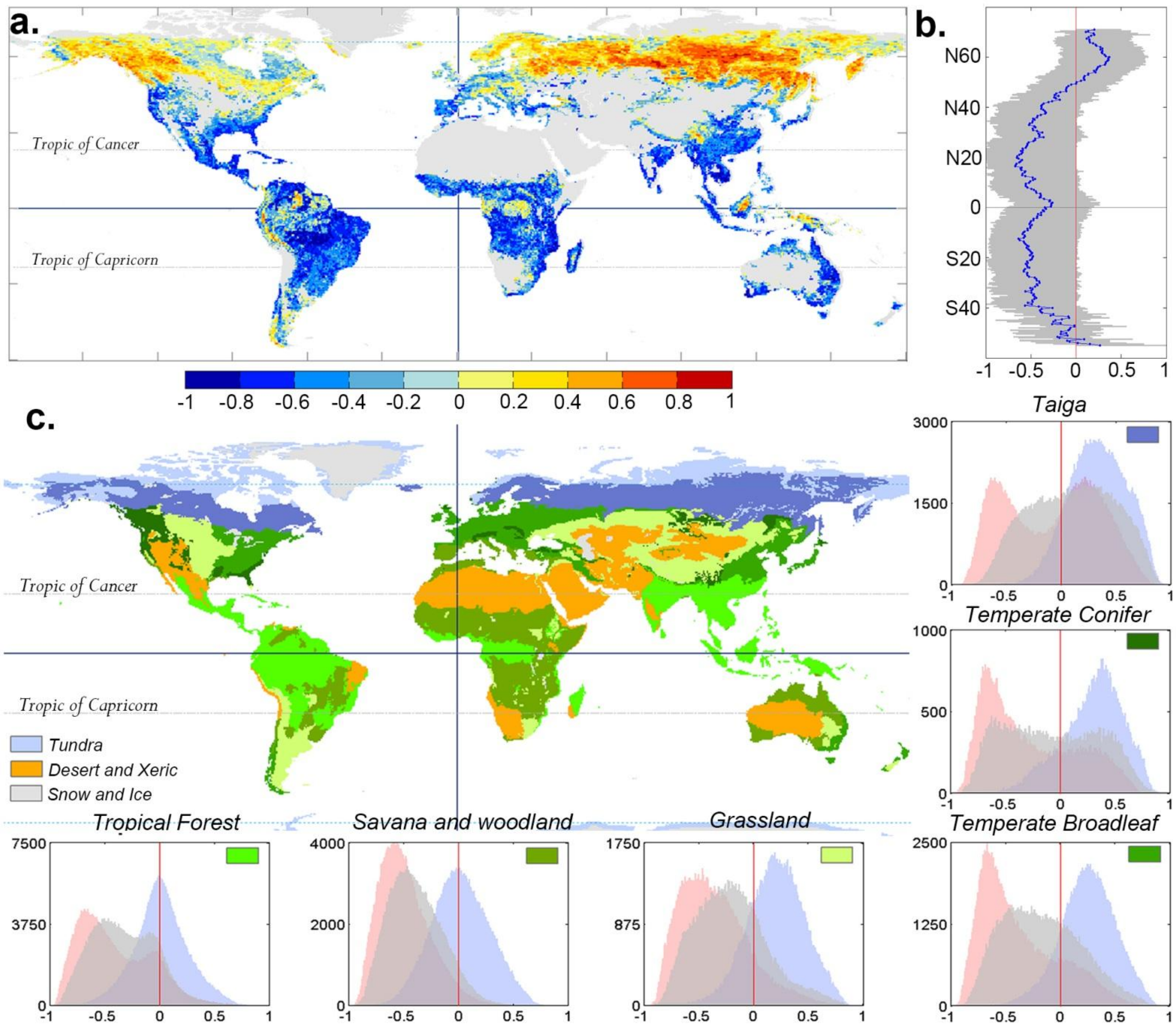


Global pattern of potential influence of tree cover on mean annual albedo (a) and annual evapotranspiration (mm yr^{-1}) (b) evaluated by linear.

Partial correlation between LST and Tree cover



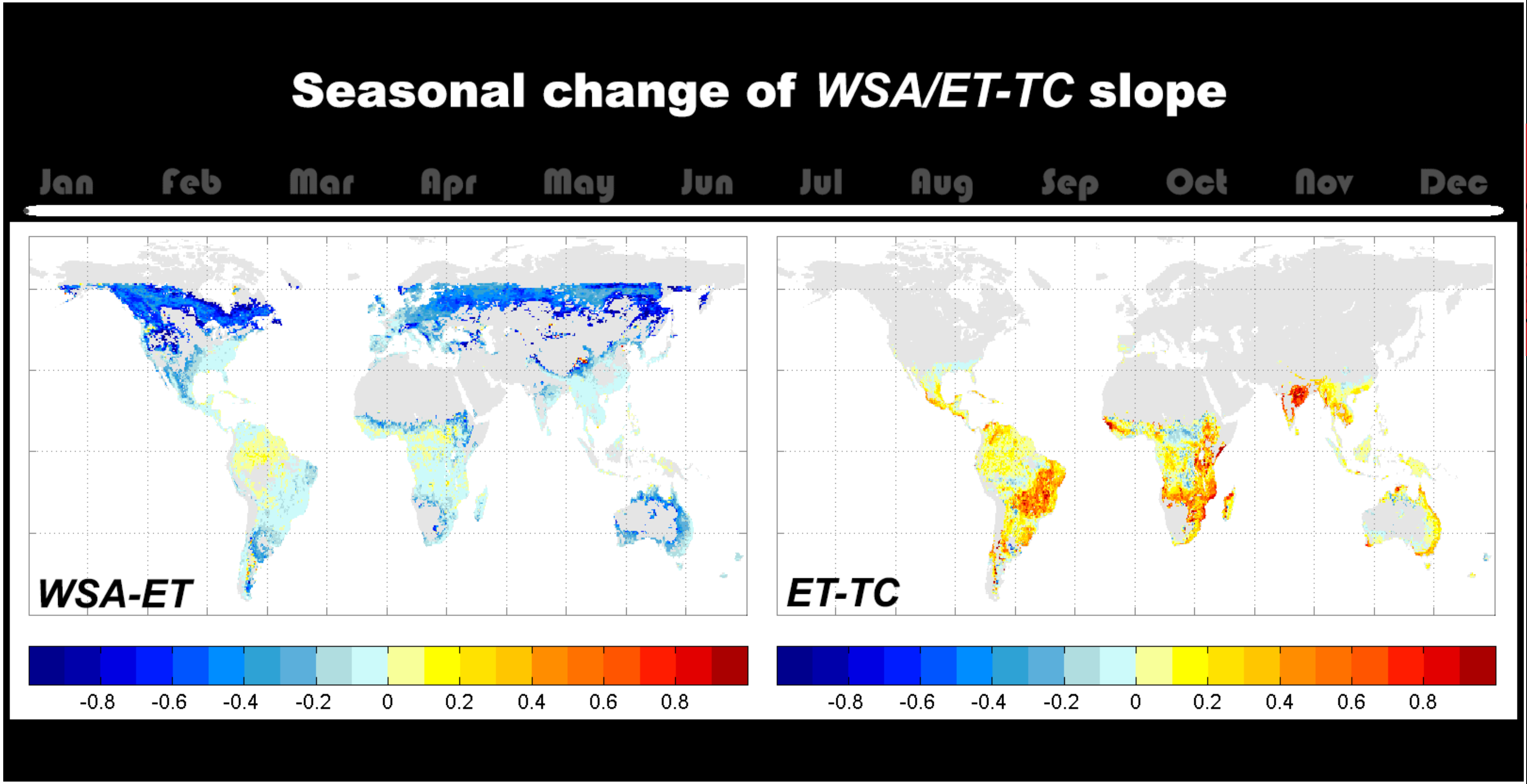
Partial correlation between LST and Tree cover



Comparison across biomes: the map shows global biome pattern, histogram subplot for each biome shows the distribution of diurnal (red), nocturnal (blue) and daily mean (grey) $\rho_{(LST*TREE/DEM)}$ calculated at 8-day steps around the year.

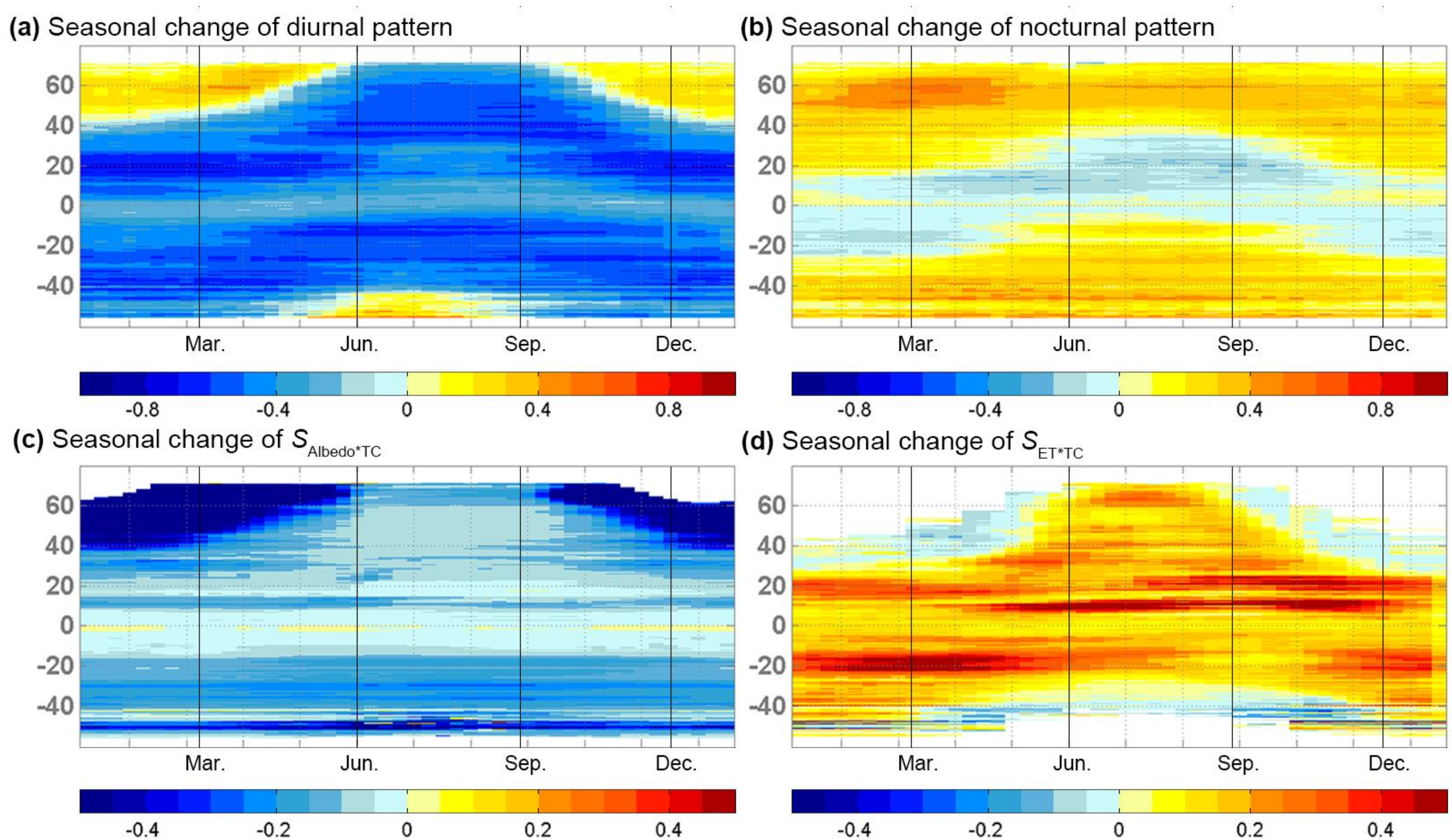
LST study

Seasonal change of Albedo/ET-TC slope



LST study

Seasonal change

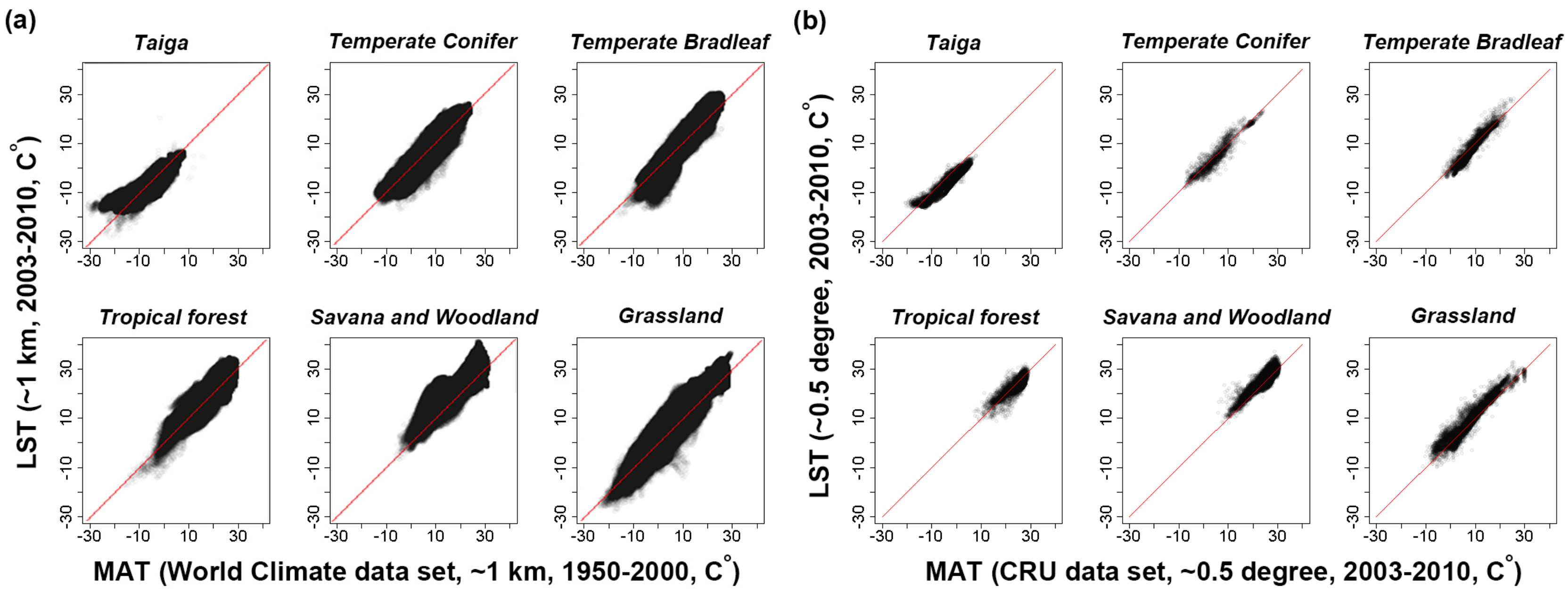


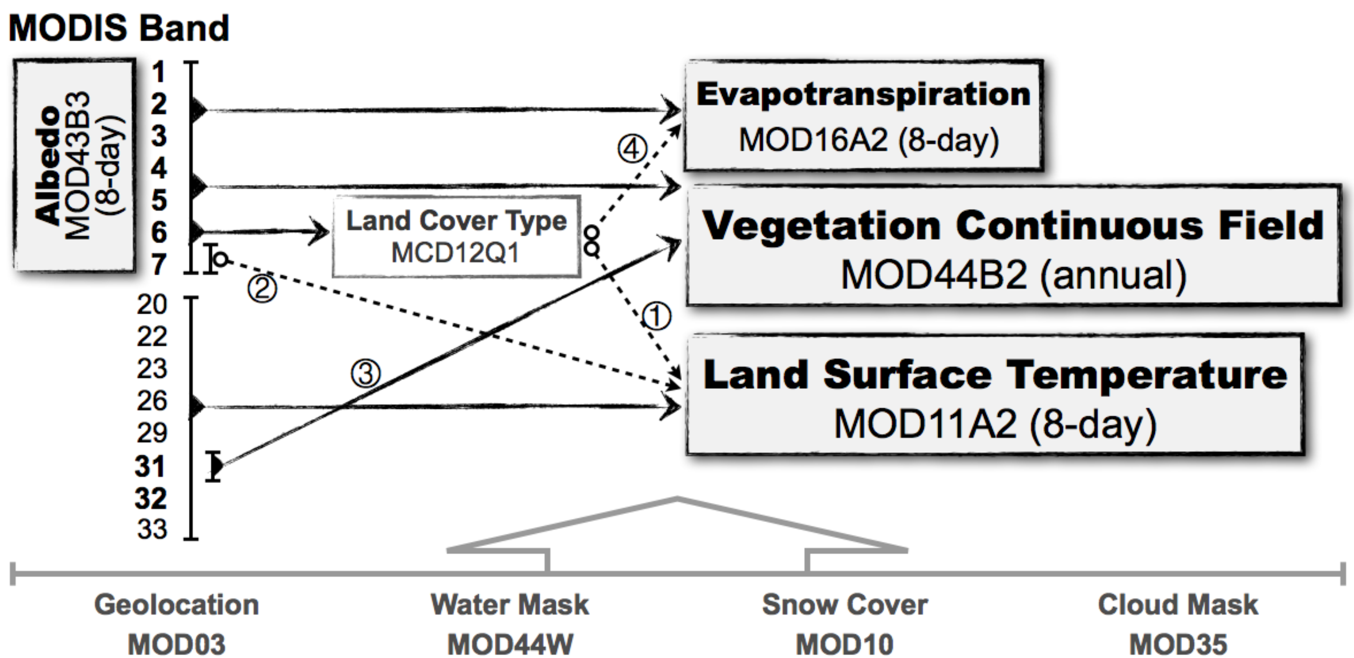
Seasonal changing pattern of correlations along latitude: partial correlation between LST and tree cover with the effect of elevation controlled during the day time (a) and during the night (b); slopes of tree cover against WSA (c), and slopes of tree cover in linear regression with ET (d). White color indicates no value.

Conclusion and Prospect

- The general global pattern (latitudinal dependence) of partial correlation between LST and tree cover agrees with previous global model simulation or regional observations, validating our first hypothesis and allowing more detailed discussion of the mid-latitudes.
- The diurnal and nocturnal thermal effect of forest are vitally different, so are the underlying mechanism, implying daily step simulation in climate models might have potential limits.
- In the temperate region, although the overall thermal effect of forest on the land surface is near neutral in coniferous forest and slightly negative in broadleaf forest, it has distinct seasonal difference, indicating a possible feedback of a smaller seasonality when afforestation.
- Potential feedback of extended growing season.
- Uncertainties

Thanks


Taiga
Temperate Conifer
Temperate Bradleaf
Tropical forest
Savana and Woodland
Grassland
LST (~1 km, 2003-2010, C°)
MAT (World Climate data set, ~1 km, 1950-2000, C°)
LST (~0.5 degree, 2003-2010, C°)
MAT (CRU data set, ~0.5 degree, 2003-2010, C°)



MODIS Band
Albedo
MOD43B3
(8-day)
1
2
3
4
5
6
7
20
22
23
26
29
31
32
33
Land Cover Type
MCD12Q1
①
②
③
④
Evapotranspiration
MOD16A2 (8-day)
Vegetation Continuous Field
MOD44B2 (annual)
Land Surface Temperature
MOD11A2 (8-day)
Geolocation
MOD03
Water Mask
MOD44W
Snow Cover
MOD10
Cloud Mask
MOD35