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Environmental controls of the photosynthesis onset across the North American boreal forest

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Highlights :

- Phenology acts as a mediator for air temperature's role in photosynthesis recovery
- Air temperature has a direct control over photosynthesis recovery only in southern, permafrost-free sites

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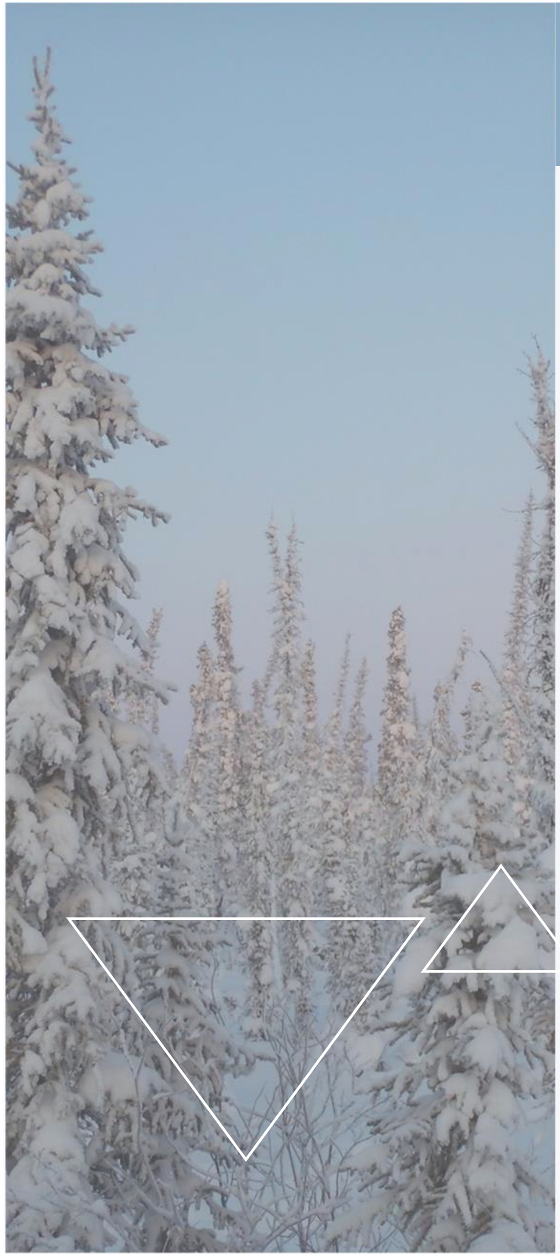


Introduction

As the North American boreal forest is expected to experience rise in spring temperatures[1], earlier starts of the growing seasons are to be anticipated, potentially resulting in a change in the source-sink strength of this ecosystem[2].

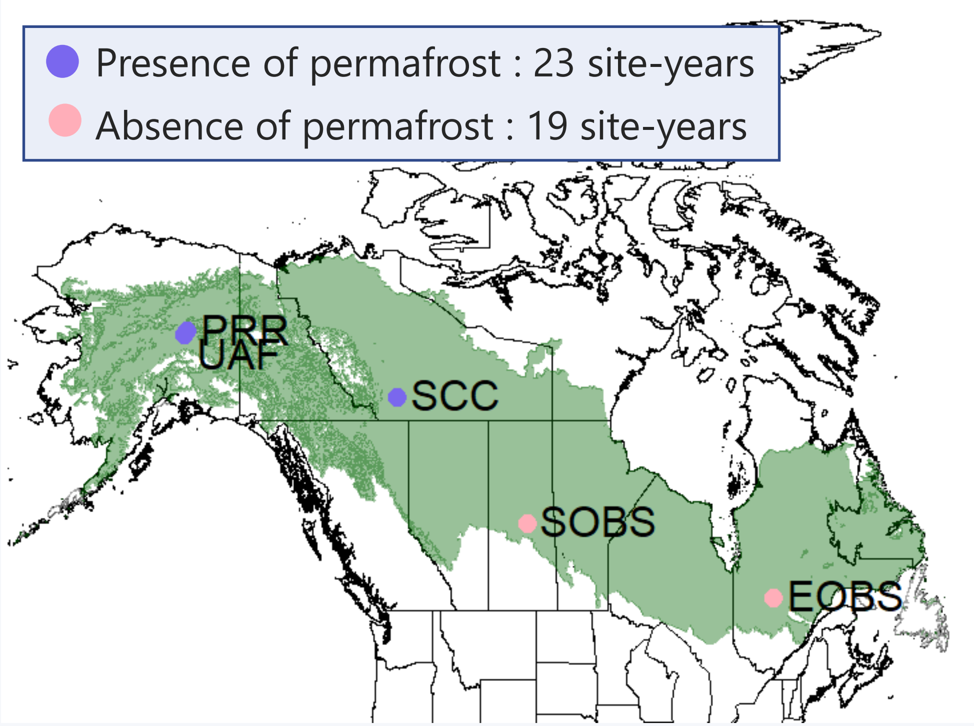
Air temperature has been known to be the main driving factor of the photosynthesis recovery[2,3], while the role of phenology might have been underestimated. More specifically, its interaction with air temperature might play an important role in photosynthesis recovery[4].

Objective of the study :
Here, we explore the mechanisms that regulate the photosynthesis recovery across the North American boreal forest, and shed light on the differences in these mechanisms between permafrost and permafrost-free sites.

Image : G. Hould-Gosselin

[1]IPCC (2013); [2] Richardson *et al.* (2010), Philos T R Soc B; [3]Suni *et al.* (2003), J Geophys Res-Atmos ; [4]Koebsch *et al.* (2019), Glob Chang Biol.

Methods : Sites and measurements

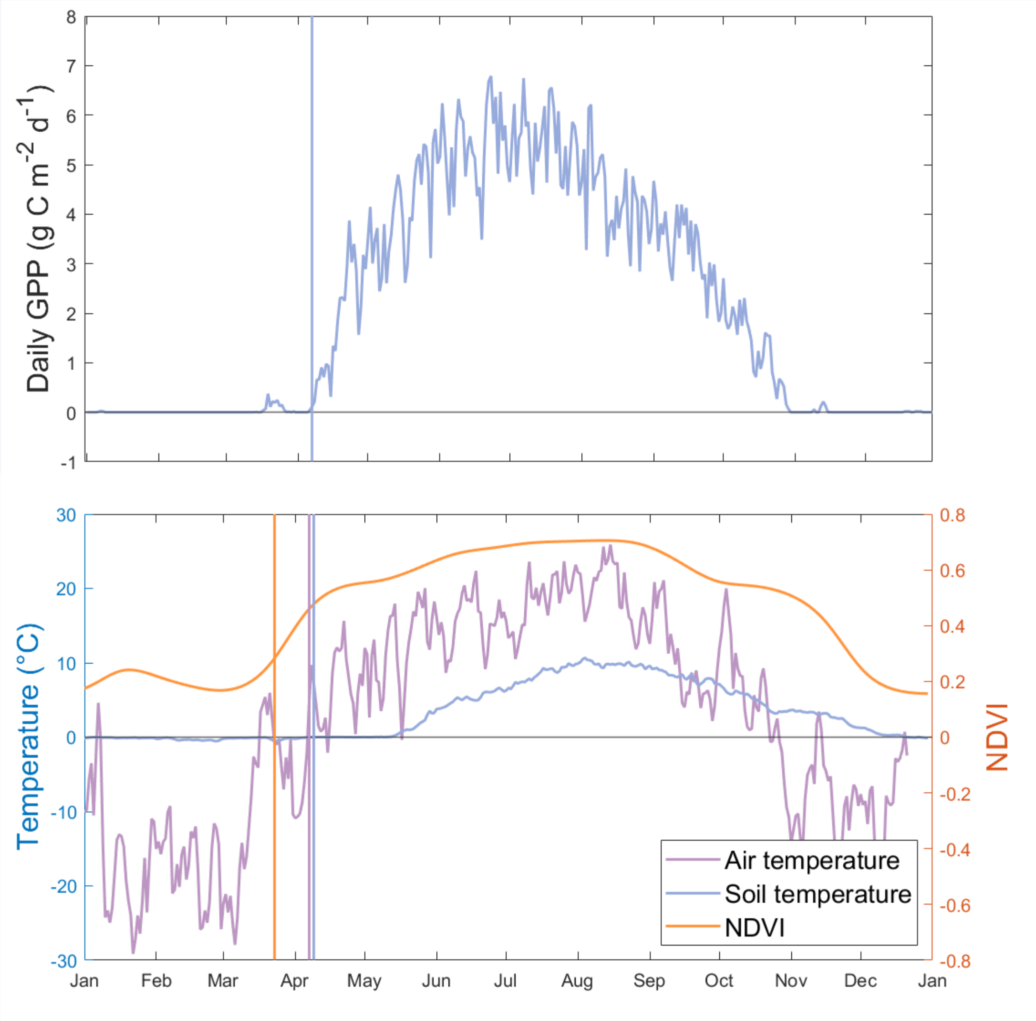


- **42 sites-years** of observations
- Carbon flux : gross primary productivity (**GPP**) data from eddy covariance measurements
- Environmental variables :
  - Air temperature (**Ta**);
  - Soil temperature (**Ts**);
  - Soil water content (**SWC**);
  - Photosynthetically active radiation (**PAR**);
  - Normalized difference vegetation index (**NDVI**)*;
  - Enhanced vegetation index (**EVI**)*

*Vegetation indices are used as proxies for phenology

Image : G. Hould-Gosselin

Methods : Start of seasons

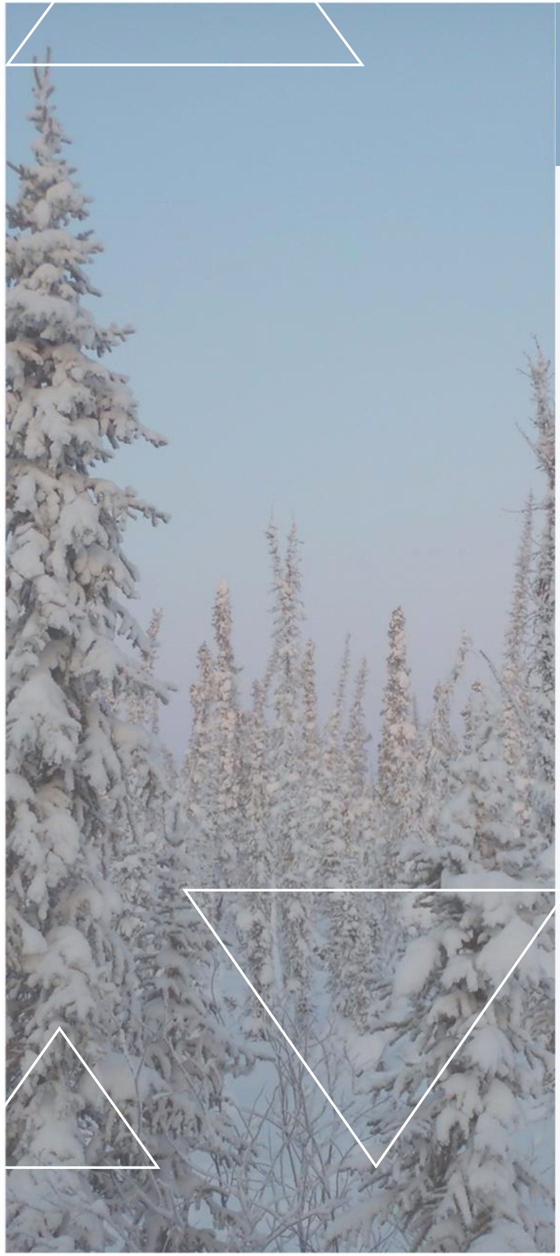


For every site-year, start of the season (**SOS**) based on the carbon fluxes and the environmental variables were determined (vertical lines on graphs)[1,2].

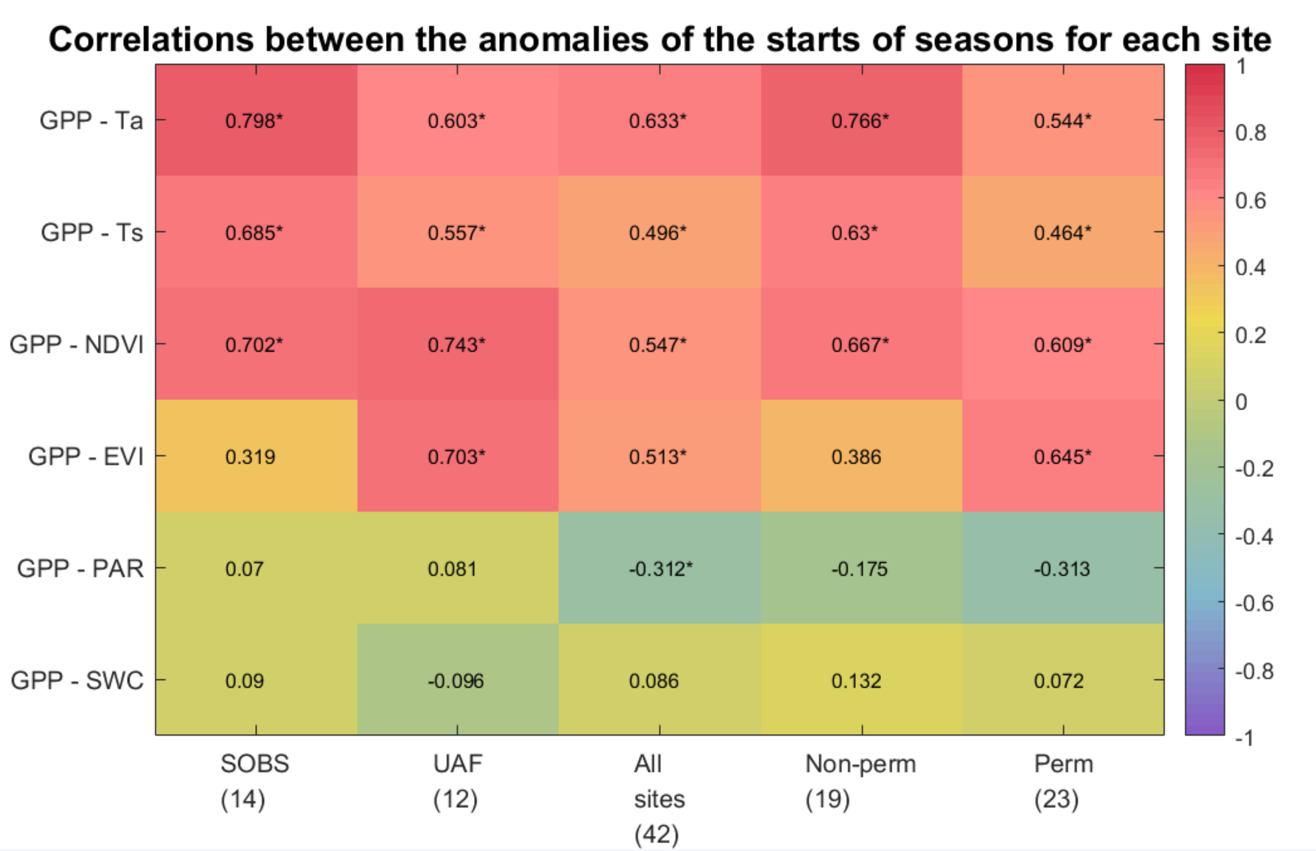
For every site, SOS anomalies (deviation from the mean) were calculated.

Image : G. Hould-Gosselin

[1]Barr *et al.* (2009); [2]Gonsamo *et al.* (2013), Ecol Indic.



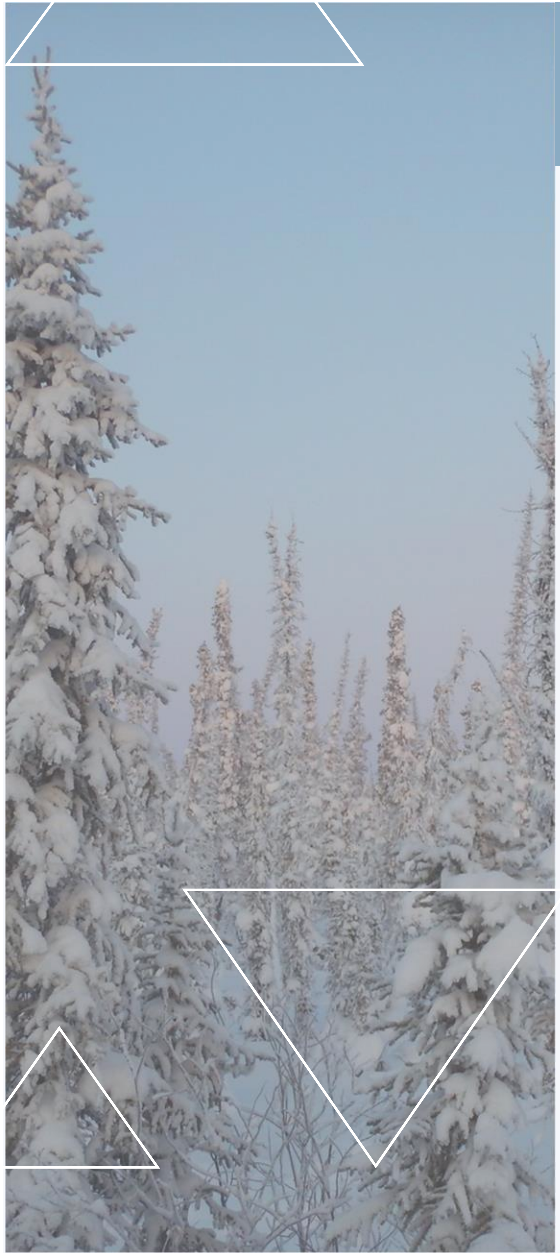
Results : correlation plot

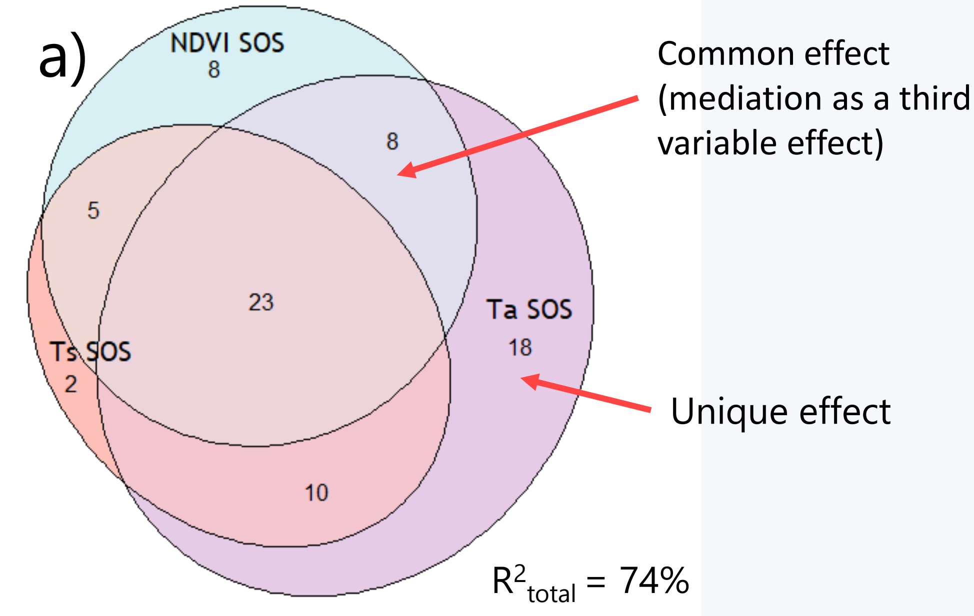


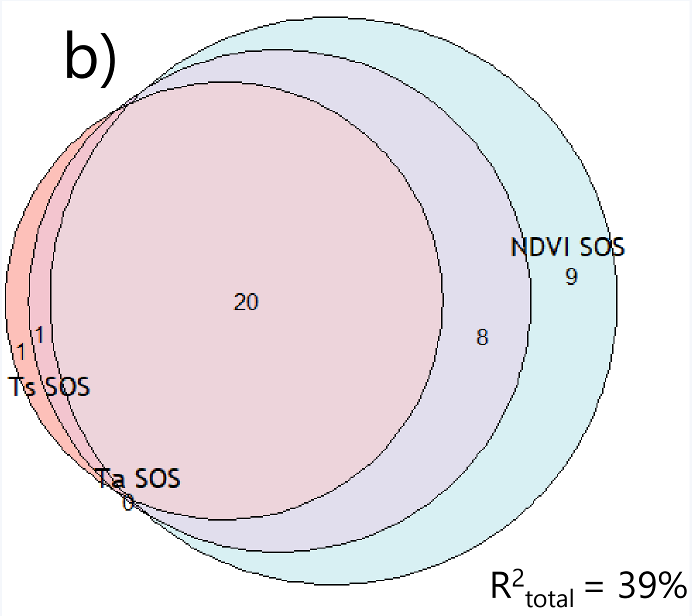
This plot of pairwise correlations shows that **Ta**, **Ts** and **NDVI** have significant correlations with GPP SOS anomalies (α = 0.05); hence they were the **environmental variables kept for the commonality analysis**.

Image : G. Hould-Gosselin

Results : commonality analysis







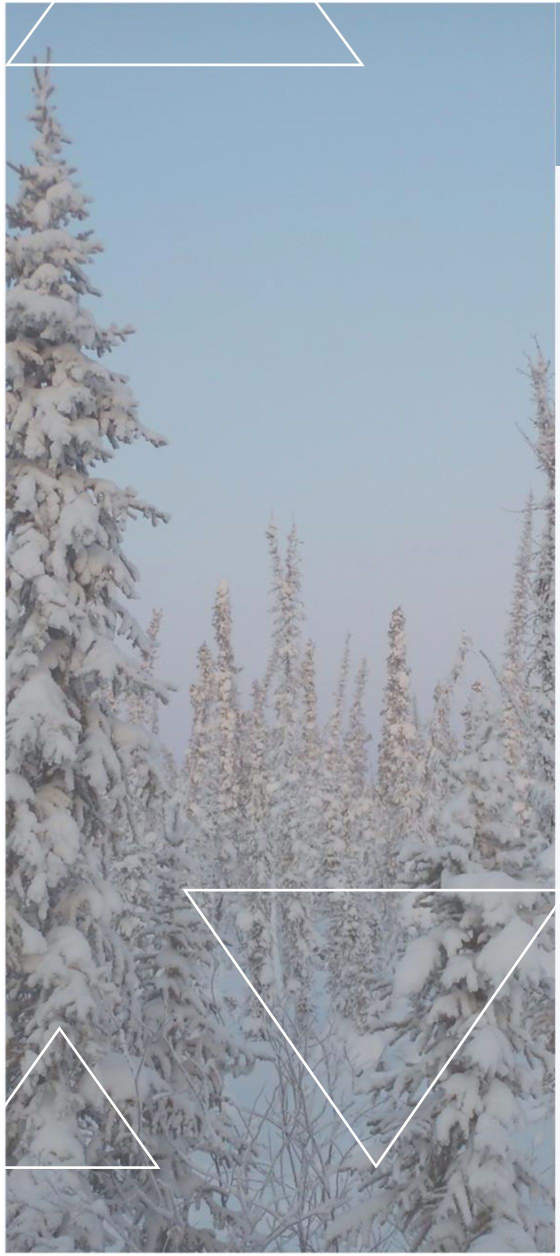
Euler diagrams summarising the results of the commonality analysis, assessing the effect sizes of each environmental variable on the anomalies of GPP SOS in (a) permafrost-free sites and (b) permafrost sites.

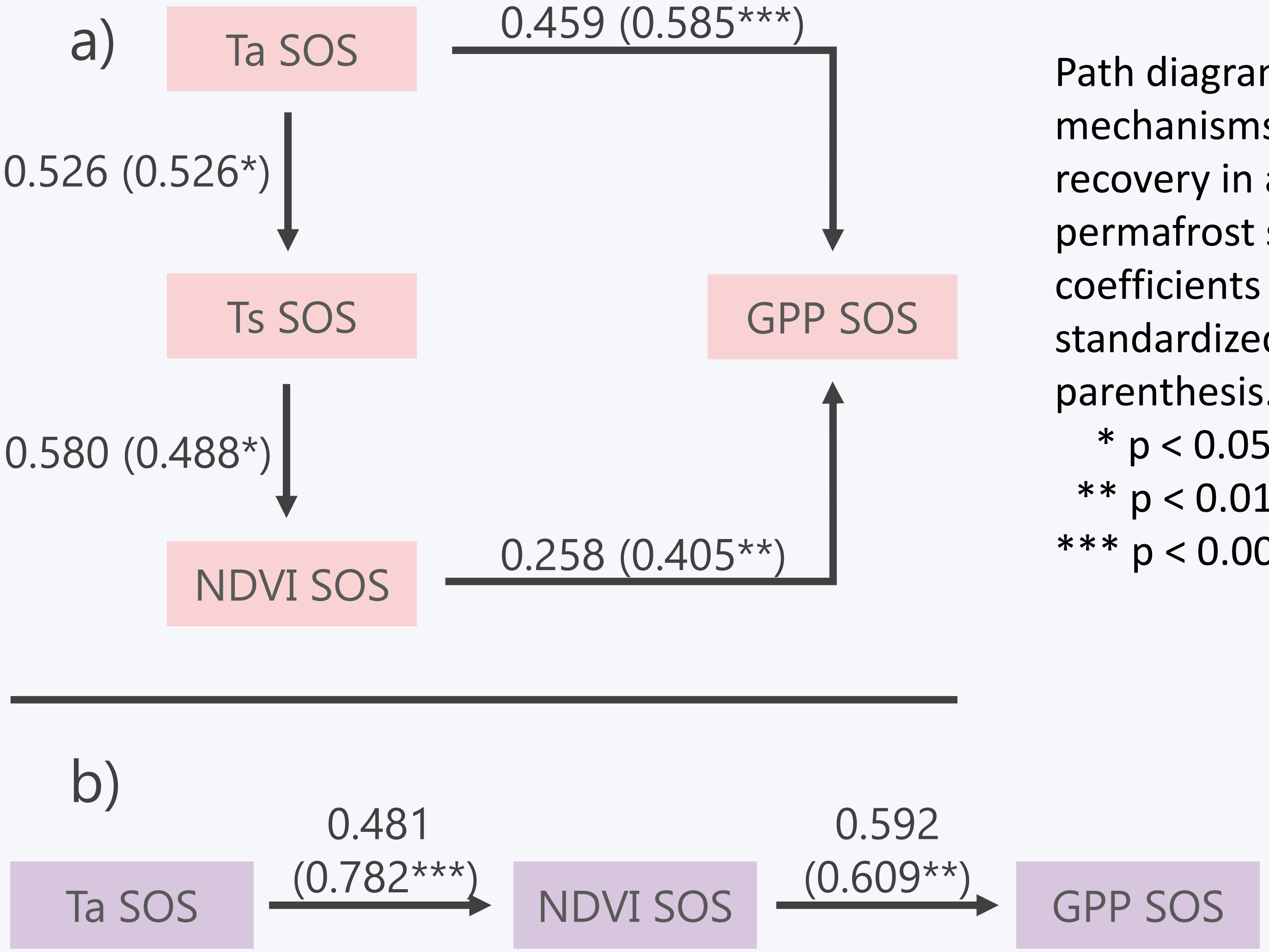
Unique effects are treated as direct effects on GPP SOS; common effects between temperature and NDVI are treated phenology-mediated temperature effects on GPP SOS[1]. Structural equation models can take into account indirect effects by incorporating a variable (here, NDVI) as an outcome and then a predictor of GPP SOS.

Image : G. Hould-Gosselin

[1]Koebsch *et al.* (2019), Glob Chang Biol.

Results : structural equation modelling

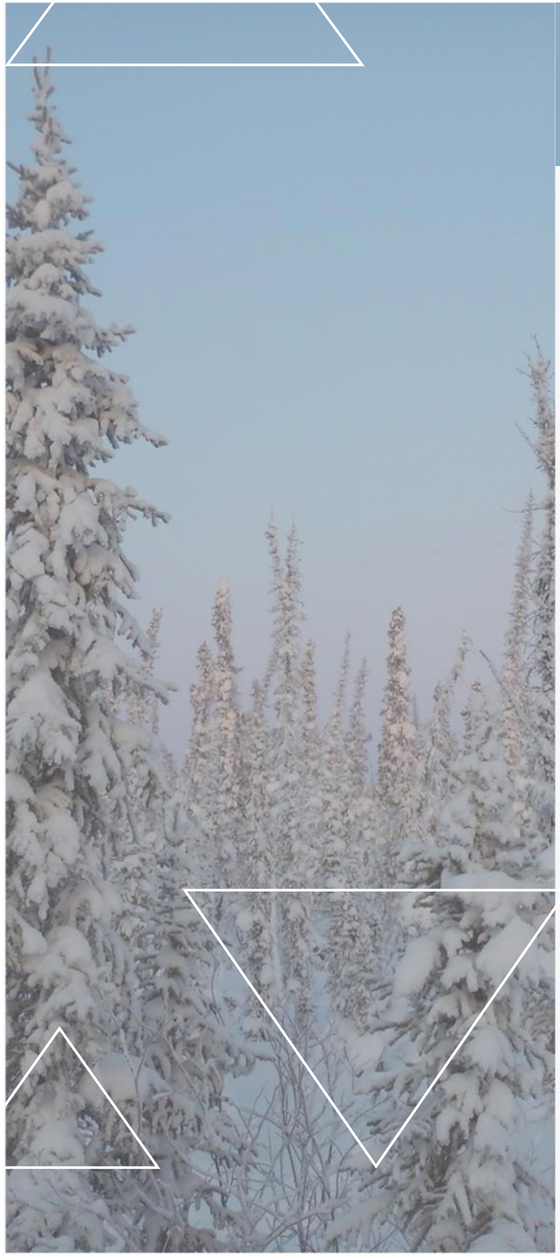




Path diagrams for the controlling mechanisms of photosynthesis recovery in a) permafrost-free and b) permafrost sites. Unstandardized path coefficients are shown, alongside the standardized coefficients in parenthesis.

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Image : G. Hould-Gosselin



Discussion

Air temperature plays an important role in photosynthesis recovery in both permafrost and permafrost-free sites, but in different ways :

- Permafrost-free sites : direct and indirect (through soil temperature and phenology) control;
- Permafrost sites : indirect role, through phenology.

Phenology : mediator for air temperature's role in photosynthesis recovery. Increase of spring temperature → rapid response of vegetation → photosynthesis recovery[1].

Effect stronger in northern latitudes - where permafrost soils are found : tree stems are smaller → less water stored[2] to reinitiate photosynthesis at spring thaw.

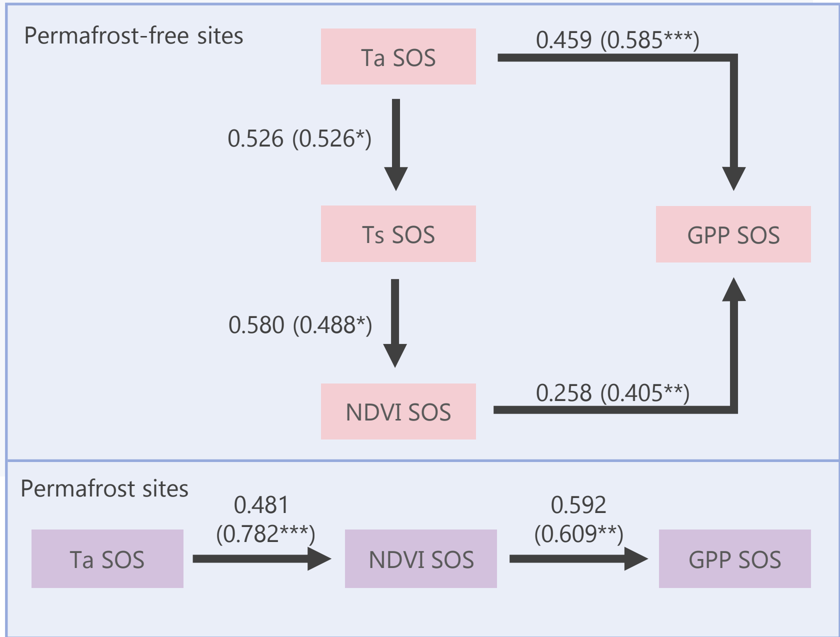


Image : G. Hould-Gosselin
[1]Linkosalmi *et al.* (2016), Geosci Intrum Meth.; [2]Young-Robertson *et al.* (2016), Sci Rep.

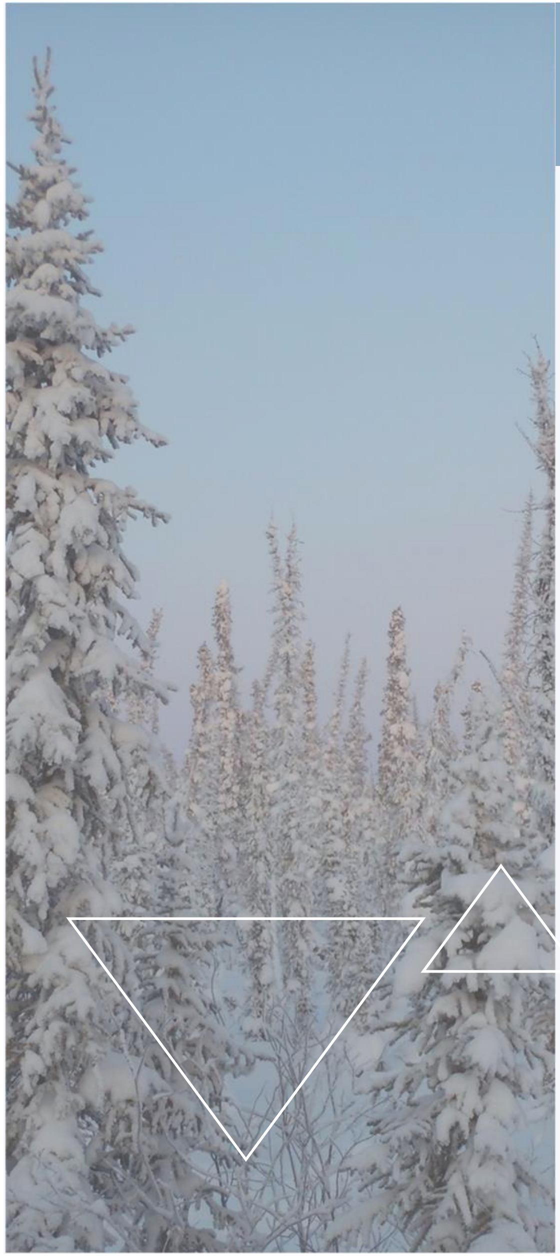


Image : G. Hould-Gosselin

Conclusion

Different path diagrams for permafrost and permafrost-free sites explain photosynthesis recovery, but both highlight the role of phenology and air temperature :

- Phenology acts as a mediator for air temperature in photosynthesis recovery
- Air temperature has a direct control over photosynthesis recovery only in southern, permafrost-free sites

Future research will explore the environmental controls of photosynthesis cessation in fall, using the same statistical framework.

References

Barr, A., Black, T. A. and McCaughey, H. (2009). Climatic and Phenological Controls of the Carbon and Energy Balances of Three Contrasting Boreal Forest Ecosystems in Western Canada. In Noormets, A., editor: Phenology of Ecosystem Processes, pages 3–34. Springer New York, New York. https://doi.org/10.1007/978-1-4419-0026-5_1

Gonsamo, A., Chen, J. M. and D'Odorico, P. (2013). Deriving land surface phenology indicators from CO_2 eddy covariance measurements. Ecological Indicators, 29:203–207. https://doi.org/10.1016/j.ecolind.2012.12.026

IPCC (2013). Climate Change 2013: The Physical Science Basis. Technical report, Intergovernmental Panel on Climate Change.

Koebsch, F., Sonnentag, O., Järveoja, J., Peltoniemi, M., Alekseychik, P., Aurela, M. *et al.* (2019). Refining the role of phenology in regulating gross ecosystem productivity across European peatlands. *Global Change Biology*. 2019;00:1–12. https://doi.org/10.1111/gcb.14905

Linkosalmi, M., Aurela, M., Tuovinen, J.-P., Peltoniemi, M., Tanis, C. M., Arslan, A. N., & Laurila, T. (2016). Digital photography for assessing the link between vegetation phenology and CO2 exchange in two contrasting northern ecosystems. *Geoscientific Instrumentation, Methods and Data Systems*, *5*, 417–426. https ://doi.org/10.5194/gi-5-417-2016

Richardson, A. D., Andy Black, T., Ciais, P., Delbart, N., Friedl, M. A., Gobron, N. *et al.* (2010). Influence of spring and autumn phenological transitions on forest ecosystem productivity. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1555):3227–3246. https://doi.org/10.1098/rstb.2010.0102

Suni, T., Berninger, F., Markkanen, T., Keronen, P., Rannik, and Vesala, T. (2003). Interannual variability and timing of growing-season CO_2 exchange in a boreal forest. Journal of Geophysical Research: Atmospheres, 108(D9):4265–4272. https://doi.org/10.1029/2002JD002381

Young-Robertson, J.M., Bolton, W.R., Bhatt, U.S., Cristóbal, J., Thoman, R., 2016.Deciduous trees are a large and overlooked sink for snowmelt water in the boreal forest. Scientific Reports, p. 6, 1–10. https://doi.org/10.1038/srep29504