The role of soil characteristics on measured and modelled carbon dioxide (CO_2) fluxes for Arctic dwarf shrub tundra sites

- Differences in net ecosystem CO_2 exchange (NEE) at two Canadian Southern Arctic dwarf shrub tundra sites 1000 km apart can be explained by differences in ecosystem respiration (R_e) due to physiographic setting affecting soil characteristics rather than differences in climate
- Combining land surface model CLASSIC and field measurements (eddy covariance and chambers) indicates that the Daring Lake dwarf shrub tundra site was an annual CO_2 source over 2004-2017

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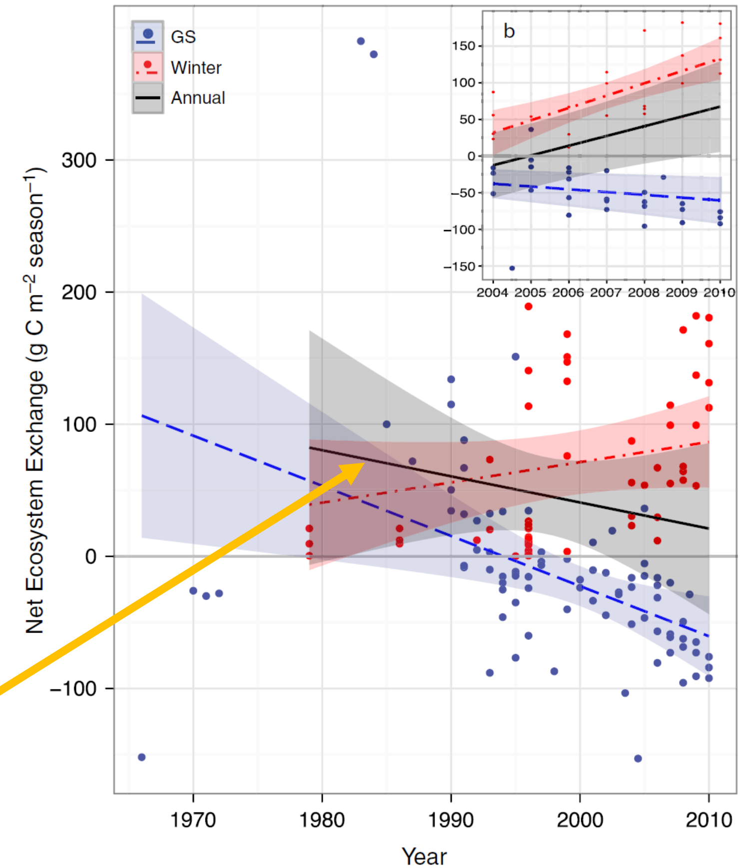
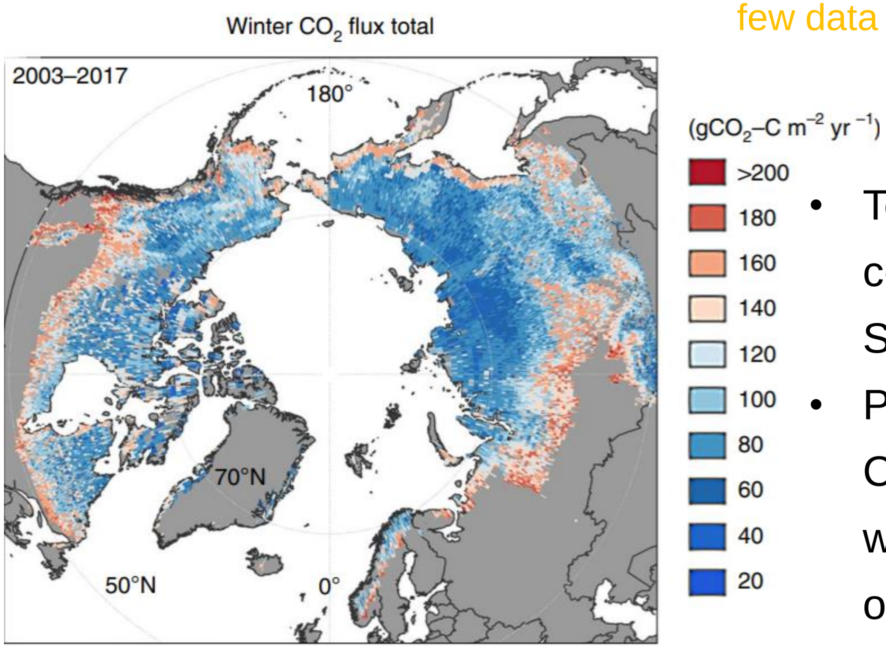
Background & Objectives

- Tundra ecosystems across the vast Arctic region vary greatly in climate, soils, and vegetation.
- The Arctic is warming more rapidly than other regions of the globe and the impact on CO_2 exchange between tundra and the atmosphere is uncertain.
- Studies suggest the CO_2 sink/source strength of the Arctic is changing (Belshe et al. 2013) but there are few studies with annual CO_2 flux observations to confirm these trends.

Belshe et al. 2013 *Ecology Letters*



Natali et al. 2019 *Nature Climate Change*

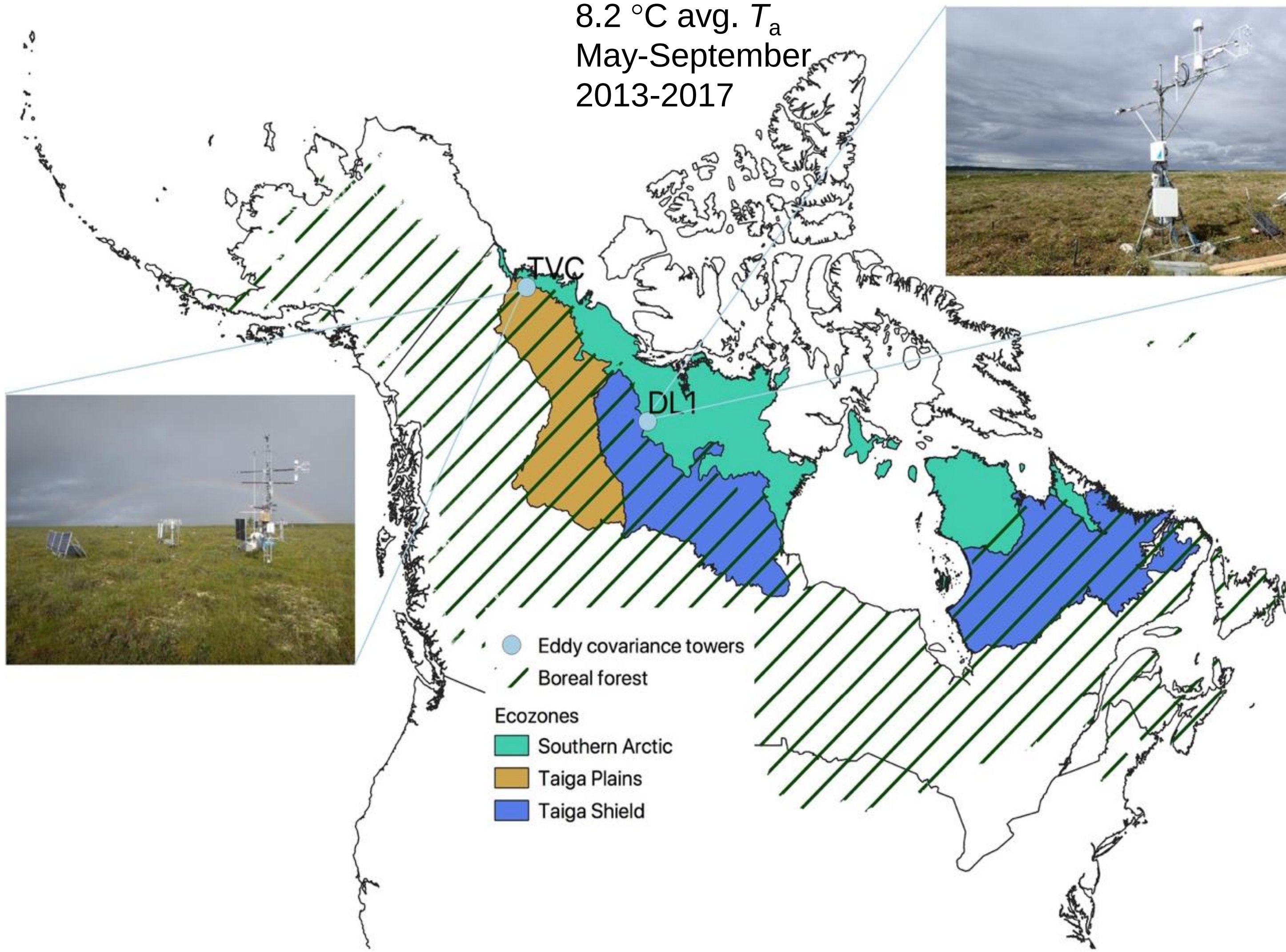


- To better understand tundra CO_2 exchange, we compare eddy covariance fluxes (2013 – 2017) at two Southern Arctic shrub tundra sites 1000 km apart.
- Process-based models enable us to determine winter CO_2 efflux (Natali et al., 2019) and thus annual NEE, where year-round measurements are very difficult to obtain.

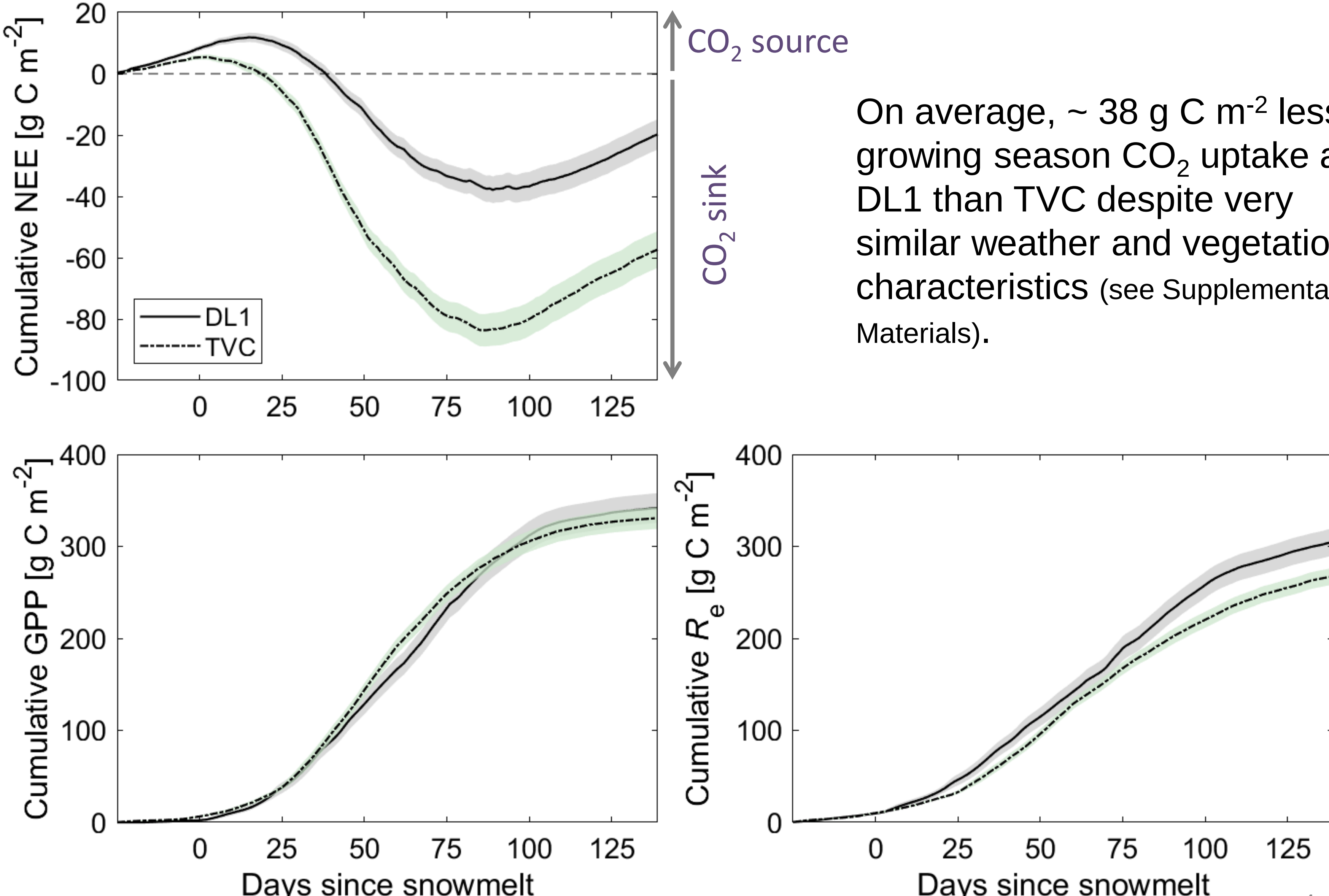
Two Southern Arctic dwarf shrub tundra sites 1000 km apart

Trail Valley Creek (TVC)
68.7°N, 133.3°W, 85 m elevation
~ 50 km NNE of Inuvik
-8.2 °C avg. annual air temperature
~240 mm annual precipitation
7.5 °C avg. T_a
May-September
2013-2017

Daring Lake (DL1)
64.8°N, 111.5°W, 425 m elevation
~ 300 km NE of Yellowknife
-8.9 °C avg. annual air temperature
200-300 mm annual precipitation
8.2 °C avg. T_a
May-September
2013-2017



Differences in average (2013-2017) cumulative NEE may be largely due to greater ecosystem respiration (R_e) at DL1 with only small differences in gross primary productivity (GPP)



On average, ~ 38 g C m^{-2} less growing season CO_2 uptake at DL1 than TVC despite very similar weather and vegetation characteristics (see Supplementary Materials).

Data was processed the same way for both sites

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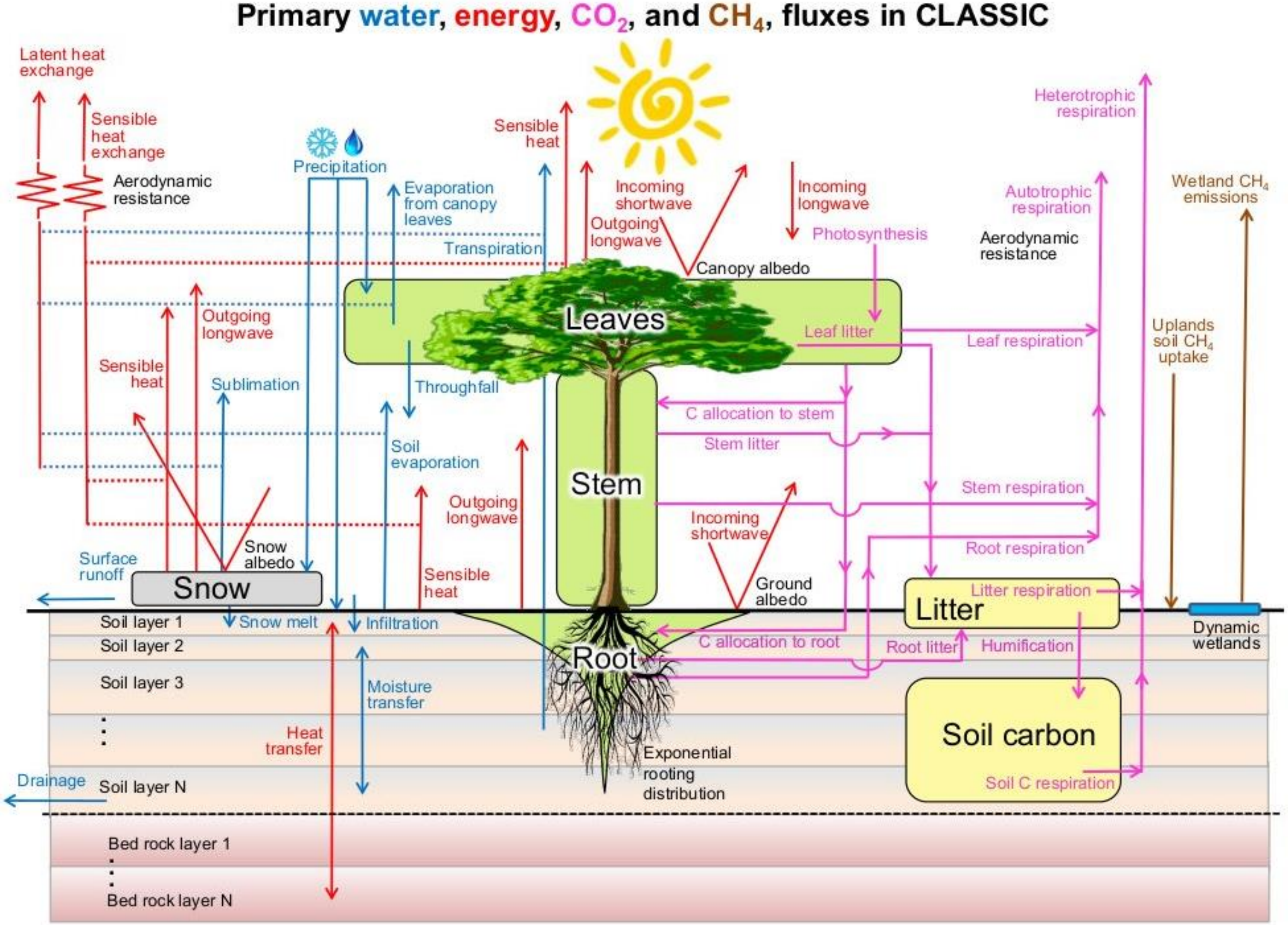
Summary: Similar GPP at the sites, greater R_e at DL1, therefore greater net CO_2 uptake at TVC . Although the two sites have similar weather and vegetation characteristics, TVC has cooler soils and less thaw.

Hypothesis: Deeper porous surface organic layer (including moss layer) at TVC dries quickly and acts as a mulch limiting ground heat penetration in summer.

Cooler soils = lower soil respiration at TVC and greater net CO_2 uptake in summer.

To estimate annual NEE we used the CLASSIC model …

Canadian Land Surface Scheme including Biogeochemical Cycles (CLASSIC) v.1.0 (successor to CLASS-CTEM)



Melton et al. 2019 *Geoscientific Model Development*

- Spin-up using GSWP3-ERA5 reanalysis meteorological data for 1901-1925; run using reanalysis data and transient CO_2 for 1901-2004 and using input variables observed at DL1 from 2004-2017

- 22 soil layers down to 20m depth,
- permeable depth of 5m,
- top 10 cm fibric organic layer,
- > 10 cm mineral soil consisting of 80% sand & 4.4% clay

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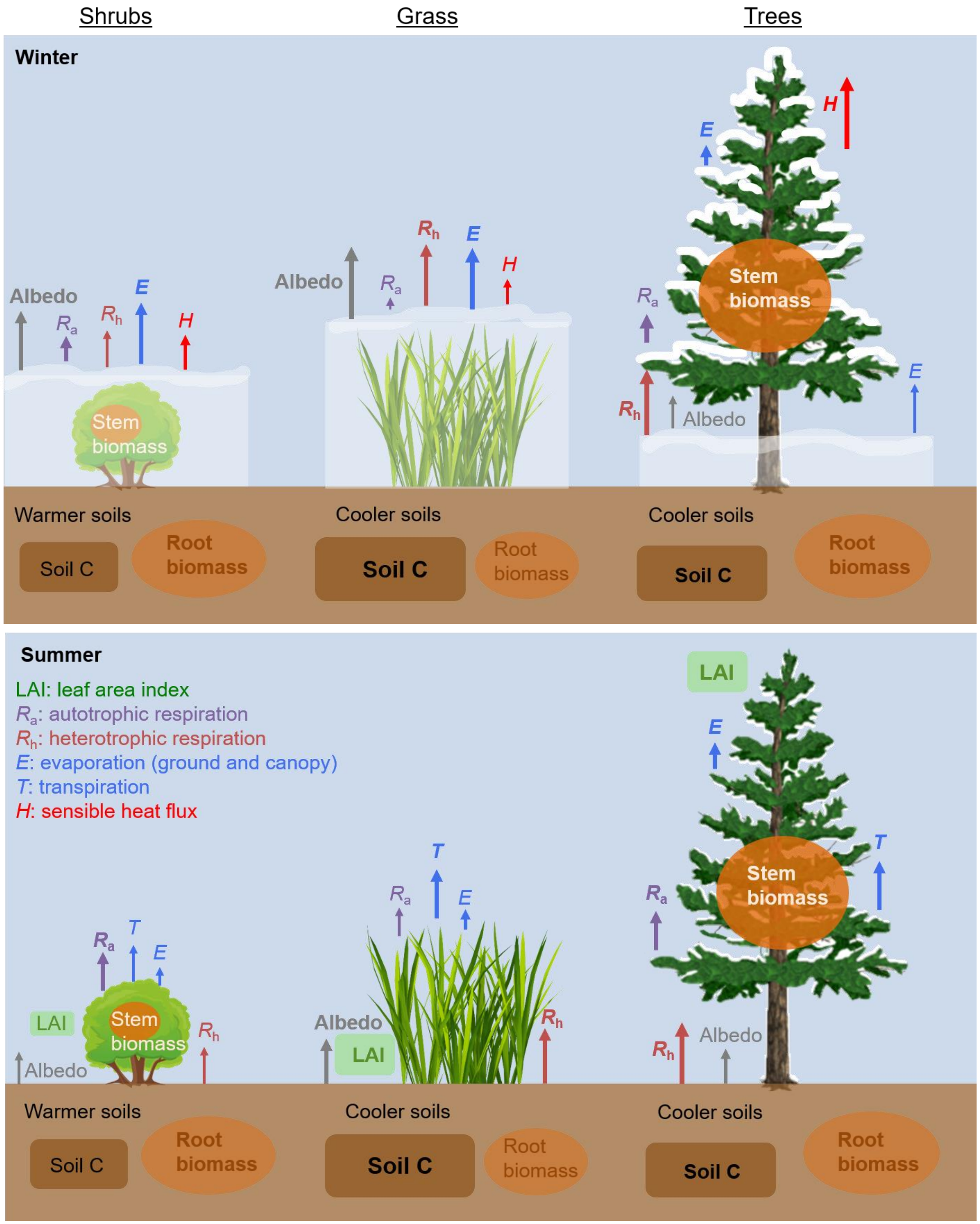

Differences between the plant functional types (PFTs) impact the carbon as well as energy and water balances

Results using the new shrub PFTs in CLASSIC are compared to grass and tree run outputs

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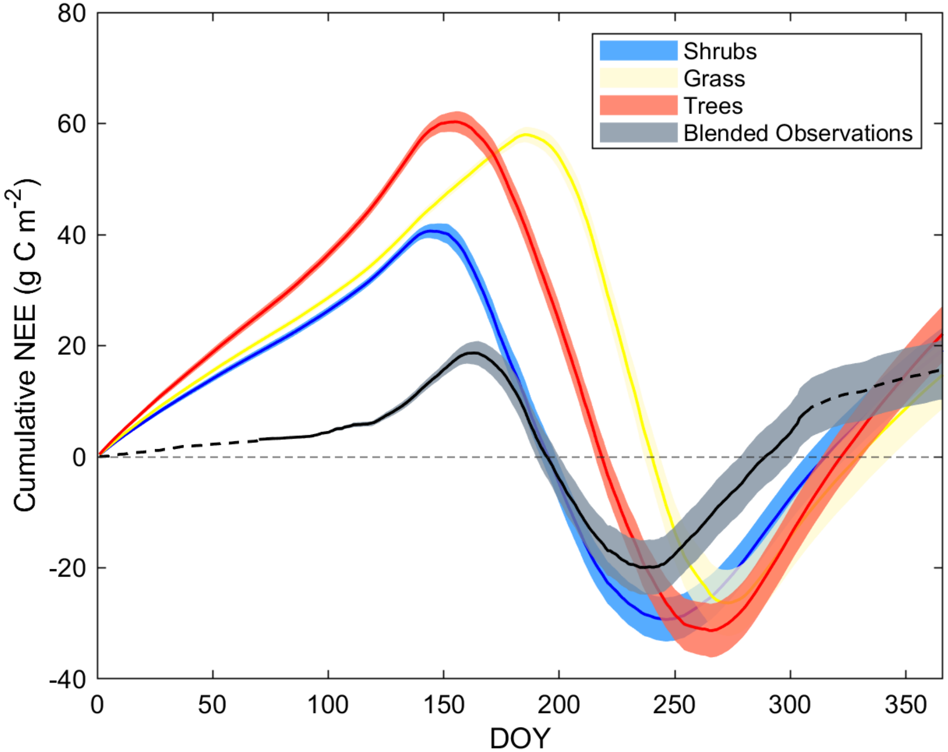
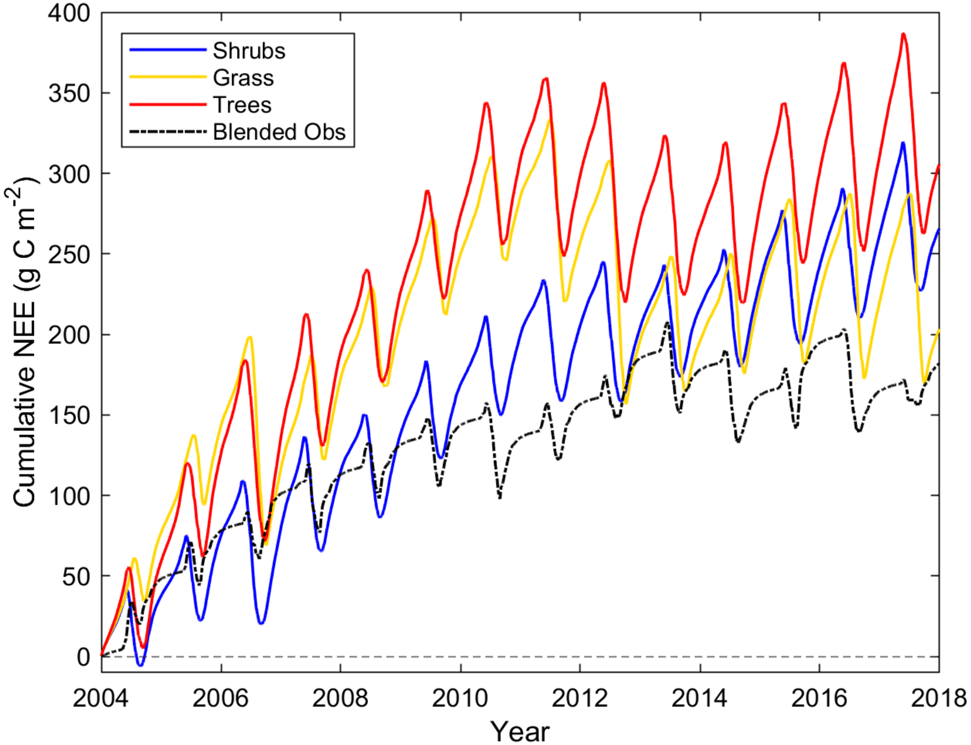
Shrub PFT improves CLASSIC representation of NEE at DL1 (over tree and grass simulations). DL1 is a CO_2 source over 2004-2017.





Error bars show the standard error of the mean, no biases are included

~182 - 306 g C m^{-2} released from the DL1 site from 2004-2017

- Shrub, grass and tree results are the CLASSIC model results and the blended observations combine eddy-covariance (EC) (solid black line) and forced diffusion chamber (dashed black line) NEE measurements.
- Chamber measurements were only available for one winter (used for all years).
- Grass and tree runs are too productive and shifted in time.

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Conclusions

1. Despite being located 1000 km apart, the two dwarf shrub tundra sites show similar growing season weather (see Supplementary Materials) and GPP. However, Trail Valley Creek showed a larger net growing season CO_2 uptake than Daring Lake.
2. Differences in R_e and NEE were linked to differences in soil characteristics such as organic matter content, soil texture and thermal properties affecting thaw depths.
3. Combination of measurements and land surface models are important to better estimate the C balance of high-latitude sites, where year-round measurements are especially difficult to obtain.
4. Both CLASSIC simulations and EC/chamber measurements indicate that Daring Lake was a net source of CO_2 over 2004-2017.
5. Shrub (266 g C m^{-2}), grass (203 g C m^{-2}) and tree (306 g C m^{-2}) model runs have different cumulative NEE over 2004-2017 showing the importance of representing tundra ecosystems with appropriate PFTs in global C models.

Supplementary Materials

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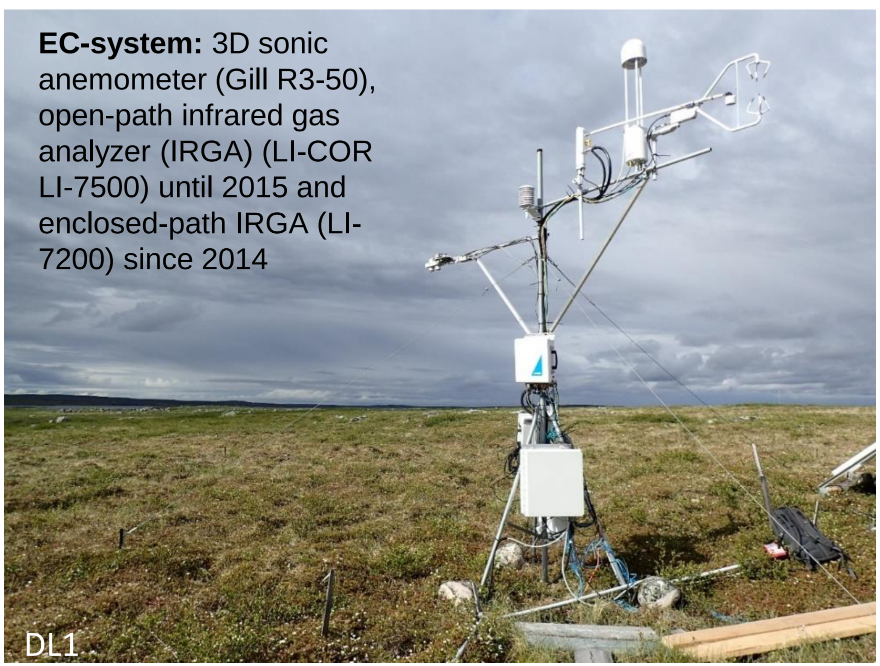
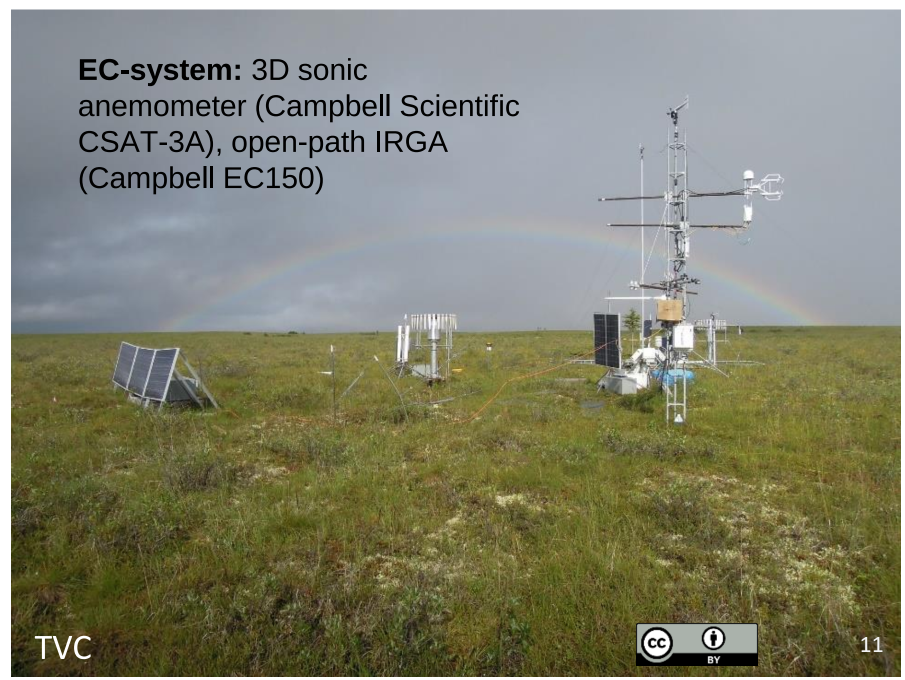
Site Characteristics	Daring Lake (DL1)	Trail Valley Creek (TVC)
Leaf area index (Avg ± SE)	0.52 ± 0.05 m^2 m^{-2}	0.66 ± 0.11 m^2 m^{-2}
Thaw depth (Avg ± SE)	85 ± 3 cm	74 ± 5 cm
Snowmelt date (DOY)	135-144	135-151
Soils	shallow organic layer (8 ± 2 cm) overlying sand to loamy sand mineral soil	deeper surface organic layer (18 ± 3 cm) overlying silty clay mineral soil

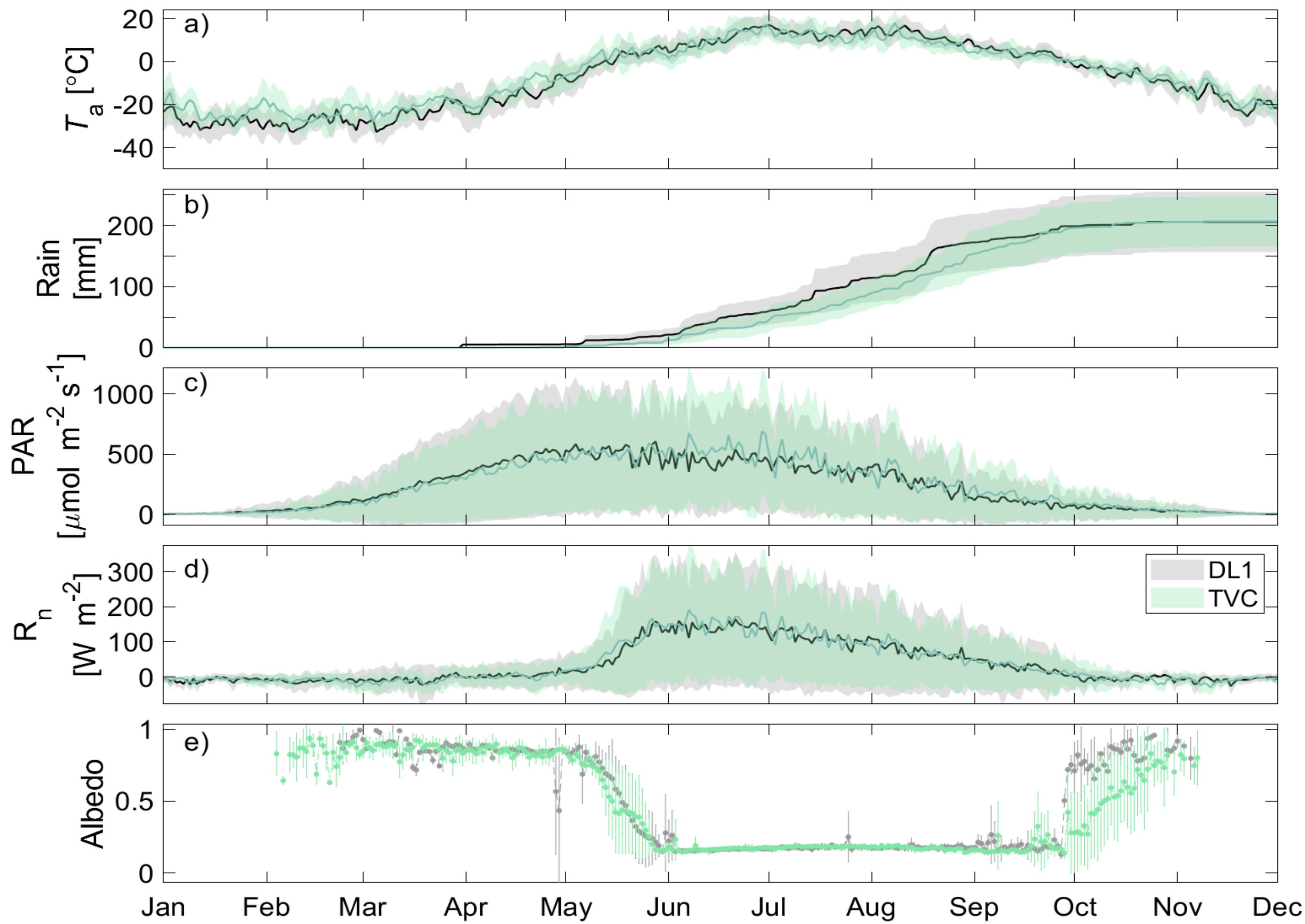
Both sites with continuous permafrost & similar vegetation species with different abundances: *Ledum decumbens*, *Empetrum nigrum*, *Loiseleuria procumbens, Betula glandulosa*, *Vaccinium uliginosum, Salix* spp., *Carex* spp., *Eriophorum vaginatum*

	DL1	TVC
% Cover ± SE	Vascular plants: 71.2 ± 4.8 Moss: 25.2 ± 8.8 Lichen: 40.4 ± 9.3	Vascular plants: 92.5 ± 3.4 Moss: 31.5 ± 10.4 Lichen: 51.0 ± 10.9
Vascular plant composition (%) ± SE	Shrubs: 81.9 ± 7.8 Graminoids: 17.6 ± 7.9 Forbs: 0.5 ± 0.2	Shrubs: 30.3± 4.1 Graminoids: 64.8 ± 3.6 Forbs: 4.9 ± 3.2





Daily mean climate variables at DL1 and TVC averaged over 2013 – 2017 including their standard deviation



Despite 1000 km separation, similar weather at the two sites

New shrub and sedge plant functional types (PFTs) in CLASSIC

CLASS PFTs	CTEM PFTs		
Needleleaf Tree (NdlTr)	Evergreen (NdlEvgTr)	Deciduous (NdlDcdTr)	
Broadleaf Tree (BdlTr)	Evergreen (BdlEvgTr)	Cold Deciduous (BdlDCoTr)	Drought/Dry Deciduous (BdlDDrTr)
Crop (Crops)	C_3 (CropC3)	C_4 (CropC4)	
Grass (Grass)	C_3 (GrassC3)	C_4 (GrassC4)	Sedges (Sedge)
Broadleaf Shrub (BdlSh)	Evergreen (BdlEvgSh)	Cold Deciduous (BdlDCoSh)	

Simulations – fractional coverage of the PFTs:

1) Shrub run: BdlEvgSh = 30%, BdlDCoSh = 12%, Sedge = 18%
2) Grass run: C3 grass = 60%
3) Tree run: NdlEvgTr = 30%, BdlDCoTr = 12%, C3 grass = 18%

40% bare ground

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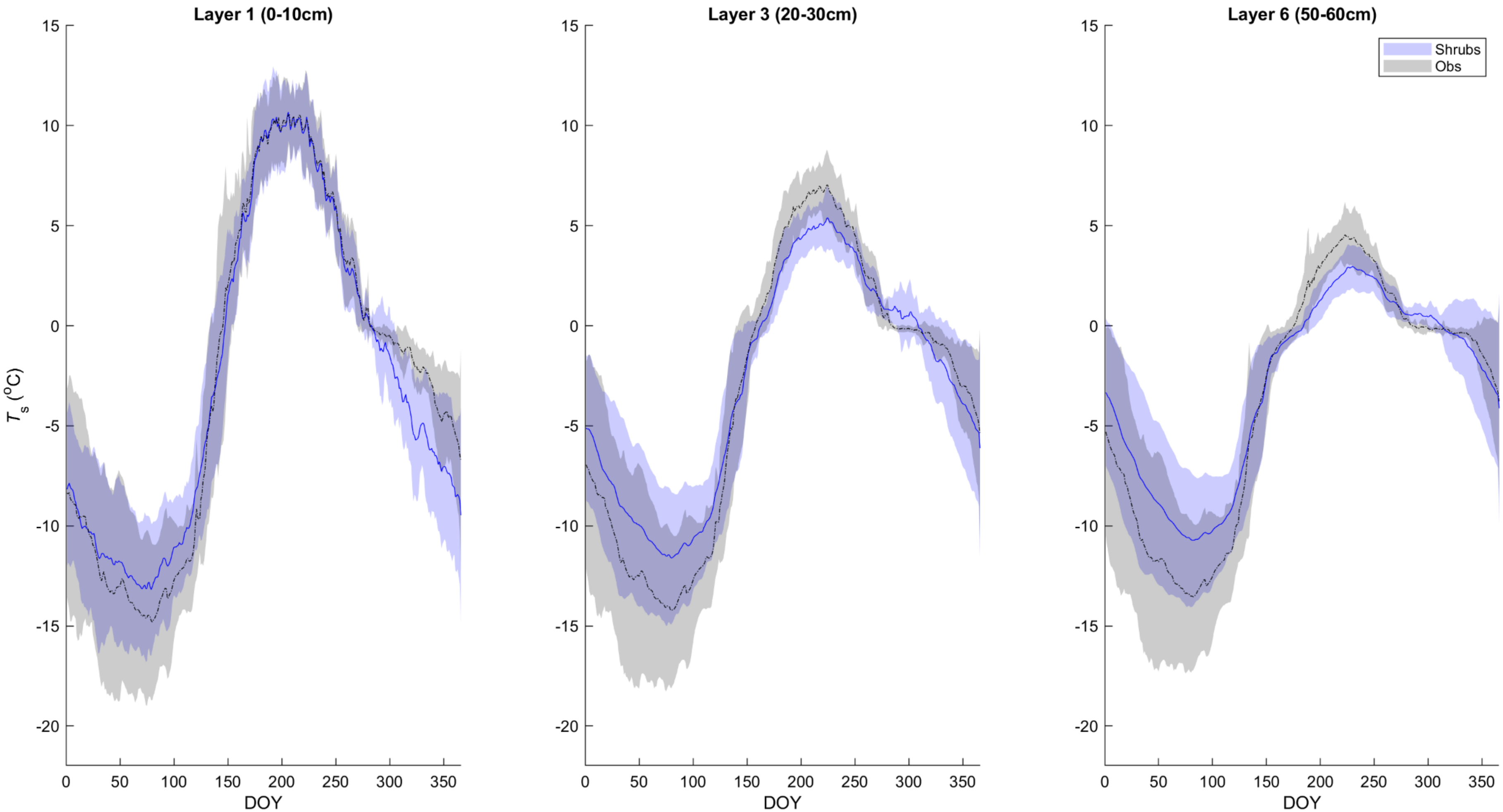
Modelled and observed daily soil temperatures at DL1 for the shrub run averaged over 2004-2017



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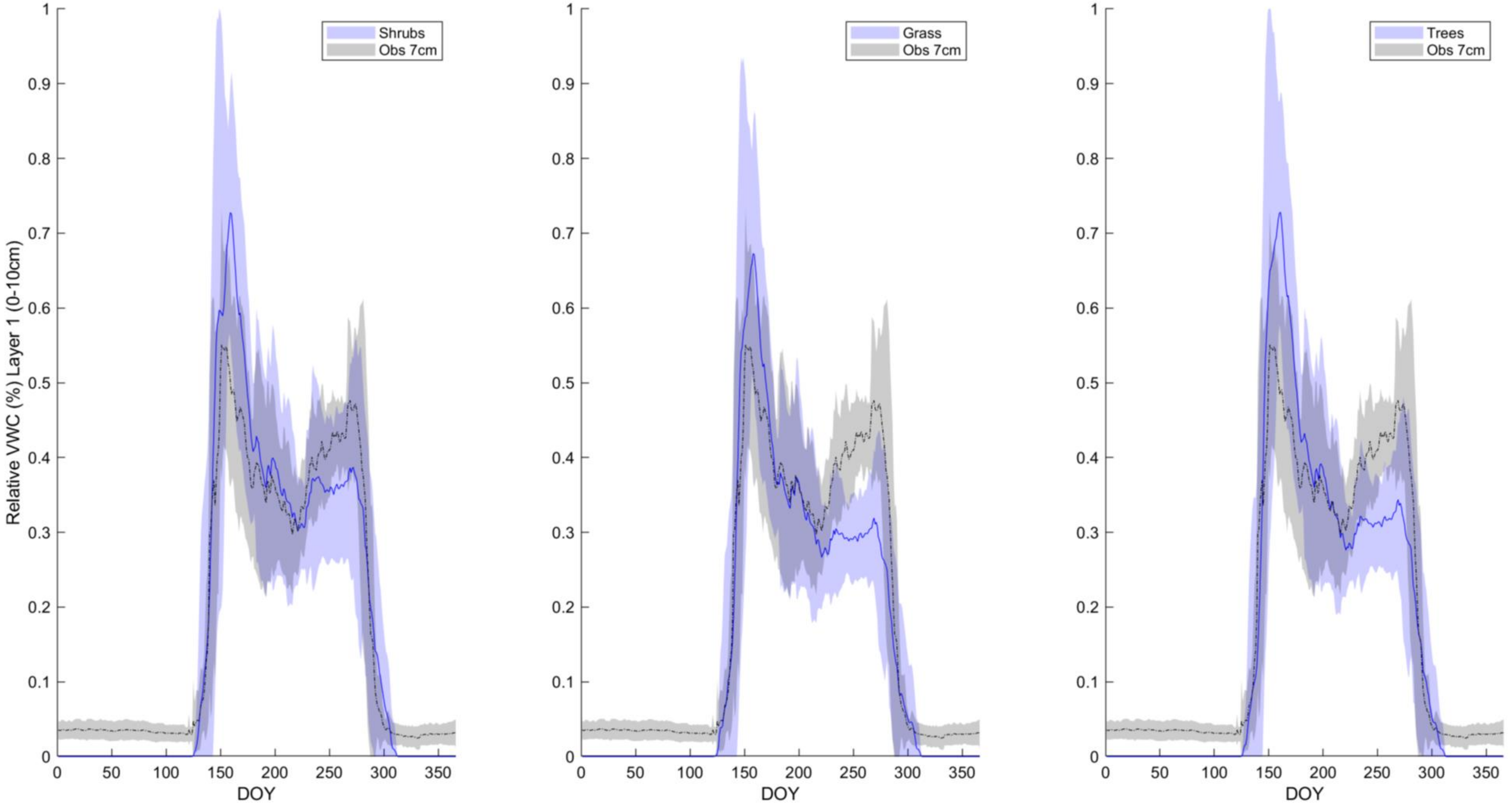
Modelled and observed relative daily volumetric water content at DL1 for the shrub run averaged over 2004-2017



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Soil and vegetation characteristics at DL1

	Model			Observations
	Shrubs	Grass	Trees	
Max. vegetation height (m)	0.22	0.35	20.68	0.18
Root depth (m)	0.38	0.48	0.40	~0.40
Active layer depth (m)	1.5	1.4	1.3	0.74 - 0.94
Max. LAI (m^2 m^{-2})	1.1	1.8	1.9	0.52
Snow depth (m)	0.76	0.76	0.73	0.20 – 0.40
Max. green leaf biomass (g C m^{-2})	123	74	137	90
Max. stem biomass (g C m^{-2})	176	0	2081	85
Max. root biomass (g C m^{-2})	491	434	570	
C soil (kg C m^{-2})	10.3	21.9	15.5	18.5 ± 4.7 (SD) for top 80 cm

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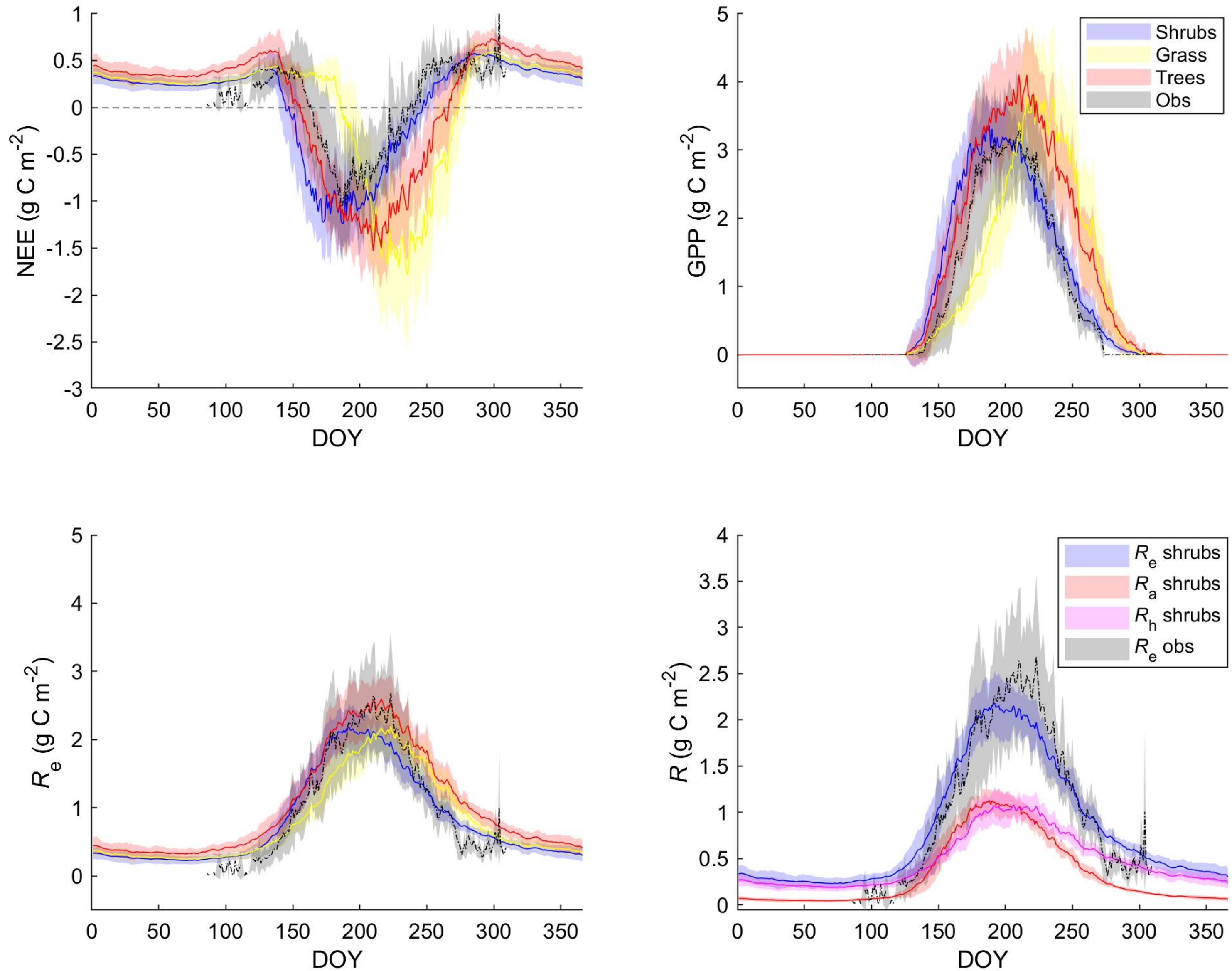
Daily mean NEE, GPP, R_e and its components autotrophic (R_a) and heterotrophic respiration (R_h) at DL1 averaged over 2004 – 2017 including their standard deviation



Despite overestimation in the spring, shrubs perform better than grasses and trees. The timing of GPP and thus NEE is shifted for grasses and peaks too high for both grasses and trees.

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