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Seasonal dynamics of spectral vegetation indices at leaf and canopy scales for a boreal evergreen coniferous forest

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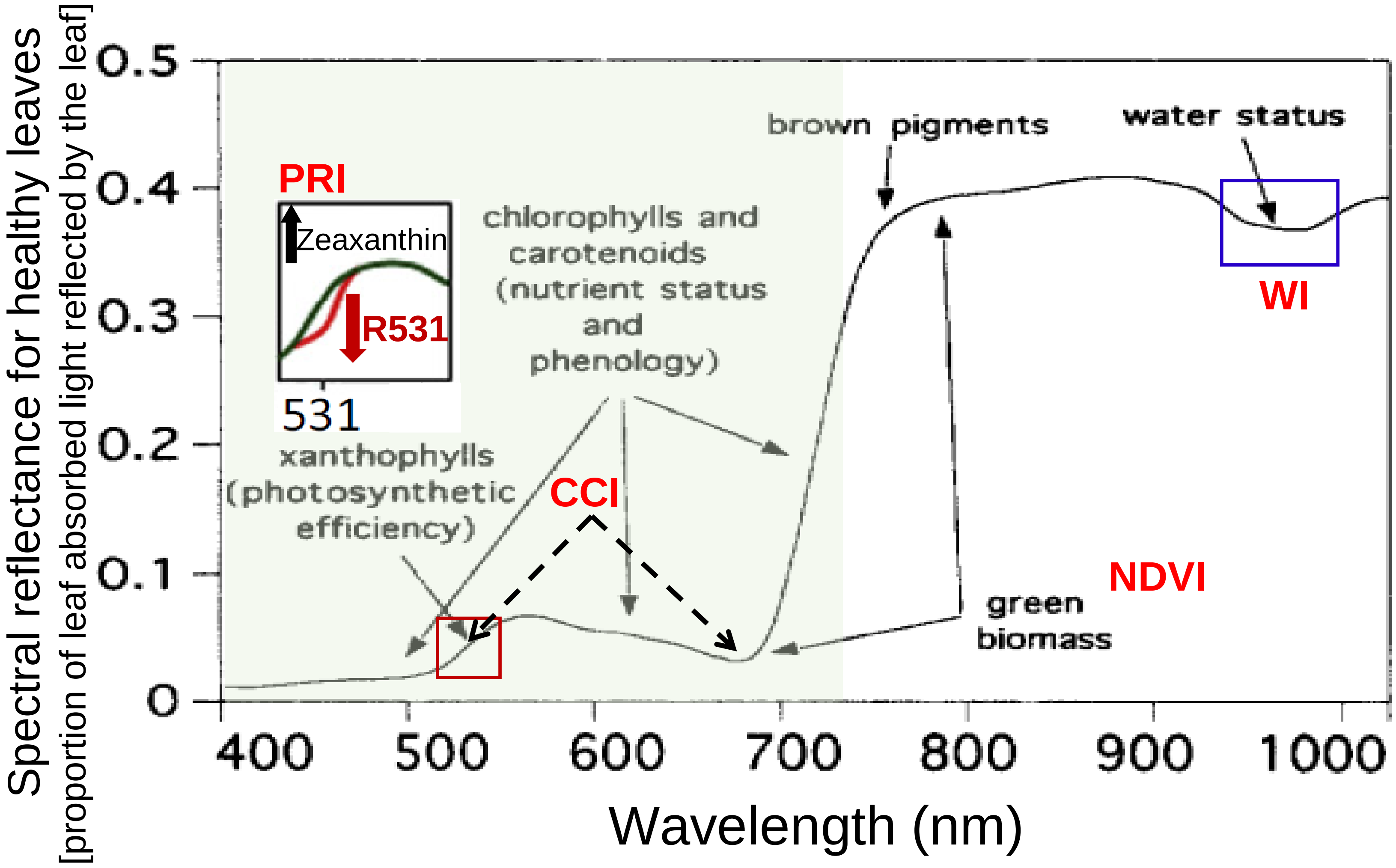
Motivations

- Boreal forests that dominated by evergreen conifers cover around one-third of global forest area. The seasonal pattern of evergreen vegetation is driven by temperature, remote sensing can potentially be used to detect changes in seasonality at scale.

- However, unlike leaf budburst in deciduous trees, evergreen forests does not generate any obvious visible sign that could be easily detected at larger spatial scales via traditional remote sensing vegetation indices (VIs) such as NDVI.

- Alternative methods based on photoprotective pigments such as PRI and CCI may work, but require detailed understanding at leaf and canopy scale.

Introduction of Vegetation Indices (VIs)



Normalized difference vegetation index
<u>NDVI = (R900-R680)/(R900+R680)</u>

Photochemical reflectance index (PRI)
<u>PRI=(R531-R570)/(R531+R570)</u>

Chlorophyll/Carotenoid Index (CCI)
<u>CCI=(R531-R695)/(R531+R695)</u>

Water Index (WI)
<u>WI = R900/R970</u>

The figure is modified from Fig.1a in Peñuelas et al., 1998. For CCI, please see Gamon et al., 2016.

Peñuelas et al., 1998. Visible and near-infrared reflectance techniques for diagnosing plant physiological status. *Trends in Plant Science*
Gamon et al, 2016. A remotely sensed pigment index reveals photosynthetic phenology in evergreen conifers. *PNAS*

Research questions

1. Is the seasonal pattern in leaf-level VIs consistent between species, canopy positions and seasons?

2. Are leaf-level VI dynamics still visible at the canopy? Do these VIs track canopy scale photosynthesis?

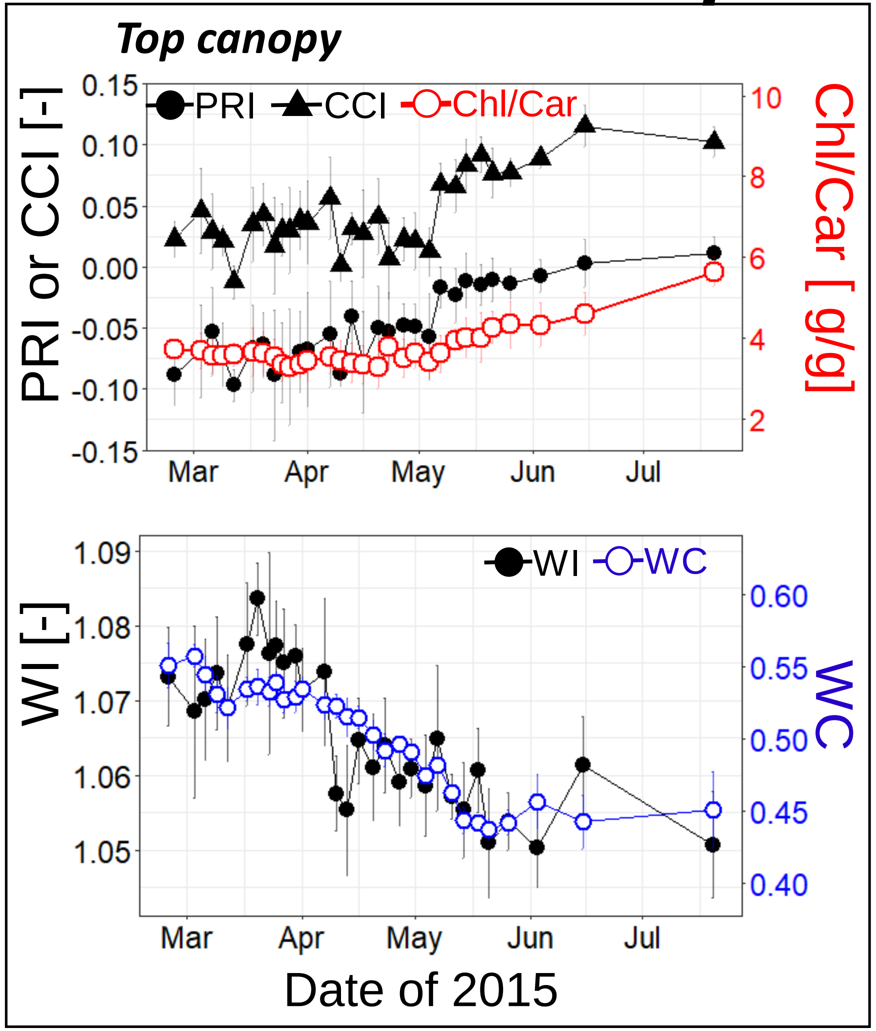
Materials and methods

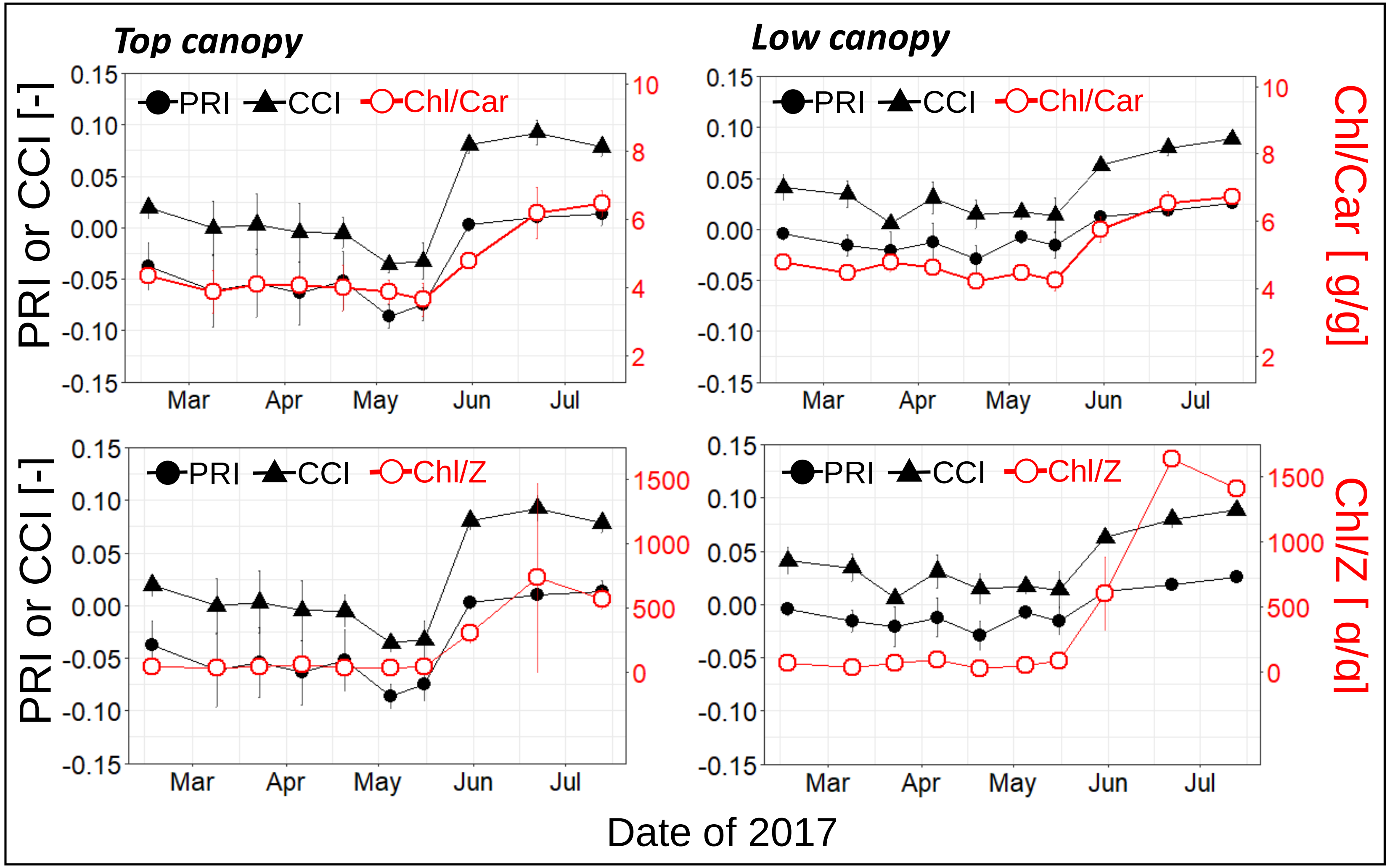
- <u>Study site</u>: Hyytiälä SMEARII forest station, Finland.
- <u>Species</u>: Scots pine *(Pinus sylvestris)* and Norway spruce (*Picea abies*).
- <u>Temporal scale</u>: two spring recovery period in 2015 and 2017
- <u>Spatial scale</u>: leaf (measured at top and low canopy in 2017) and canopy

- <u>Parameters at the leaf level measurement</u>:
  - PRI,CCI,NDVI (not shown here) and WI
  - Light-use efficiency at low light (LUE) and light saturated photosynthesis rate (*A*max).
  - Maximum photochemical efficiency (F_V/F_M), sustained photochemical (PQ_S) and non-photochemical quenching (NPQ_S)
  - Pigment composition
  - Leaf water content (WC)

- <u>Canopy data at 31 m tower</u>
  - PRI and NDVI are measured using Skye sensor
  - GPP and PAR measured at tower were used to estimate LUE (Eqn1) on a daily timestep by fitting a polynomial equation (Eqn2):
    - LUE=GPP/PAR (Eqn1); GPP= a × PAR+ b × PAR+c (Eqn2)
    - LUE used here is when PAR is 400 (µmol photons m^{-2} s^{-1}), namely, LUE=GPP(400)/400

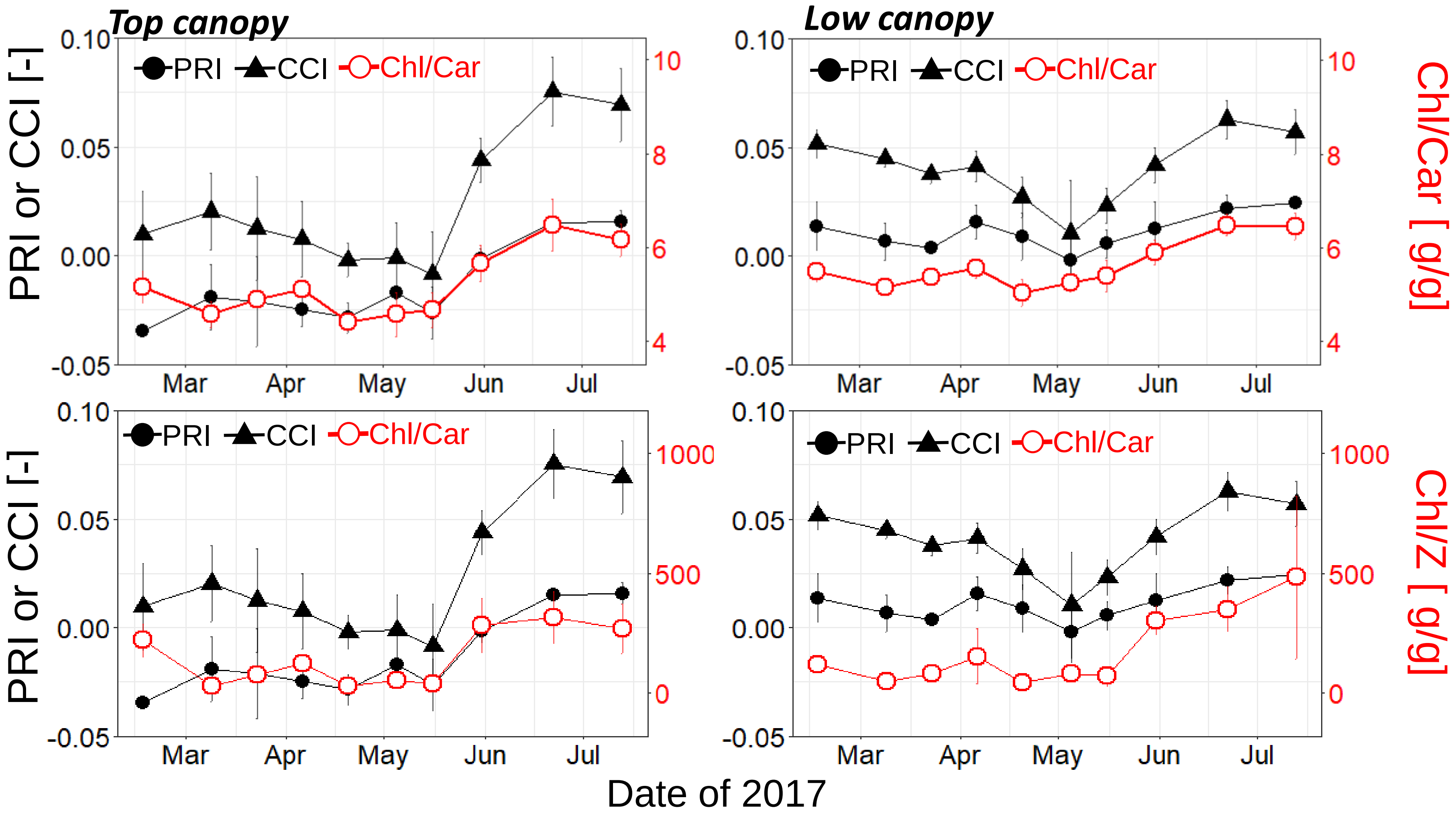
Leaf level: *Scots pine*





- Seasonal variations of low canopy PRI (and CCI) were relatively smaller than the top canopy. However, the Chl/Car ratio had similar variability at top and low canopy. When approaching the summer, Chl/Z ratio at the top canopy increased much more than the low canopy.
- Top canopy PRI (and CCI) showed clearly seasonal trend during the two spring recovery period, and changed coincident with Chl/Car ratio at both top and low canopy. PRI (and CCI) also presented similar seasonal changes with Chl/Z ratio.
- Seasonal variation of leaf water contents were well followed by WI.

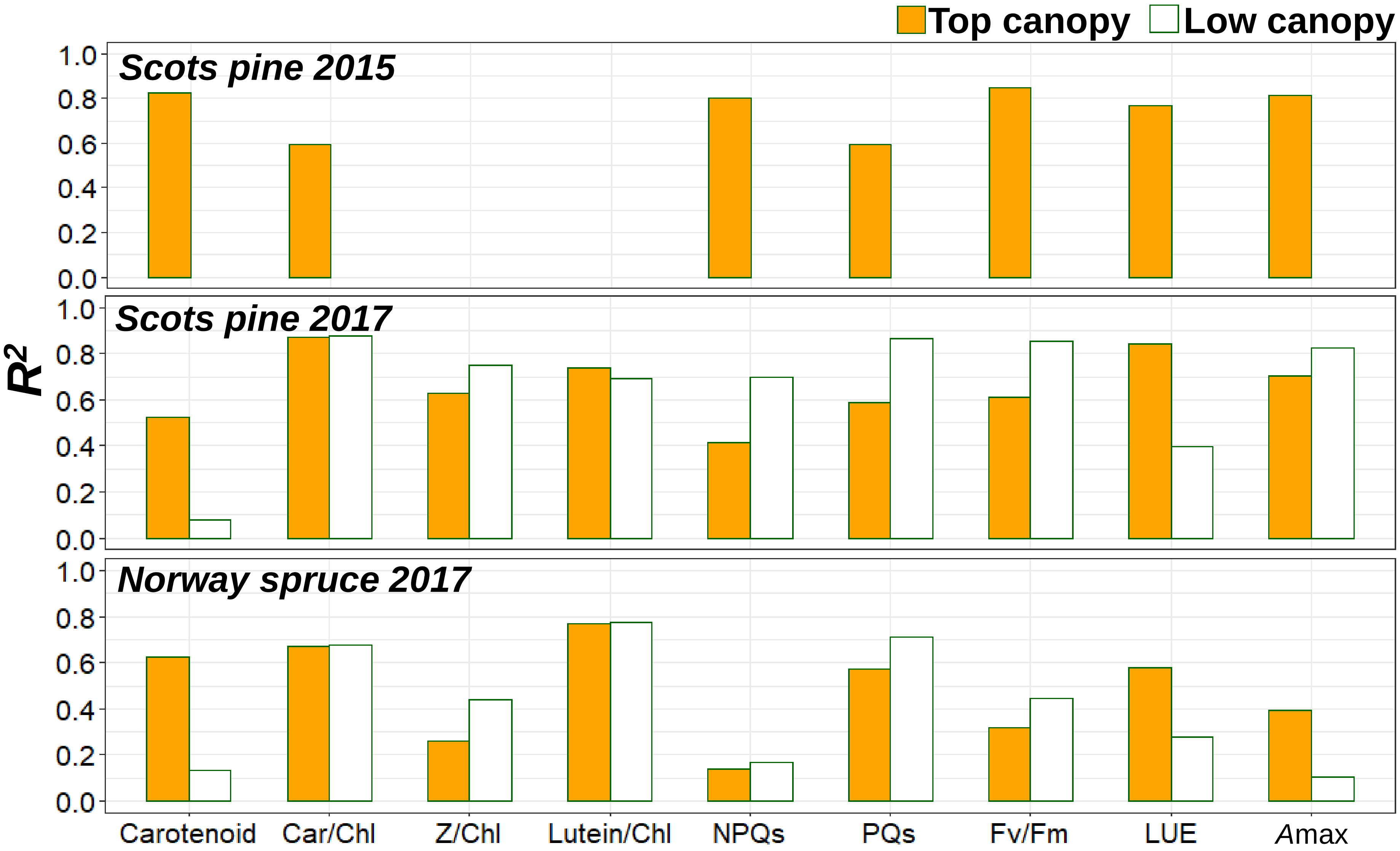
Leaf level: *Norway spruce*



- PRI (and CCI) showed clearly seasonal trend at both top and low canopy, but with slightly different variability. From winter to end of spring, PRI (and CCI) values at top canopy (around -0.025) were much lower than the low canopy (around 0.012). When approaching the summer, PRI at top canopy were only slightly lower than the low canopy.
- From winter to the end of spring, Chl/Car ratio values at top canopy were slightly lower than low canopy, and increased to similar level when approaching the summer. Chl/Z ratio had similar variability at top and low canopy.
- PRI (and CCI) changed coincident with Chl/Car at both top and low canopy.

Leaf level correlations

Coefficient of determination (R^2) of linear regression model of **PRI** with pigments and photosynthetic parameters



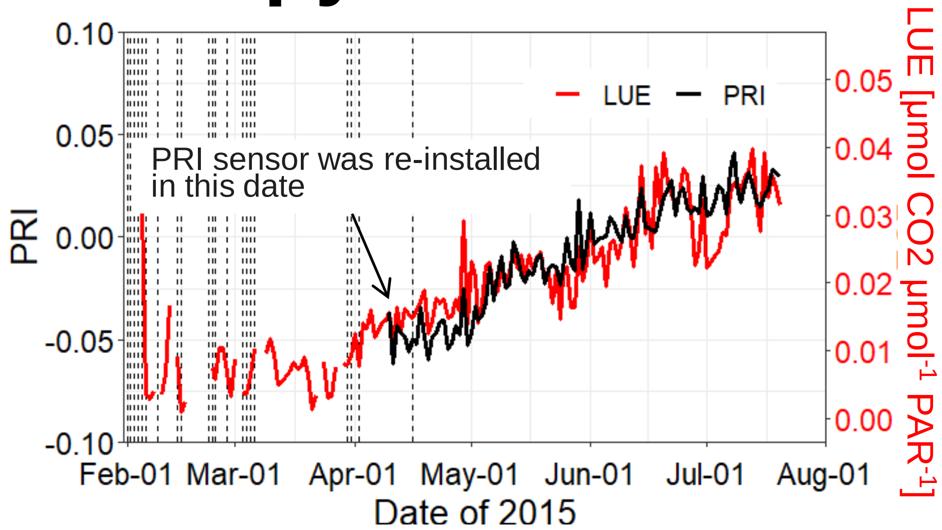
Car/Chl showed strong correlations with PRI for both pine and spruce regardless of canopy position.

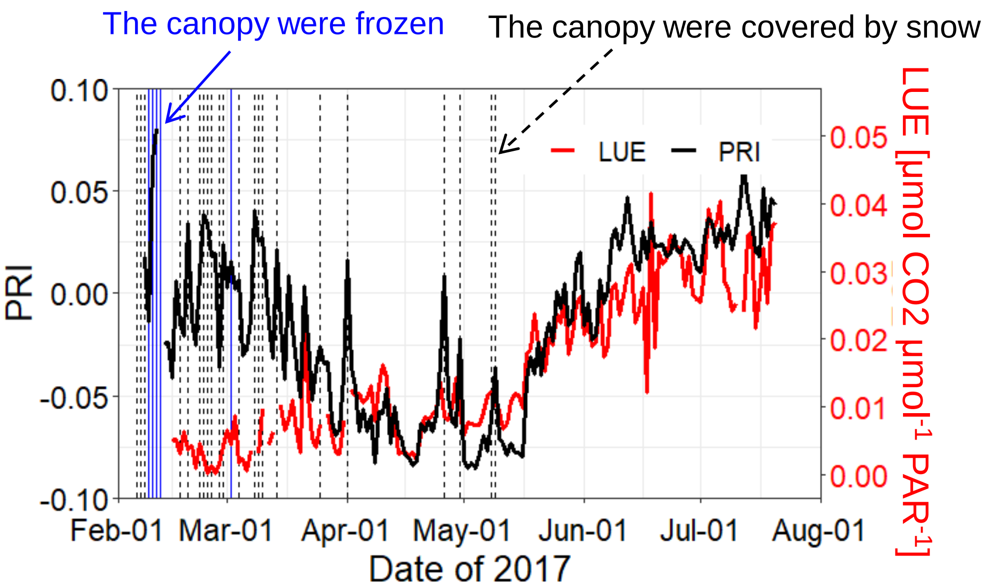
Both Z/Chl and NPQs had a role in controlling PRI for pine needles but not for spruce.

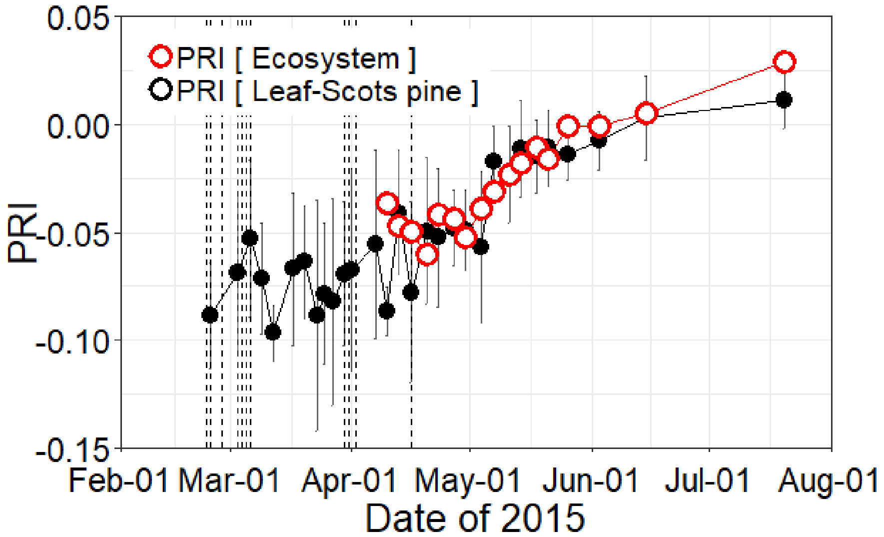
PRI for both species were strongly correlated with Lutein/Chl ratio.

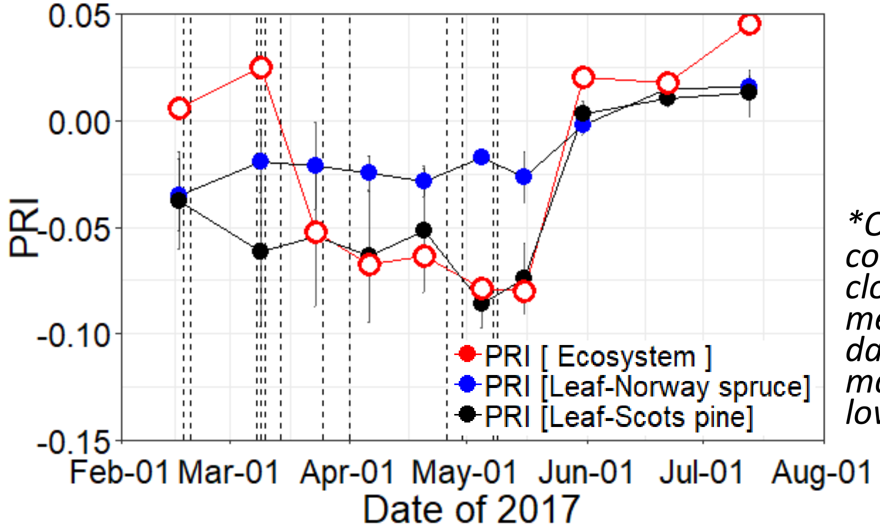
Correlations of PRI versus LUE were only significantly at the top canopy

Canopy level

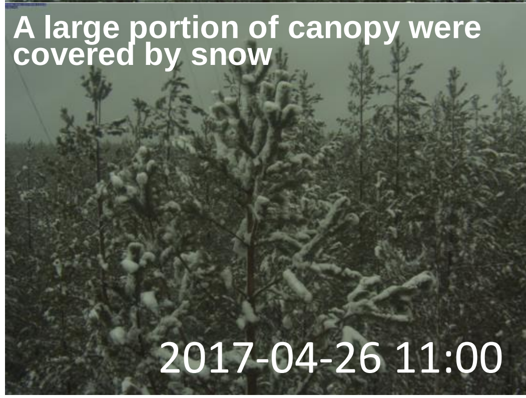








**Only snow covered dates closed to leaf measurement dates are marked in lower panel*



- At the canopy level, snow increased the PRI levels by increasing radiance, and PRI changed coincident with LUE when high PRI caused by snow not considered.
- PRI measured at the canopy level had similar seasonal trend and values with PRI measured at leaf level for pine species not for spruce, this is because most footprint of the tower measurement was covered by Scots pine.

Conclusions

At leaf level

- Seasonal variations of PRI and CCI at top canopy were higher than low canopy for both Scots pine and Norway spruce.
- Seasonal patterns of PRI and CCI were covaried with Chl/Car for both species regardless of canopy positions and seasons.
- Xanthophyll cycle (represented by Z/Chl in this study) and NPQs showed strong correlations with PRI in Scots pine but not in Norway spruce.

At canopy level

- Two seasonal dynamics of canopy PRI are consistent with leaf-level PRI.
- Canopy PRI changed coincident with canopy LUE across two spring recovery periods.

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Thank you.

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