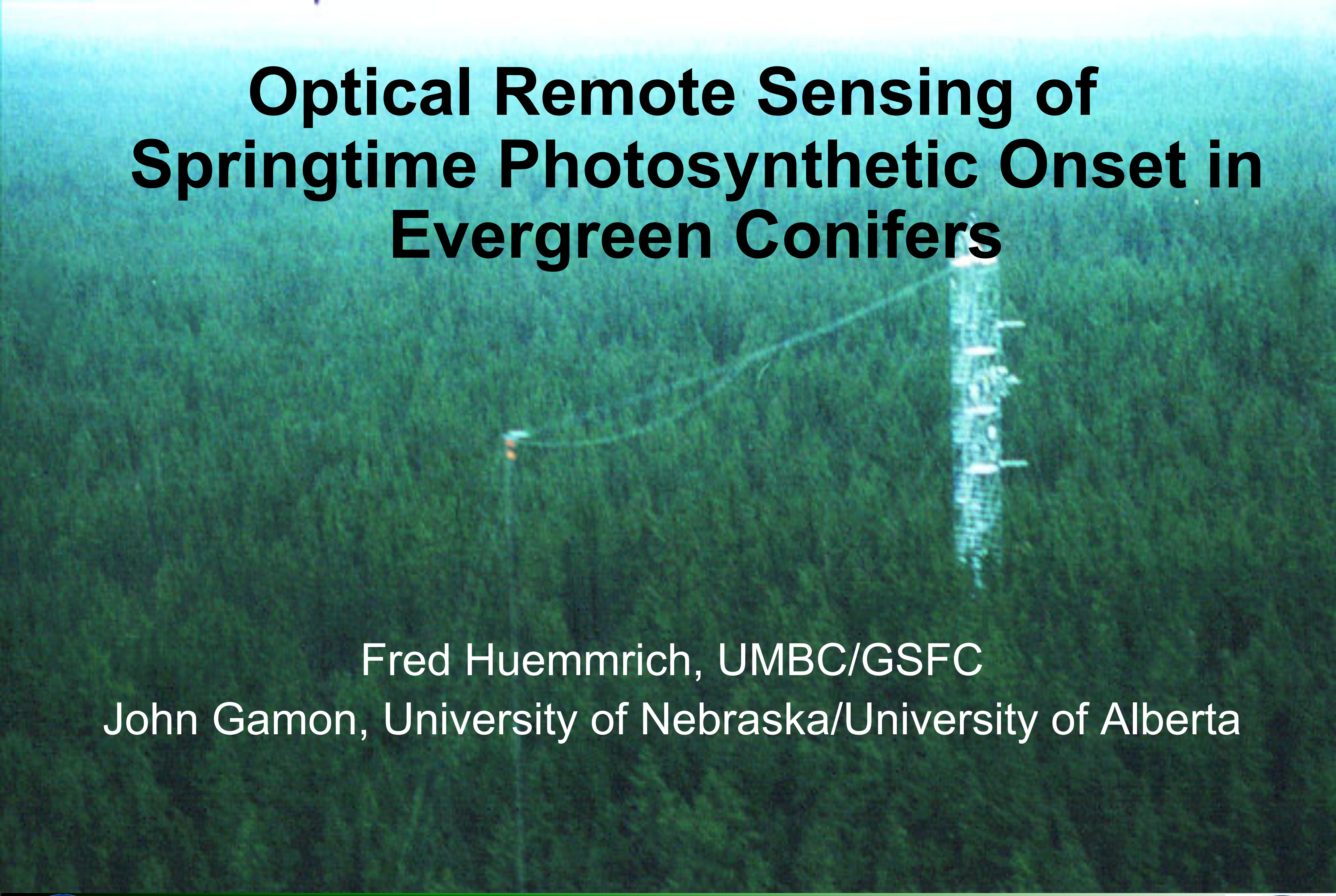
Optical Remote Sensing of Springtime Photosynthetic Onset in Evergreen Conifers



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SPACE FLIGHT CENTER

Problem

High latitudes are experiencing significant climate change

Possible ecosystem effects include changes in the timing of the photosynthetically active growing season

- Effecting timing of onset, duration, and end of growing seasons
- Affects productivity and stress occurrence
  - Longer growing seasons may result in increased productivity
  - However, longer growing seasons may also result in increased mid-summer plant stress
    - Increased plant stress may lead increased vulnerability to disturbances such as insect infestations or forest fires resulting in dramatic changes to the forests

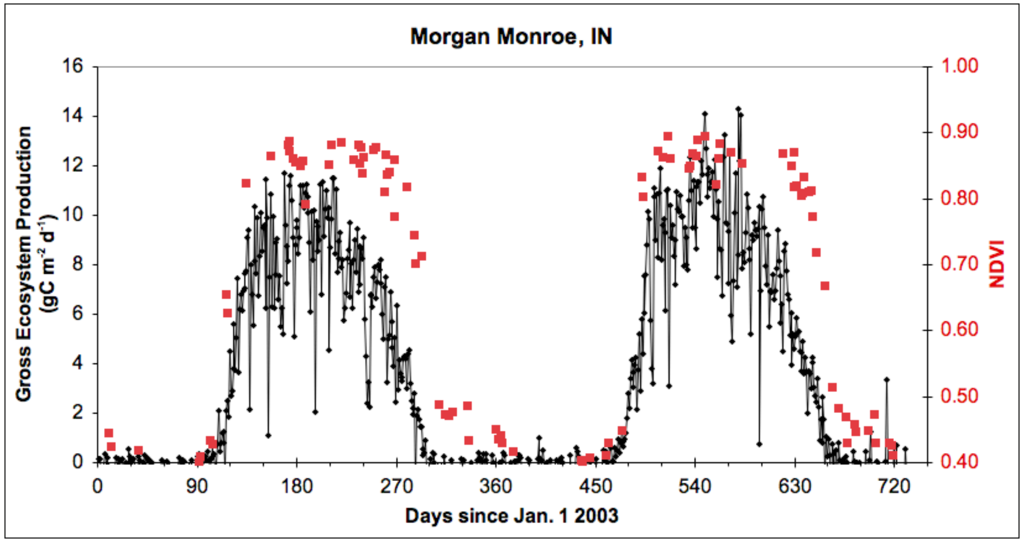
Problem

Possible effects of high latitude climate change on ecosystems include changes in the timing of the photosynthetically active growing season

- Describing the the onset of photosynthetic activity in the spring is particularly important because of relatively high incident solar radiation at that time of year
  - Compared to the end of the season when light levels are low and day lengths are short, limiting potential productivity
- Detection of the start of photosynthetic activity by commonly-used broad band remote sensing is particularly difficult in evergreen conifers
  - Evergreens do not display large seasonal changes in NDVI

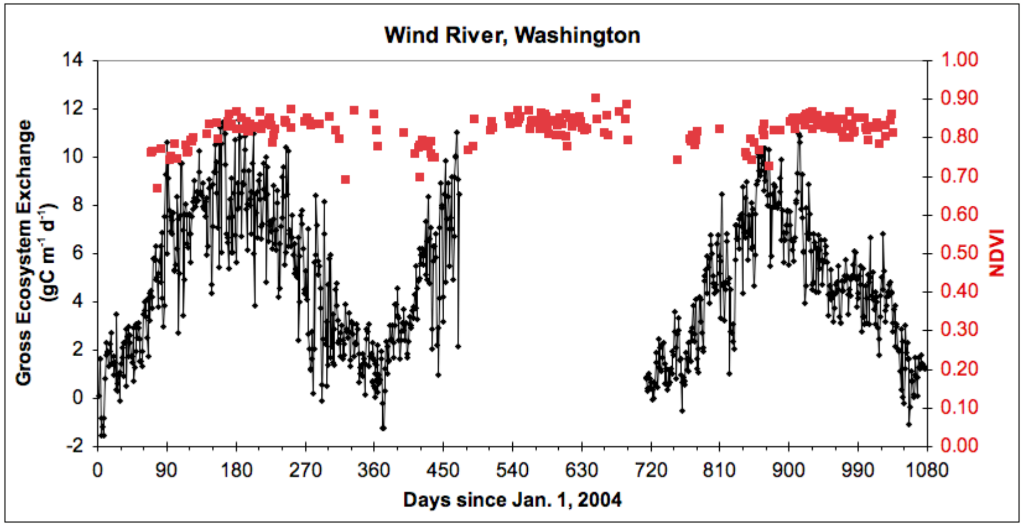
Seasonal Change in Forest Stands

Deciduous forest



Morgan Monroe, IN

Conifer forest



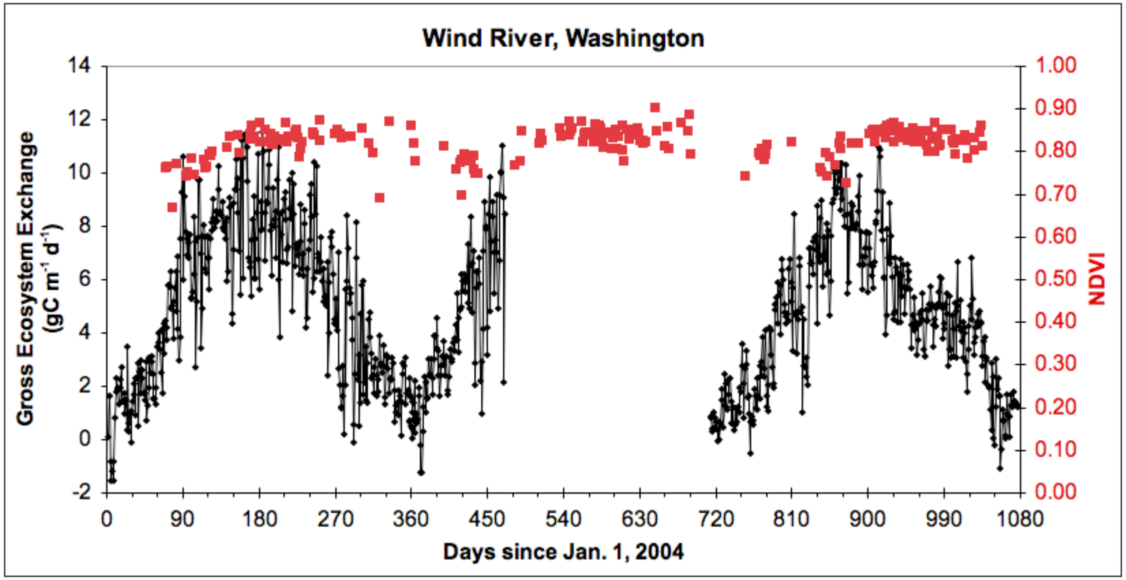
Wind River, WA

Red points: NDVI from Aqua MODIS

Black lines: Daily GEP from flux tower

Flux data from Fluxnet Synthesis
Gamon et al. 2016

Seasonal Change in Evergreen Conifer Stands



Wind River, WA

Red points: NDVI from Aqua MODIS

Black lines: Daily GEP from flux tower

For this evergreen forest there are strong seasonal changes in Gross Ecosystem Production (GEP)
- but little seasonal change in NDVI

Often the major seasonal markers in NDVI for evergreen conifer forests are actually driven by the timing of snowmelt (snow has a negative NDVI)

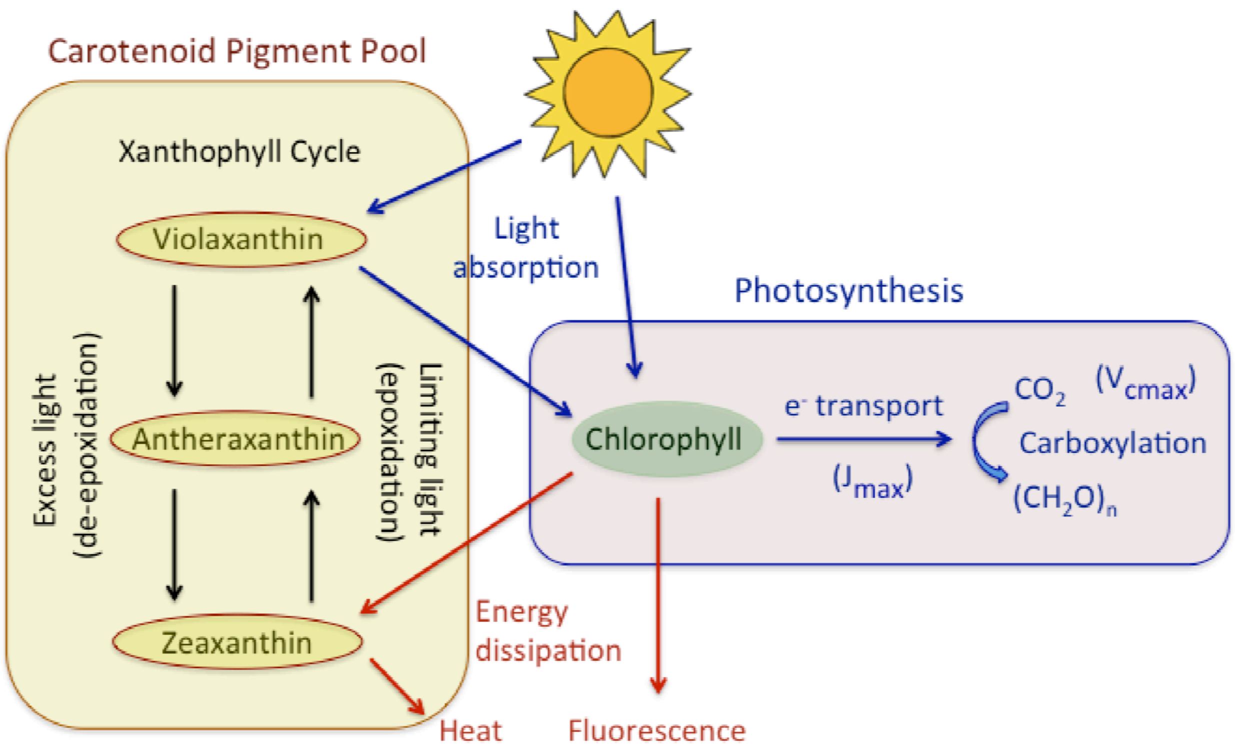
NDVI generally is not a good index for determining evergreen conifer productivity

Flux data from Fluxnet Synthesis
Gamon et al. 2016

Photosynthetic Energy Pathways

Briefly, if energy absorbed by leaves cannot be used by photosynthesis, then it must be dissipated

Pigment amounts can vary for leaf energy management



Radiation absorbed by a leaf can go to: productive photosynthesis (blue text and arrows), energy dissipation (red text and arrows), regulatory processes associated with the xanthophyll cycle (black text and arrows), and carotenoid and chlorophyll pigment pools, all of which can be assessed with optical sampling

Gamon 2015

Optical Signals

Leaf biochemistry responds to stresses over varying time scales

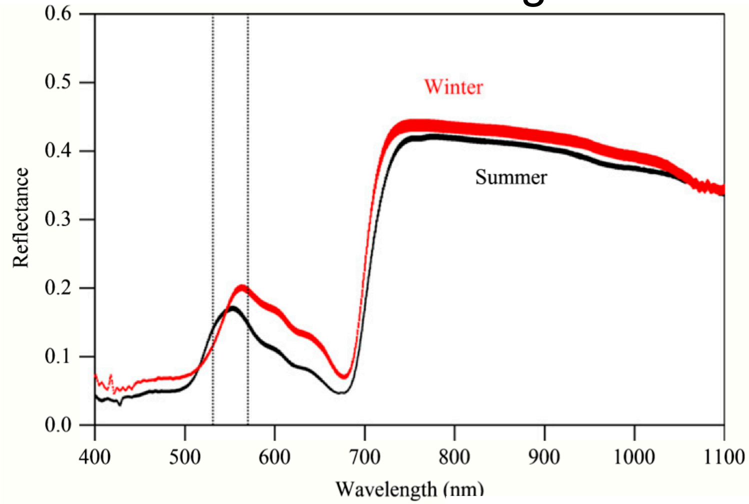
- Short term stress responses (minutes to hours) change relative amounts of Xanthophyll cycle pigments in leaves
- There are also longer term changes (days) in the relative amounts of photosynthetic and photoprotective pigments (Chlorophylls and Carotenoids) in leaves

These biochemical changes produce detectable changes in leaf optical properties - we are trying to relate them to carbon fluxes and productivity

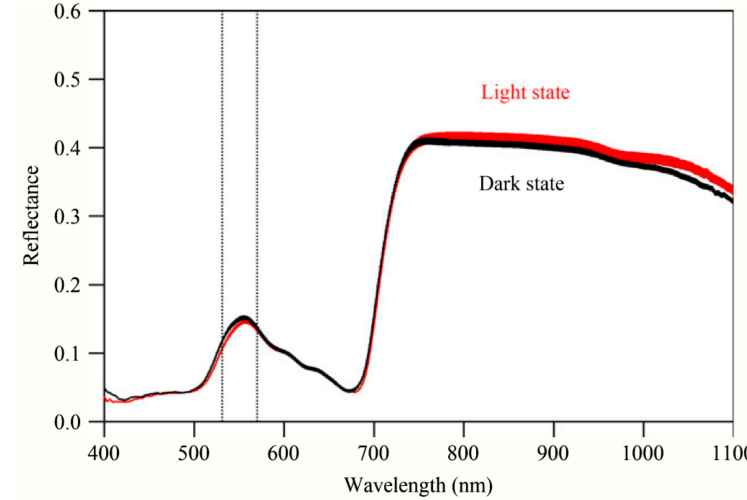
Boreal Conifer Needle Reflectance

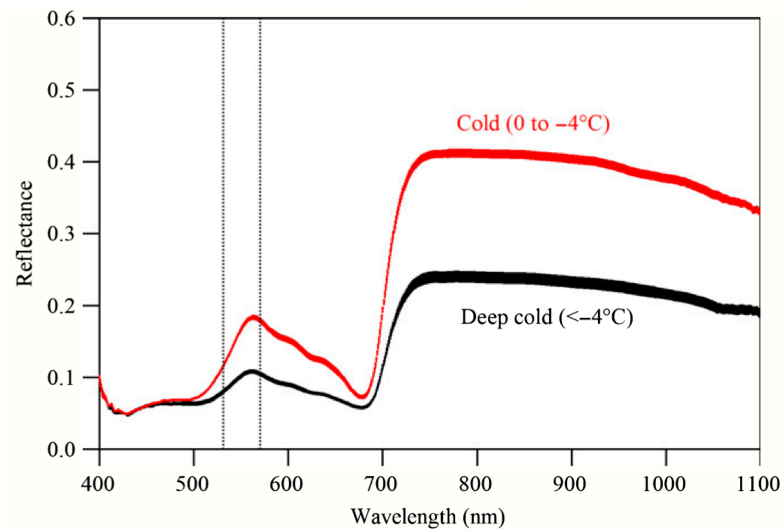
Variations in needle spectral reflectance

Seasonal Change



Diurnal Change





Change due to extreme cold (<-4^{o}C)

Wong and Gamon 2015

Optical Signals

Shifts in pigment pools affects the spectral region around 531 nm (MODIS band 11)

- The Photochemical Reflectance Index (PRI) is the normalized difference of reflectances at 531 nm and a reference band at 570 nm (which we don't have on MODIS)
  - it was developed to detect Xanthophyll pigments
- PRI is also affected by the overall size of the the Chlorophyll and Carotenoid pools in leaves
  - we are calling an index for this the Chlorophyll-Carotenoid Index (CCI), the normalized difference of MODIS bands 11 and 1 (red band)

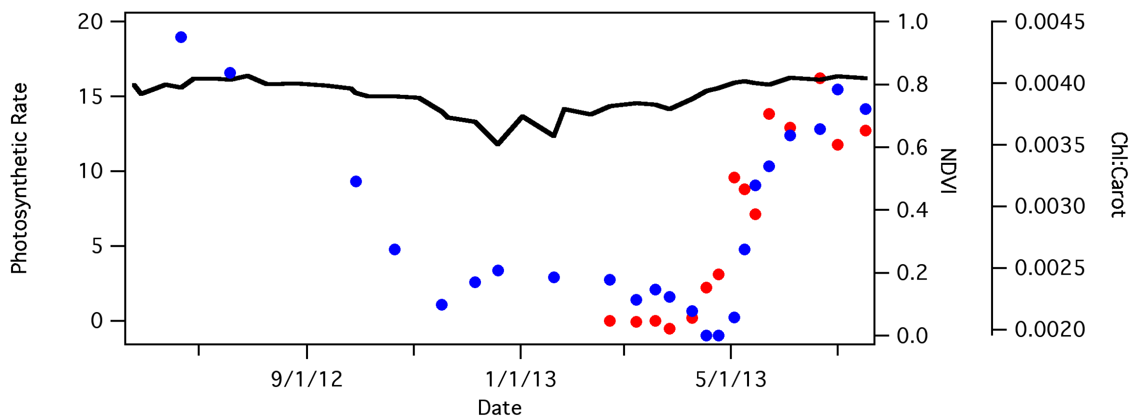
Seasonal Change in Boreal Conifer Needles

Points are leaf level measurements of photosynthesis and Chl/Car made from the fall through the winter and into spring.

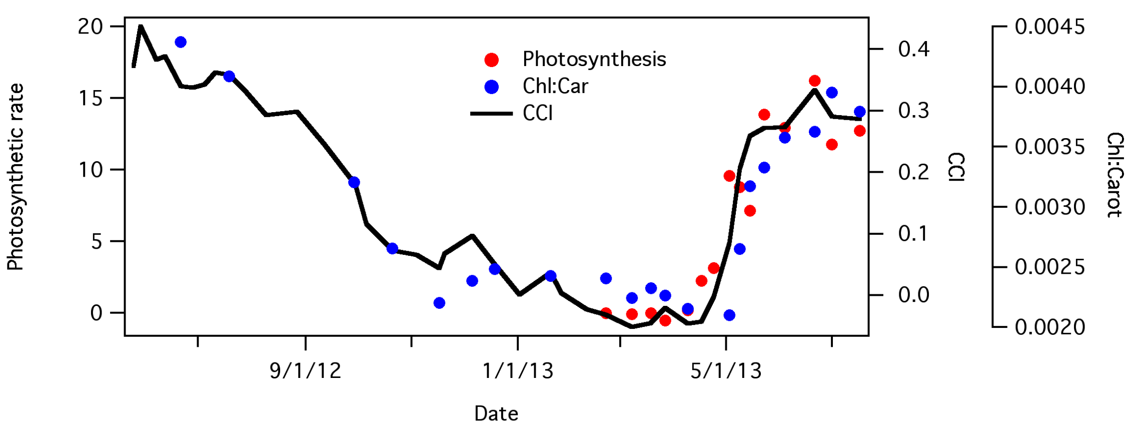
Time trends for *Pinus contorta* needles exposed to a boreal climate

Red points - needle photosynthesis

Blue points - chlorophyll:carotenoid ratio



Black line: NDVI



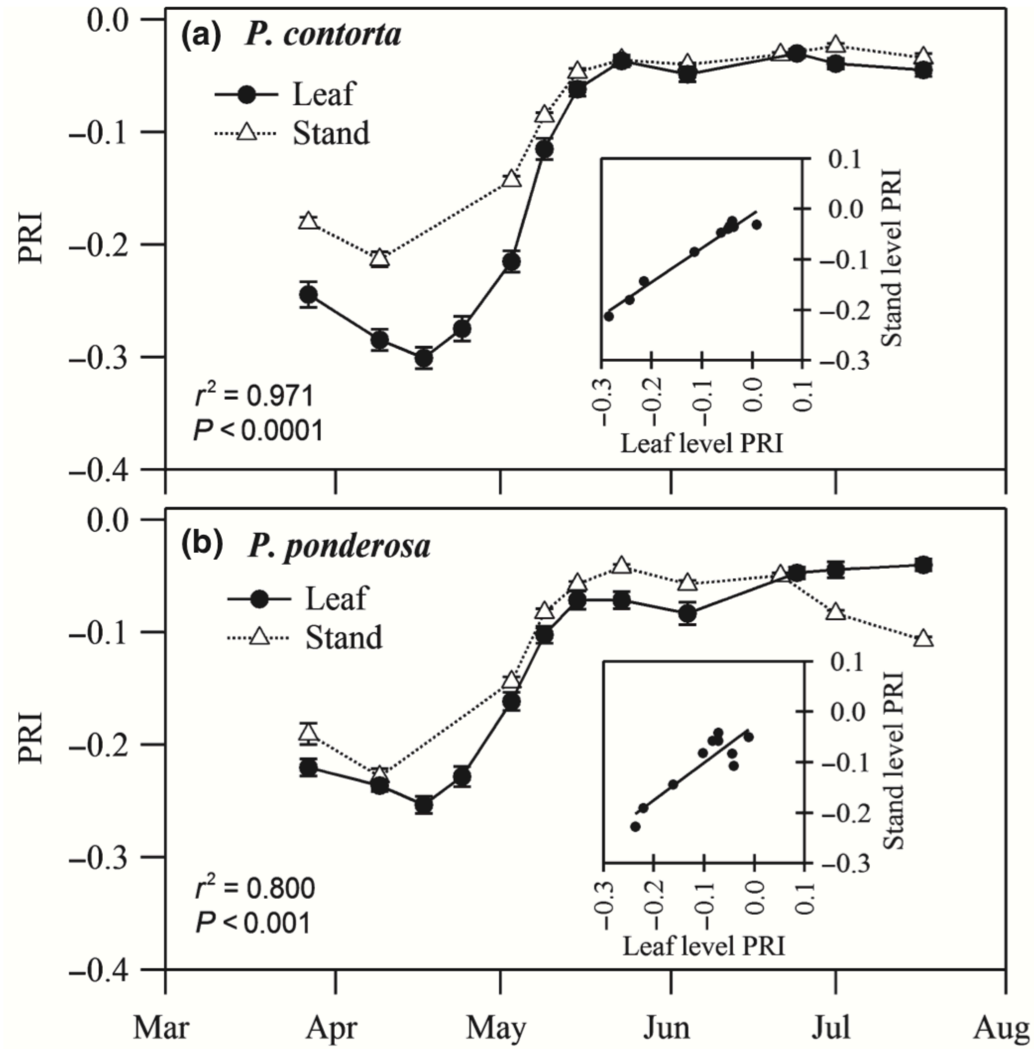
Black line: CCI, Chlorophyll-Carotenoid Index

$$CCI = \frac{(R_{11} - R_1)}{(R_{11} + R_1)}$$

Wong and Gamon 2015

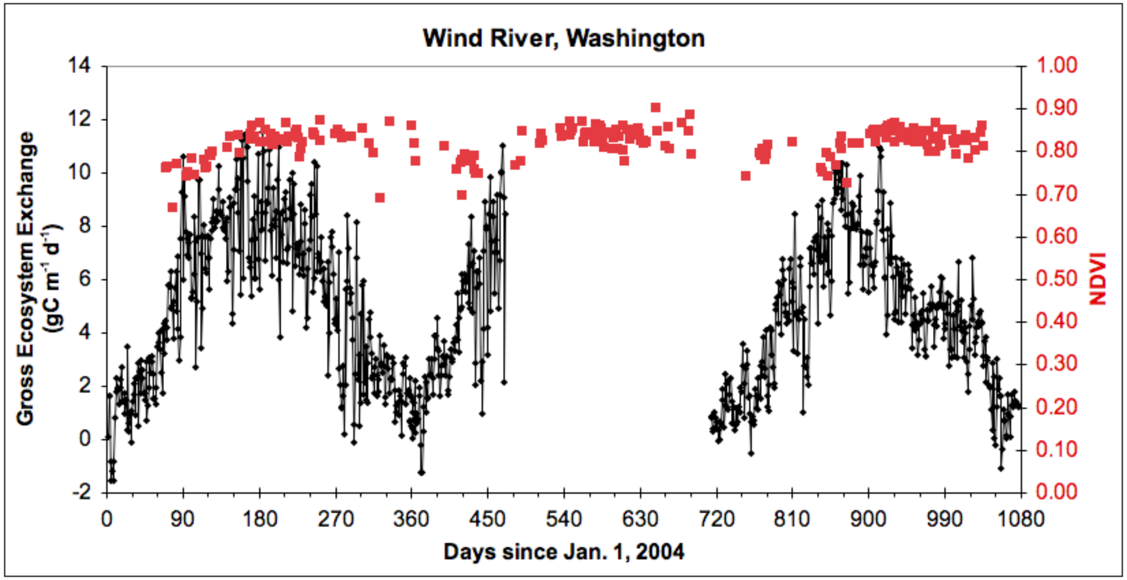
Spring Changes in Conifer Needles and Trees

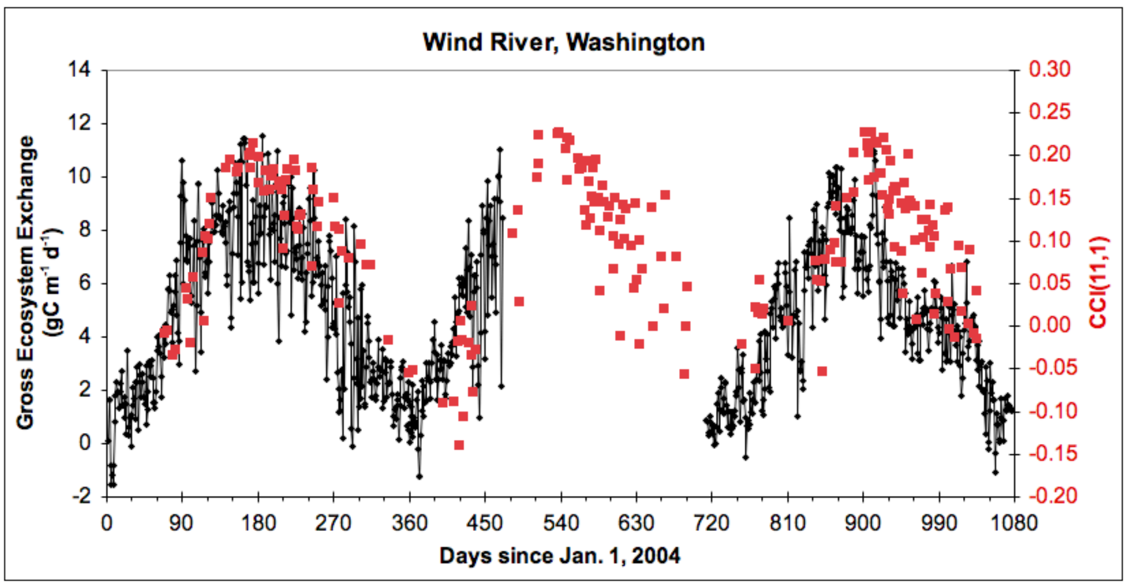
Changes in needle reflectance can be observed at the tree scale



Wong and Gamon 2015

Seasonal Change in Evergreen Conifer Stands





Wind River, WA

NDVI from Aqua MODIS

CCI from Aqua MODIS

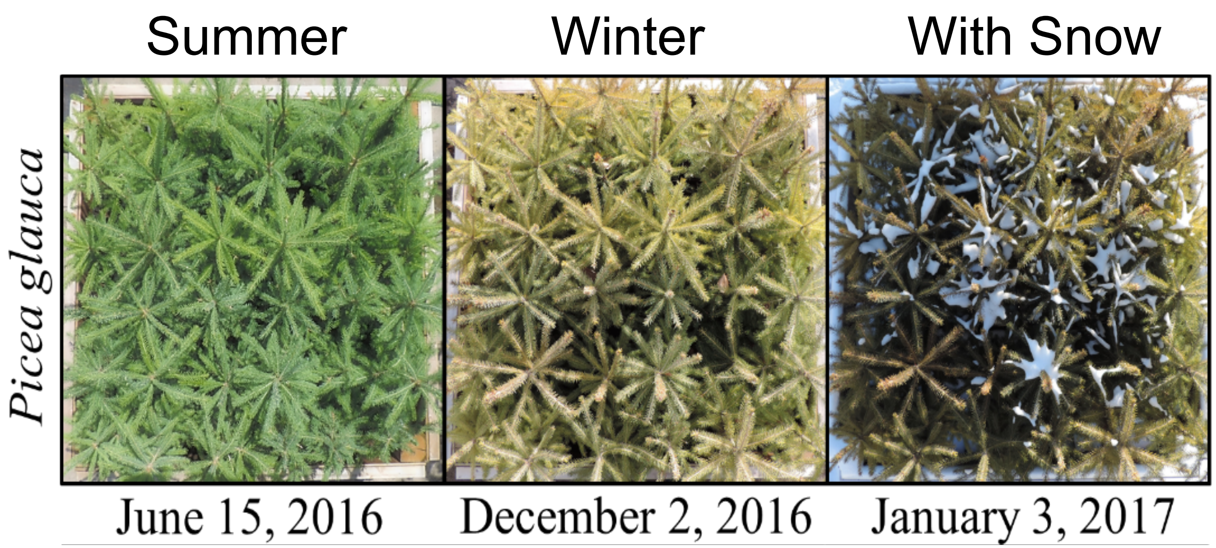
$$CCI = \frac{(R_{11} - R_1)}{(R_{11} + R_1)}$$

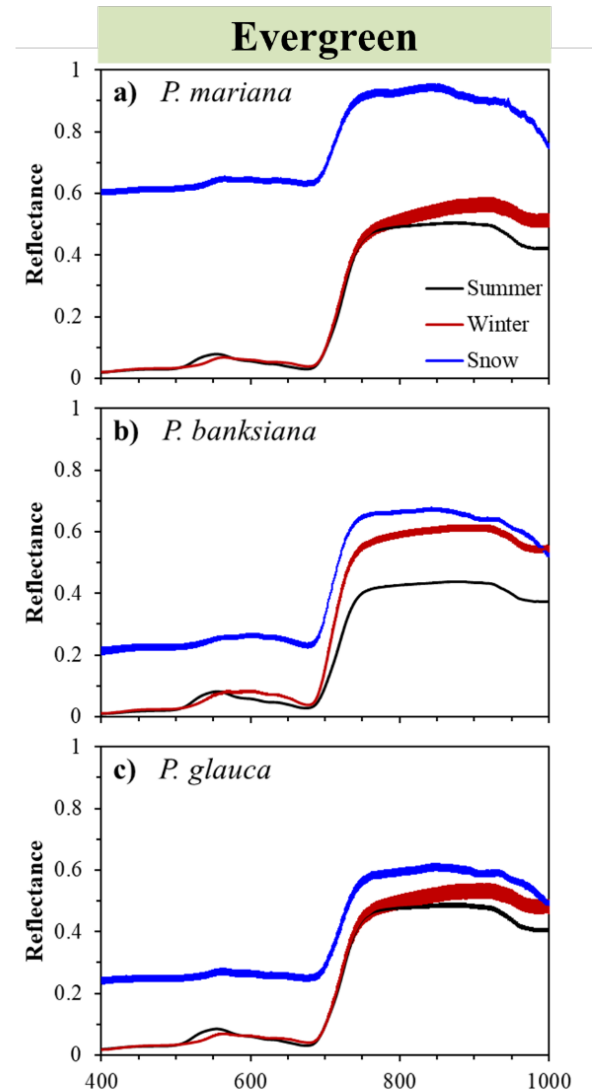
Black lines: Daily GEP from flux tower

Flux data from Fluxnet Synthesis
Gamon et al. 2016

Effects of Snow

Snow in canopies significantly affects reflectance spectrum, increasing the difficulty in determining the vegetation spectra





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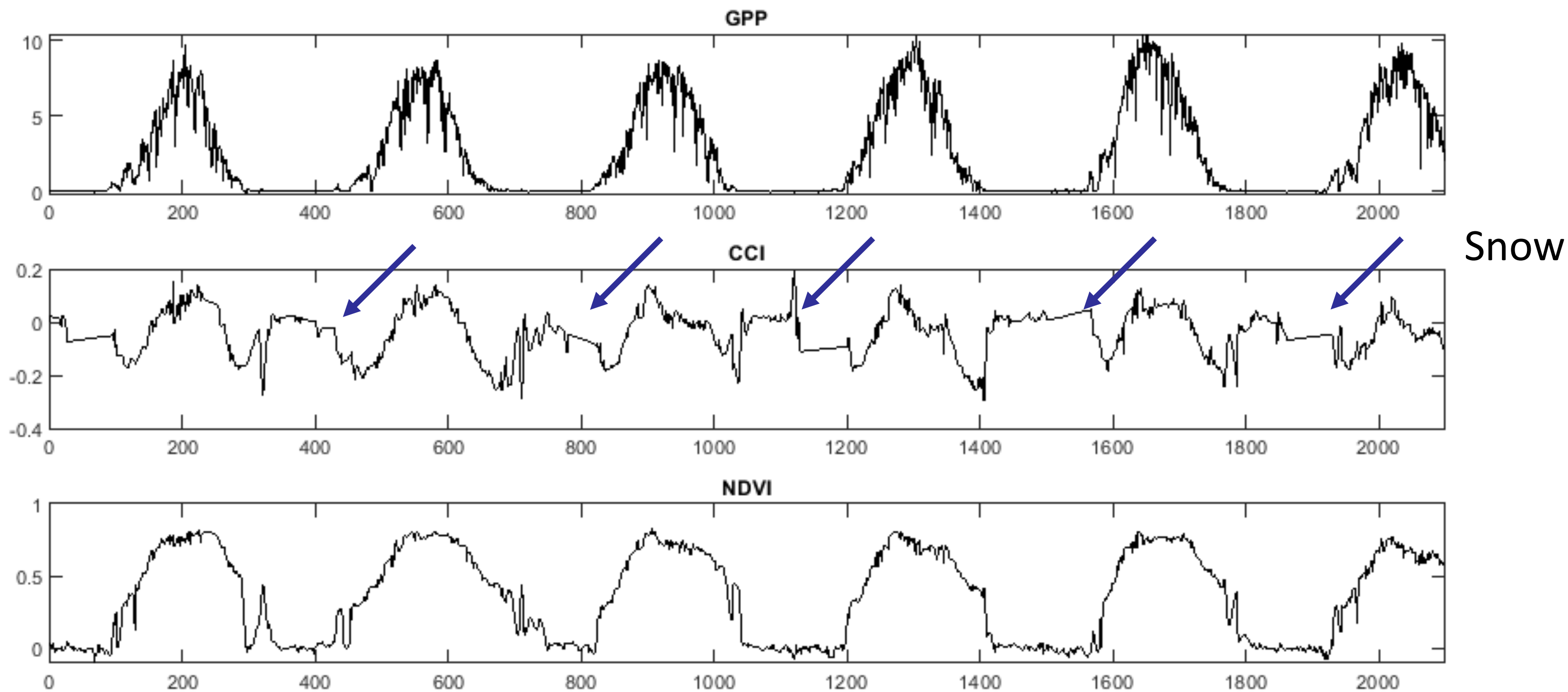
Effects of Snow

Snow in scenes affects CCI, resulting in anomalously large values, complicating detection of biochemical change during the critical springtime snowmelt/photosynthetic onset period



Time series daily GPP, CCI and NDVI at Alberta peatlands (54.82 N, 112.47 W) from 2004 to 2009. The dominant tree species are *Picea mariana* and *Larix laricina*, with high abundance of a shrub, *Betula pumila*, and a wide range of moss species. GPP data were provided by Larry Flanagan from University of Lethbridge. CCI and NDVI were calculated using MODIS MAIAC data.

Wang and Gamon

Conclusions

- Describing the onset of photosynthetic activity during the boreal springtime is critical for accurate descriptions of high latitude ecosystem productivity as well as detecting the effects of climate change
- Commonly used broad-band approaches, such as NDVI, do poorly detecting seasonal changes in evergreens
- Conifer needle spectral reflectance seasonally change as their biochemistry changes
  - providing a method of remotely sensing the invisible phenology of evergreens
  - Have been detected at needle, experimental plot, and 1 km MODIS scales
  - Requires more work to establish differences in responses due to environmental conditions and species, particularly at the tree and stand levels
- Presence of snow complicates detection vegetation condition
  - To accurately describe photosynthetic onset, methods for addressing effects of snow must be developed

Recommendations

Our understanding of these processes will be improved if we can collect data with better spectral and spatial characteristics than 1 km MODIS ocean bands

- With the aim of improving understanding of optical changes associated with photosynthetic onset and stress responses and develop methods to mitigate effects of snow in scenes

Significant advancement in this area could be achieved by

- Repeated hyperspectral imagery collected throughout the springtime period for boreal/alpine forest sites
  - at a spatial resolution that resolves individual tree crowns
  - Including flight after all the snow has melted
- Imagery should be collected in conjunction with eddy covariance flux measurements and field measurements of needles

Results of such a field campaign would address ABoVE science questions as well as inform SBG algorithm development