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# The effect of winter frozen season changes on Northern Hemisphere vegetation canopy growth determined from satellite microwave and optical remote sensing

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## Introduction:

The winter frozen season strongly influences vegetation dormancy and productivity at northern high latitudes (NHL) and upper elevations where seasonal frozen temperatures are a major constraint to vegetation growing seasons. The landscape freeze-thaw (FT) signal from satellite microwave remote sensing is closely linked to frozen temperature constraints to surface water mobility, vegetation phenology, productivity and land-atmosphere trace gas exchange. We developed a consistent global record of daily landscape FT dynamics at moderate (~25-km) spatial resolution using a temporal change classification of overlapping 37GHz frequency brightness temperatures (Tb) from AM and PM overpass retrievals of the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) satellite sensor records. A temporally consistent and continuous long-term (from 1979) FT record was created that distinguishes daily frozen, non-frozen and transitional (AM frozen and PM non-frozen) conditions. The FT results show mean annual spatial classification accuracies of 91 (+/-8.6) and 84 (+/-9.3) percent for PM and AM overpass retrievals relative to global weather station observations. The FT record is used to quantify variability and regional trends in NHL frozen seasons and transitional frost days. The significance of these changes for vegetation productivity is evaluated using satellite (MODIS, AVHRR) based summer NDVI (JJA) growth anomalies and seasonal anomalies in atmospheric $CO_2$ concentrations.

## Data and Methods:

### Primary datasets employed in the investigation:

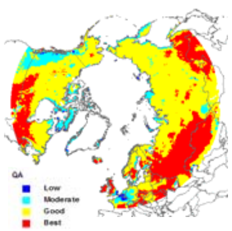
(1) FT-ESDR: Global Satellite Microwave Record of Daily Landscape Freeze/Thaw Status, Version 02 [1979 to 2010]. Digital media (http://freezethaw.ntsg.umt.edu; http://nsidc.org/data/nsidc-0477.html), 25 x 25 km global EASE-Grid;

(2) VIP ESDR vegetation index: NDVI & EVI2, 1982 to 2010 (http://phenology.arizona.edu), 25 x 25 km global EASE-Grid;

(3) NOAA ESRL Globalview (http://www.esrl.noaa.gov/gmd/ccgg/globalview/): Integrated atmospheric $CO_2$ concentrations (≥50°N )*

*Masarie & Tans *JGR* 1995

### FT-ESDR Quality Assessment (QA) for 1979-2010:

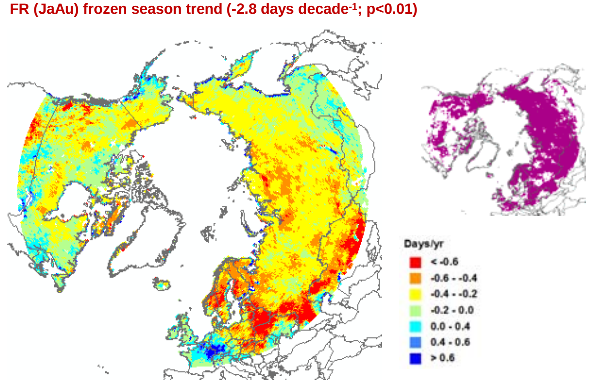



The FT-ESDR QA map (**left**) provides a discrete, qualitative indicator of FT product quality for each grid cell within the NHL domain. The QA map shows regions of relative high to low quality in relation to potential negative impacts from sensor data gaps, active precipitation, RFI, open water, terrain and land cover heterogeneity, and uncertainty associated with use of global reanalysis temperature data to define per grid-cell FT reference states for seasonal threshold algorithm (STA) based temporal change classifications. The QA based regressions accounted for ~44% of variability in FT classification accuracy inferred from the regional weather station network. The dimensionless (0 to 1) QA values were stratified into a smaller set of discrete categories ranging from low (estimated mean spatial classification accuracy < 70 %) to best (accuracy > 90%) quality. Mean proportions of the four QA categories encompass 30.6 % (best), 59.5 % (good), 9.2 % (moderate), and 0.7 % (low) of the NHL domain.

## Results:

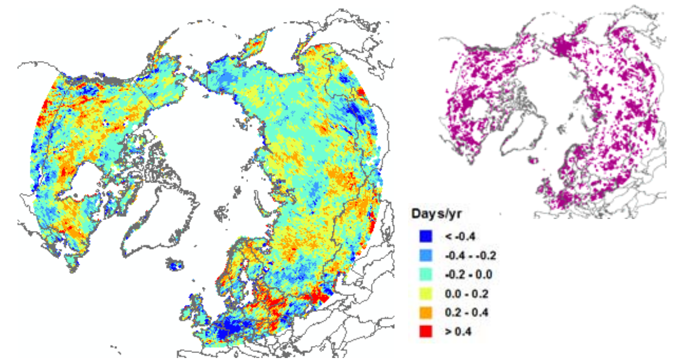
### Regional Kendall's tau trend patterns (day yr$^{-1}$) and associated significant (p<0.1; in purple on adjacent inset map) trend areas derived from the 32-year FT record (1979-2010) for frozen (FR) and transitional (TR) records from Jan to Aug (JaAu) :

**FR (JaAu) frozen season trend (-2.8 days decade$^{-1}$; p<0.01)**




The satellite FT results show a strong, negative (decreasing FR season) NHL trend in mean annual frozen period (-2.8 days decade$^{-1}$; p<0.01). The annual frozen season (JaAu) is decreasing for 83.9% of the NHL domain. The relative proportions of cells with significant (p<0.1) frozen season trends is 52.1%.

**TR (JaAu): frost days trend (0.09 days decade$^{-1}$)**

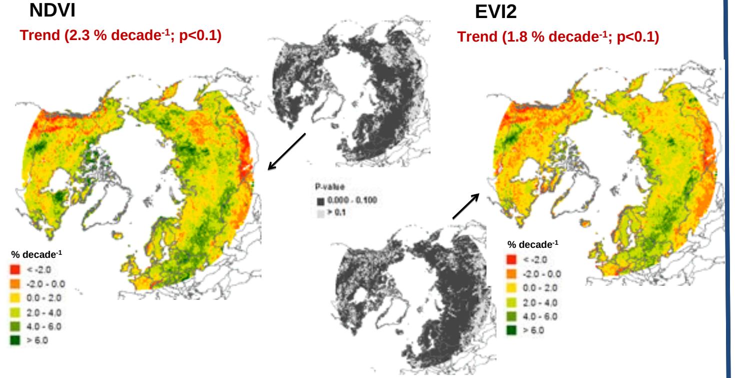



The satellite FT results show a weak (p>0.1) positive NHL trend in mean annual number of transitional (AM frozen and PM thaw) frost days. The number of frost days is increasing for 44.8% of the NHL domain. The relative proportions of cells with significant (p<0.1) TR trends is 17.3%.

### Regional Kendall's tau VI trends (% decade$^{-1}$) and associated significant (p<0.1) trend areas derived from the 29-year summer VI (Jun to Aug; JJA) records (1982-2010):

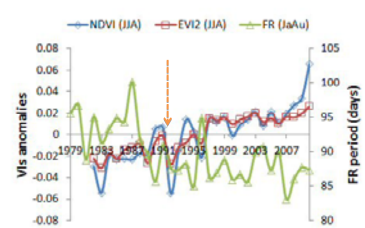
**NDVI** — Trend (2.3 % decade$^{-1}$; p<0.1)

**EVI2** — Trend (1.8 % decade$^{-1}$; p<0.1)



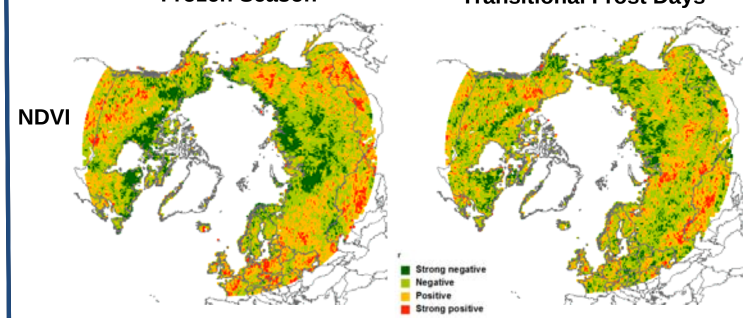

Mean summer (JJA) NDVI and EVI2 trends show strong, positive NHL decadal trends (p<0.1). Summer NDVI (EVI2) values are increasing for 87.3% (83.1%) of the NHL domain. The NHL FT metrics show generally stronger and predominantly positive VI impacts on spring rather than summer growth conditions; however, these relationships may be influenced by other artifacts independent of canopy growth changes, including snow effects on VI retrieval accuracy.

### Mean annual NHL VI and FR (JaAu) season variability:



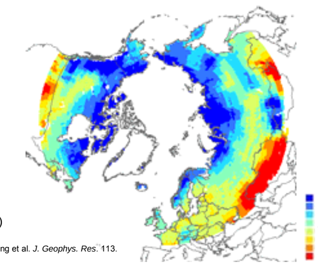

Mean annual summer NDVI/EVI2 and FR (JaAu) season records for the NHL domain (**left**). The VIs anomalies are determined relative to their long-term means. Weak correspondence between the VIs and FR season variability reflects opposing FR impacts on vegetation growth between energy and water constrained portions of the domain. The Jun 1991 Mt. Pinatubo eruption is also denoted (vertical dashed arrow).

### Pixel-wise correlations (r) between frozen and transitional seasons (JaAu), and VI summer growth anomalies :



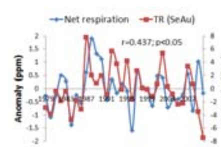

The spatial correlation pattern between summer NDVI & FR/TR season (JaAu) anomalies (**above**) shows generally negative correspondence in predominantly cold constrained NHL regions, and reduced or reversed correspondence in more water limited areas (**right**); the relative climate constraints to productivity (NPP) are derived using temperature and moisture constraint [4]factors determined from global reanalysis data. Regional increases in TR (JaAu) frost days negatively impact NDVI summer growth for ~61% of the NHL domain; decreases in the number of FR (JaAu) days promotes greater summer NDVI growth for ~57 % of the domain. The EVI2 result is largely consistent with NDVI (not shown). The satellite VI records indicate a general increase in NHL vegetation productivity that corresponds with decreasing FT-ESDR defined frozen season trends; however, positive trends in TR frost days in some areas appear to negatively impact canopy growth. Four r-value categories are classified by their significance level above, including strong negative (p≤0.1), negative (p>0.1), positive (p>0.1) and strong positive (p≤0.1) levels.

**Temperature & Water constraints to NPP**




[4]Zhang et al. *J. Geophys. Res.* 113.

### Frozen season influence on NHL atmospheric $CO_2$ seasonal cycle:




The satellite microwave derived TR ($T_{TR}$; day yr$^{-1}$) season (Sep to Aug; SeAu) anomalies coincide with net ecosystem respiration ($T_{CO2}$ ; ppm yr$^{-1}$) defined as the difference between annual maximum and minimum atmospheric $CO_2$ concentrations from northern NOAA ESRL Globalview monitoring sites (**left**). Positive correspondence between $T_{TR}$ and $T_{CO2}$ (r=0.437, p<0.05) indicate adverse impacts of frost events on net ecosystem respiration, though soil frost events may benefit productivity in some ecoregions; negative correspondence between frozen season anomalies ($T_{FR}$; day yr$^{-1}$) and $T_{CO2}$ (r=-0.402, p<0.05; not shown) indicate that shorter FR seasons increase the $CO_2$ max-min concentration anomaly by either increasing ecosystem respiration (increasing $CO_2$ max) or enhancing ecosystem productivity (decreasing $CO_2$ min), or both within the NHL domain.

## Conclusions:

- The 32-yr (1979-2010) FT-ESDR record shows mean annual classification accuracies of 91 (±1.1) and 84 (± 0.9) percent for PM & AM overpass retrievals relative to in situ weather station records;
- The FT record shows that the FR season is significantly decreasing for 50.2% of the NHL domain and 1979-2010 period;
- The NDVI and EVI2 trends indicate that NHL vegetation is predominantly greening & coincident with a declining FR season;
- A declining FR season is generally promoting vegetation growth in NHL cold temperature constrained areas, while these effects are weaker or reversed in more water constrained areas; potential benefits of a shorter FR season are offset by apparent negative productivity effects of an increasing trend in TR frost days in some areas.
- Annual variability in FT processes has a signficant impact of atmospheric $CO_2$ seasonality; years with more (fewer) TR frost days or shorter (longer) FR season coincide with larger (smaller) seasonal amplitude in atmospheric $CO_2$ concentrations.

## Acknowledgements

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## References

1. Kim, Y., J.S. Kimball, K.C. McDonald & J. Glassy, 2011. Developing a Global Data Record of Daily Landscape Freeze/Thaw Status using Satellite Passive Microwave Remote Sensing. *TGARS*. 49 (3), 949-960.
2. Kim, Y., J.S. Kimball, K. Zhang, & K.C. McDonald, 2012. Satellite Detection of Increasing Northern Hemisphere Non-Frozen Seasons from 1979 to 2008 and Associated Impacts to Vegetation Growth and Carbon Exchange. *Rem. Sens. Environ*, 121, 472-487.
3. Kim, Y. J.S. Kimball, K. Zhang, K. Didan, & K.C. McDonald, 2013. Responses of northern high latitude vegetation growth to non-frozen season and drought variability (*to be submitted*)
4. Zhang, K., J.S. Kimball, E.H. Hogg, M. Zhao, W.C. Oechel, J.J. Cassano and S.W. Running, 2008. Satellite-based model detection of recent climate driven changes in northern high latitude vegetation productivity. *J. Geophys. Res.* 113, G03033.