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Documenting recent northern hemisphere trends in annual freeze-thaw cycles over land using satellite passive microwave remote sensing

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Approximately 66 million km2 (52.5 %) of the global vegetated land area experiences seasonally frozen temperatures that constrain ecosystem processes. The landscape freeze-thaw (FT) signal from satellite microwave remote sensing is closely linked to surface energy and hydrological activity, vegetation phenology and terrestrial carbon budgets. We utilized a seasonal threshold algorithm based temporal change classification of 37V GHz brightness temperatures (Tb) from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) pathfinder and Special Sensor Microwave Imager (SSM/I) to classify daily FT status for all global land areas where seasonal frozen temperatures are a major constraint to plant growth. A temporally consistent, long-term (30 year) FT record was created by pixel-wise adjustment of the SMMR Tb record based on empirical analyses of overlapping SMMR and SSM/I measurements. The resulting FT record shows mean annual spatial classification accuracies above 84 percent relative to air temperature measurements from the global weather station network. The FT results were also compared against other measures of biosphere activity including satellite vegetation greenness (NDVI) and tower measurements. A strong ($P<0.001$) increasing (0.189 days yr-1) trend in the mean Northern Hemisphere thaw season coincides with a 0.033 deg C yr-1 mean warming trend. The FT defined thaw season largely bounds the active vegetation growing season and net ecosystem carbon uptake period, while the positive effect of a lengthening thaw season on vegetation greening is more widespread at higher (>45 N) latitudes and elevations. The FT record also shows a positive (0.199 days yr-1) trend in the number of transitional (AM frozen and PM non-frozen) frost days, which coincide with reduced productivity. The relative benefits of a lengthening thaw season for vegetation growth under global warming may be declining due to opposing increases in disturbance, drought and frost damage related impacts.