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Satellite detection of Northern Hemisphere Non-Frozen season changes and associated impacts to vegetation growing seasons

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Introduction:
Approximately 68 million km² (52 %) of the global vegetated land area experiences seasonally frozen temperatures as a major constraint to ecosystem processes. The freeze/thaw (FT) status of the landscape as derived from satellite microwave remote sensing is closely linked to surface energy budget and hydrological activity, vegetation phenology, terrestrial carbon budgets and land-atmosphere trace gas exchange. We applied a temporal change classification of 37 GHz brightness temperature (Tb) series from the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) to classify daily FT status over global land areas where seasonal transition temperatures influence ecosystem processes. A temporally consistent, long-term (>30 year) FT record was created ensuring cross-sensor consistency through proximate time periods and changing sensor footprints. The resulting record was used in empirical primary overlapping SMMR and SSM/I measurements. The resulting combined FT record was validated against in-situ temperature measurements from the global weather station network and applied to quantify regional patterns and trends in timing and length of non-frozen seasons. The FT results were also compared against other measures of biophysical activity including satellite (MODIS) vegetation greenness (NDVI), tower CO2 flux measurements and NOAA ESRL atmospheric CO2 measurements (>45°N).

Data and Methods:
Primary datasets employed in the investigation:
(1) NASA SMMR S1 Data and ASCII (daily, Tm, dates: 1978-1986, 37GHz, V-pol);
(2) DSSM SSM/I ascending/descending orbit, daily Tb series: 1987-2008, 37GHz, V-pol;
(3) MODIS Terra NDVI record: 2000-2008, 25 x 25 km global EASE-Grid;
(4) NOAA ESRL Globalview: Integration of atmospheric CO2 concentration data;
(5) FLUXNET daily C-flux data: Net ecosystem CO2 exchange (NEE), Gross Primary Production (GPP)

Ancillary data for masking and quality assessment:
(K) Global land cover maps (IGBP, 2000-2001), EASE grid resolution (36 x 36 km)

FT links to C-flux and NDVI patterns at FLUXNET sites:
The daily FT results were evaluated in relation to satellite (MODIS) 16-day composited NDVI records and in situ tower daily ecosystem CO2 exchange datasets collected in the V Net ecosystem CO2 exchange (NEE), Gross Primary Production (GPP) GeoCover Globalview of atmospheric CO2 concentration data

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A correlation (r) map between coincident SMMR & SSM/I 37GHz Tb series and coincident global model reanalysis (GMAO) based surface air temperatures on a grid cell-basis. The SSMR Tb series was adjusted to the SSM/I Tb series using a dynamic threshold defined as the mean of the SMMR Tb series and a quality factor (QC) SMMR & SSM/I Tb values during the overlap period (0.39 and RMSE = 3.2 K). The FT classification accuracy is assessed using in situ daily air temperatures from global WMO weather stations. The stations are pre-screened for homogenous land cover & terrain conditions with the overlying 25 km grid cell. The resulting classification accuracy (91 %) was validated against 3.701 validation sites selected in 2008 (above right). The annual FT classification accuracies of 91 (±1.0) & 84 (±0.9) % were determined for PM (AM & PM) overpass retrievals relative to in situ station records for the 30-year FT record (above left). Increasing FT accuracy trends are artifacts of global warming, while normalizing the trends relative to the mean global temperature trend shows no significant FT accuracy difference between SMMR & SSM/I portions of record.

Mean annual FT accuracy (%) relative to in situ station data

The landscape FT status was classified from daily (AM & PM) retrievals from SMMR & SSM/I time series using a seasonal threshold algorithm (STA). The STA uses a dynamic threshold defined annually on a grid cell basis from empirical relations established between Tm retrievals & global model temperature anomalies (Tm) based on air temperatures (e.g. NNR) above right). The above maps show examples of (i) threshold [Tm] maps derived using SSM/I 37GHz (PM & AM) & SSMR Tm (PM & AM) overpass & (ii) in-situ station records. The STA based FT results are daily time series of thawed (AM & PM), Non-Frozen (AM & PM), Frozen (AM & PM), and Inverse-Transitional (AM & PM) frozen conditions.

FT accuracy assessment using global weather stations:
 FT accuracy assessment is assessed using in situ daily air temperatures from global WHO weather stations. The stations are pre-screened for homogenous land cover & terrain conditions with the overlying 25 km grid cell. The resulting classification accuracy (91 %) was validated against 3.701 validation sites selected in 2008 (above right). The annual FT classification accuracies of 91 (±1.0) & 84 (±0.9) % were determined for PM (AM & PM) overpass retrievals relative to in situ station records for the 30-year FT record (above left). Increasing FT accuracy trends are artifacts of global warming, while normalizing the trends relative to the mean global temperature trend shows no significant FT accuracy difference between SMMR & SSM/I portions of record.

The Northern Hemisphere NDVI & FT transitional season correlation (r) map for the 2000-2008 period is shown above right. The FT transitional season anomalies show widespread negative correlations of 0.50 for the 1987-1997 non-frozen season and +0.60 for the Northern Hemisphere domain, indicating possible negative impacts of these events on vegetation growth.

NDVI productivity and Transitional period:
Northern Hemisphere NDVI & FT transitional season correlation (r) map for the 2000-2008 period is shown above right. The FT transitional season anomalies show widespread negative correlations of 0.50 for the 1987-1997 non-frozen season and +0.60 for the Northern Hemisphere domain, indicating possible negative impacts of these events on vegetation growth.

Conclusions:
The merged satellite microwave (SMMR-SSM/I) 30-yr (1979-2008) FT record shows mean annual classification accuracies of 91 (±1.0) and 84 (± 0.9) percent for PM & AM overpass retrievals relative to in situ weather station records; earlier & longer non-frozen seasons are promoting widespread NDVI summer growth anomalies and enhancing atmosphere carbon sequestration at higher latitudes; the relative growth benefits of earlier/non-frozen seasons may be watering due to declining cold temperature constraints, increasing local temperature and precipitation. The multivariate ENSO index (MEI) seasonal index for winter is shown as a vertical red & blue shading indicating respective positive (C) and negative (N) MEI values. The June 1998 El Nino/Southern oscillation event is also denoted by a (vertical dashed line).

Acknowledgements:
Portions of this work were conducted at the University of Montana and Jet Propulsion Laboratory, California Institute of Technology under contract to NASA. This work was supported under the NASA Making Earth Science Data Records for Use in Research Environments (MEASURE) program (HSD0200620, HSD0300151).

References:
2NCEP/DOE (NCEP2, 1979-2008) 6-hour reanalysis (1.875º x 2º);
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FT accuracy assessment using global weather stations:

Conclusions:
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