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Improvements and Extension to a Global Earth System Data Record of Daily Landscape Freeze-Thaw Status Determined from Satellite Microwave Remote Sensing

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Abstract:
A global satellite microwave Earth System Data Record of daily landscape freeze-thaw status (FT-ESDR) has been developed to provide new understanding of freeze-thaw cycling in the Earth’s surface environment. The new FT-ESDR data is derived using 35 year reference states from the NASA SURFRAD, the CSU HyMap, and the University of Montana FT-GLOBE satellite footprint. The FT-ESDR includes a suite of daily, monthly and annual FT products and has been validated against ground stations, snow products, and lake ice breakup date. The FT-ESDR provides the first global consistent daily FT product and is expected to provide valuable data for ecologists, hydrologists, and climatologists.

Sensitivity of FT accuracy to reference states:
- FT data derived using reference states from same alternate sources: Multichannel Microwave Radiometer (SURFRAD) and Special Sensor Microwave Imager (GLOBE) were integrated to produce a temporally consistent and continuous global FT data product from 1979 to 2013, and derived at 25 km pixel resolution. In this study, we evaluate and found FT-ESDR enhancements, including expanded reference length and spatial coverage, alternative algorithm calibrations and a finer scale FT classification. A large global domain is evaluated on the basis of more than 70 years of freeze-thaw state data, including snow, ice, barren, and permafrost landscapes. The FT-ESDR is determined using a stochastic hidden Markov model driven by satellite-derived Microwave Radiometer (SURFRAD) and Special Sensor Microwave Imager (GLOBE) FT data. The FT-ESDR is calculated and compared with FT data derived using 35 year reference states provided by NASA SURFRAD, the CSU HyMap, and University of Montana FT-GLOBE satellite footprint. The FT-ESDR shows an improvement of ~12% in the accuracy of FT reference states on a per-pixel basis. STA sensitivity to FT reference states is evaluated and alternative ancillary data sources are applied. STA FT data derived using independent FT reference states shows best performance.

FT accuracy assessment:
- Mean annual FT accuracy for 2012: The FT-ESDR shows a mean annual spatial classification accuracy of 93% and 87% for PM and AM periods which is 5% better than the previous FT product (Kim et al., 2013). The FT-ESDR shows a ~13% percent spatial classification accuracy improvement over previous technology and across different regions. Areas with vegetation include Canada, Russia, and North and Central Europe. Sub-grid scale and per-pixel spatial accuracy are determined for the FT-ESDR using a stochastic hidden Markov model driven by satellite-derived Microwave Radiometer (SURFRAD) and Special Sensor Microwave Imager (GLOBE) FT data. The FT-ESDR shows an improvement of ~12% in the accuracy of FT reference states on a per-pixel basis. STA sensitivity to FT reference states is evaluated and alternative ancillary data sources are applied. STA FT data derived using independent FT reference states shows best performance.

Ground and Lake surface melt season:
- Mean annual FT accuracy for 2001: The FT-ESDR shows a mean annual spatial classification accuracy of 92% (±1.3%) for PM and 86% (±1.2%) for AM. The FT-ESDR uses a stochastic hidden Markov model driven by satellite-derived Microwave Radiometer (SURFRAD) and Special Sensor Microwave Imager (GLOBE) FT data. The FT-ESDR shows an improvement of ~12% in the accuracy of FT reference states on a per-pixel basis. STA sensitivity to FT reference states is evaluated and alternative ancillary data sources are applied. STA FT data derived using independent FT reference states shows best performance.

Conclusions:
- New FT-ESDR product with expanded global domain, longer record and 1-3% improved spatial classification accuracy over previous FT product.
- Favorable FT classification accuracy over non-vegetated areas (mean annual spatial accuracy from 62-79%).
- Lower FT accuracy with larger fractional open water cover; greater DEM heterogeneity, and during seasonal FT transitions.
- General FT-ESDR consistent with other cryosphere data FT senitivity to lake area and river ice seasonality; similar FT season and snowmelt cycles over Greenland; realistic FT patterns over Antarctica.
- These results are being used for continuing NASA MEASUREs FT-ESDR product enhancements and, to inform development of similar FT algorithms and products from the NASA SMAP mission.
- FT-ESDR available online through the NASA NSIDC/DAAC: http://nsidc.org/data/nsidc-0477.html

References

FT metrics comparison against independent Cryospheric data:
- FT-ESDR shows a mean annual non-frozen (NF) season (1979-2013) of 40.6 ± 3.2% (Spatial-S2%) days over Greenland, with longer NF season but lower FT quality (QA) along coasts resulting from open water contamination (a); NF season and MEASUREs Greenland Surface Melt record shows a similar seasonal climatology, with NF conditions preceding surface melt (b); SH distant reaches display 2-3% wider range around the NF season mean (multi-annual FT season range is 50-60% from the mean); FT-ESDR mean annual non-frozen season over lower open water contaminated cells (open water fraction < 5%) in the Greenland. The FT-ESDR shows a mean annual NF season (1979-2011) of 41.75±0.8 days over Antarctica, with longer NF season for west Antarctica glacier, and coastal areas (d). FT-ESDR accuracy vs mean daily FT retrieved from different land cover classes ranges from 80% (for snow/ice areas to 97% for bar grid density non-Frozen-T on per grid validation in each class, while vertical bare onsite one square km. Delta. Dev range around the accuracy mean.

Data and Methods:
Satellite microwave T0 observations:
- Ancillary data for FT-ESDR calibration and validation:
  - NNR reanalysis: 1979-2012, 1.3°×1.3° resolution, 2 daily max/min air temperatures.
  - ERA-Interim reanalysis: 1979-2013, 0.25°×0.25° resolution, 2 daily max/min air temperatures.
  - NCEP: 1979-2013, daily summary of the day from WMO weather stations.
  - Historical Arctic and Antarctic Surface Observation Data: 2001, daily surface air temperatures.

Ancillary data for mapping as quality assessment:
- MDC1C1: 2001-2012, CMS (5.6 km), 17 class ISDIP (Fried et al. 2010).
- QGLOBE: Digital elevation model (GLOBE 1999).

FT algorithms: Seasonal Threshold Approach (STA)
- A modified single T0 reference state STA algorithm was applied for anomalous areas where the annual T0 frozen season reference state existed (Kim et al. 2014a, b).

FT classification accuracy (%): 
- where n = cell × day and T0 = mean state reference

Global FT-ESDR domain:
The FT-ESDR coverage (QA map) includes a suite of daily, monthly and annual FT products. The QA map shows regions of high quality in low quality in order to pull negative impacts from open water fraction, terrain heterogeneity, transition FT duration, and correlation between ERA-Interim reanalysis temperature data. The FT-ESDR is calculated and compared with FT data derived using 35 year reference states provided by NASA SURFRAD, the CSU HyMap, and University of Montana FT-GLOBE satellite footprint. The FT-ESDR shows an improvement of ~12% in the accuracy of FT reference states on a per-pixel basis. STA sensitivity to FT reference states is evaluated and alternative ancillary data sources are applied. STA FT data derived using independent FT reference states shows best performance.