A Global Data Record of Daily Landscape Freeze/Thaw status
Version 2.0

Contact Information:

Youngwook Kim, John S. Kimball and Joseph Glassy

Numerical Terradynamic Simulation Group (NTSG)

The University of Montana

Missoula MT, 59812

Email: john.kimball@umontana.edu; youngwook.kim@umontana.edu; joe.glassy@ntsg.umt.edu

Project URL: http://freezethaw.ntsg.umt.edu/

Release date: 7/1/2012

The following references can be used to cite these data:

Kim, Y., J.S. Kimball, J. Glassy and K.C. McDonald, 2012. MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 02 [1979 to 2010]. Boulder Colorado USA: National Snow and Ice Data Center. Digital media (http://nsidc.org/data/nsidc-0477.html).

Kim, Y., J.S. Kimball, K. Zhang, and K.C. McDonald, 2012. Satellite detection of increasing Northern Hemisphere non-frozen seasons from 1979 to 2008: Implications for regional vegetation growth. *Remote Sensing of Environment*, 121, 472-487.

Acknowledgements:

These data were generated through a grant from the NASA MEaSUREs program. Portions of this work were conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

Contents:

I. Data Description:

This document describes a global data record of daily landscape Freeze/Thaw (FT) status derived from satellite microwave remote sensing. The FT state parameter derived from satellite microwave remote sensing quantifies the predominant frozen or non-frozen state of the landscape and is closely linked to surface energy budget and hydrologic activity, seasonal dynamics of vegetation growth, terrestrial carbon budgets and land-atmosphere trace gas exchange. Satellite microwave remote sensing is well suited for global FT monitoring due to its relative insensitivity to atmospheric contamination, its independence from solar illumination, and its strong sensitivity to changes in landscape dielectric properties between frozen and thawed conditions. The current FT earth system data record (FT-ESDR) is derived using daily radiometric brightness temperature (T_b) measurement time series at 37GHz (V-pol) frequency from the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave Imager (SSM/I). The resulting FT-ESDR represents a consistent, daily FT global record that extends from 1979 to 2010, ensuring cross-sensor consistency through pixel-wise adjustment of the SMMR T_b record based on empirical analyses of overlapping SMMR and SSM/I measurements (Kim et al. 2012). These data represent product release Version 2.0, which effectively replaces an earlier (Version 1.1) product release. Changes from Version 1.1 to 2.0 include a longer FT record (1979 to 2010); use of a modified single T_b reference state STA algorithm for anomalous dry soil areas; inclusion of both combined SMMR-SSM/I and AMSR-E

based FT data records; revised data quality (QA) annual maps; updated product format options (GeoTIFF) with projection file information, and quick-look image formats (GIF).

The FT-ESDR records are intended for quantifying FT state dynamics over vegetated land areas within a global domain where seasonally frozen temperatures are a major constraint to ecological processes. A detailed description of the FT-ESDR product, methods development and validation scheme is provided by Kim et al. (2011, 2012). This is a Stage II data release and will be periodically updated to reflect potential algorithm changes and additional years of record. The current (version 2.0) data release effectively replaces the initial Stage I (version 1.1) FT-ESDR record. The Stage II release encompasses a longer (from 1979) data record enabled by overlapping SMMR and SSM/I time series, and includes further refinement of the FT classification routines and data quality assessment (QA) protocols; the Stage II data release also includes additional file format options (e.g. HDF5 and GeoTIFF) and file conversion software (HDFview and Panoply) designed to enhance data usability. In addition, this Stage II data release includes an additional Freeze/Thaw data record derived from 36V GHz daily (1:30 AM/PM equatorial crossing) T_b records from the NASA Aqua AMSR-E (Advanced Microwave Scanning Radiometer for EOS) sensor record, for years 2002-2011 inclusive, whose formats follow those of the SMMR and SMMI derived FT products. The FT-ESDR data are available for public access via FTP download through the FT-ESDR project web site (http://freezethaw.ntsg.umt.edu) and through the NASA National Snow and Ice Data Center (NSIDC) DAAC (Kim et al. 2012); these data include HDF5 v.1.8.x file formats and searchable metadata.

A related FT classification record is included with the NASA AMSR-E global land parameter database (Jones and Kimball 2010). The FT parameter record from these data is consistent with the FT-ESDR methodology, but was derived using 36V GHz daily T_b data from the 10-year (from 2002 to 2011) AMSR-E operational record.

The FT-ESDR is intended to have sufficient accuracy, resolution, and coverage to resolve physical processes linking Earth's water, energy and carbon cycles. The product is designed to determine the FT status of the composite landscape vegetation-snow-soil medium to a sufficient level to characterize the frozen temperature constraints to surface water mobility, vegetation

productivity, ecosystem respiration and land-atmosphere CO_2 fluxes. The FT-ESDR involves a daily binary FT state classification on a grid cell-by-cell basis, posted to a regular Earth grid. The FT classification algorithm uses a temporal change detection of radiometric T_b time-series that identify FT transition sequences by exploiting the dynamic temporal T_b response to differences in the aggregate landscape dielectric constant that occur as the landscape transitions between predominantly frozen and nonfrozen conditions (McDonald and Kimball 2005). Satellite ascending and descending orbital data time series are processed separately to produce information on AM, PM and composite daily FT conditions (CO). Additional variables distinguished by the FT-ESDR include transitional (AM frozen and PM thawed) or inverse transitional (AM thawed and PM frozen) conditions. The global FT-ESDR domain encompasses unmasked vegetated land areas where low temperatures are a significant constraint to annual vegetation productivity as defined from climatological reanalysis data. Masked areas include permanent ice and snow, barren land, open water and regions unconstrained by freezing temperatures. The FT-ESDR map projection is defined in terms of a global cylindrical Equal-Area Scalable Earth (EASE) grid (Brodzik and Armstrong 2002).

The stage II FT-ESDR release is developed by merging the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) 37 GHz frequency (vertical [V] polarization) T_b records, and applying the same algorithms and protocols used to construct the earlier stage I FT-ESDR product (Kim et el. 2010, 2011). The stage II FT-ESDR record extends from 1979 to 2010 and encompasses large climate variations and longer-term trends in terrestrial FT cycles, which have been verified against global weather station records and other biophysical data including satellite vegetation greenness and tower CO2 flux measurement networks (Kim et al. 2012). The FT-ESDR product accuracy was assessed in relation to daily maximum (T_{mx}) and minimum (T_{mn}) air temperature measurements from the global WMO weather station network (3207±427 [temporal-SD]); mean annual FT spatial classification accuracies were 91.4 ±1.05 [inter-annual SD] and 84.2 ±0.92 [inter-annual SD] percent for respective FT-ESDR PM and AM retrievals over the global domain and long-term record. The FT classification accuracy shows strong seasonal and annual variability and is reduced during active FT transition periods when spatial heterogeneity in landscape FT processes is maximized in relation to the relatively coarse (~25-km) satellite footprint. Additional data

quality (QA/QC) metrics were developed and provide more spatially explicit accuracy information, including potential negative impacts of temporal gaps in sensor data time series, precipitation, open water, terrain and land cover heterogeneity effects, and uncertainty associated with use of global reanalysis temperature data to define per grid-cell frozen and non-frozen reference state thresholds for the seasonal threshold algorithm (STA) based FT classifications. The resulting database provides a consistent and continuous, multi-year (1979 onward) record of daily (AM and PM) FT dynamics for the global biosphere. The QA maps represent a discrete measure of relative data quality ranging from low (estimated spatial classification accuracy <70%) to best (accuracy > 90%) quality categories.

This FT-ESDR delivery consists of the following component data directories as documented in the table below:

FT_ESDR Directory Layout Summary of FTP Site	
Directory	Summary of Contents
DAILY_BINARY	32-year record of global daily FT status in binary file format
DAILY_HDF5	32-year record of global daily FT status in HDF5 file format
DAILY_GEOTIFF	32-year record of global daily FT status in GeoTIFF file format. An ESRI projection (.prj) file for viewing data in ArcMap is included at the top of the directory.
DAILY_GIF	32-year record of global daily browse images (GIF format) for quick visual evaluation
QA_ACCURACY	Daily FT-ESDR mean global classification accuracy (%) and annual QA metadata in a variety of file formats
TAR_ARCHIVES	Compressed (tarfile and gnuzip) FT gridded (global EASE-grid) data files in a variety of file formats, /DAILY_TAR_ARCHIVES, /DAILY_HDF5_ARCHIVES and /DAILY_TIFF_ARCHIVES
MD5	MD5 checksum hash signatures for each F/T file in the collection
DOCS	FT-ESDR database documentation files
TOOLS	File viewing software, including Panoply (v3.1.5) and HDFView (v2.8) for HDF5 (on MacOS,windows, Linux platforms)

Note that within a given directory tree such as DAILY_BINARY, there are two sub-trees ("AMSRE", and "SMMR_SSMI", with a series of year-wise directories e.g. 2002-2011) below each of these.

II. FT algorithms:

The FT classification algorithm involves a seasonal threshold approach with radiometric brightness temperature (T_b) time-series that identify FT transition sequences by exploiting the dynamic T_b temporal response to differences in the aggregate landscape dielectric constant that occur as the landscape transitions between predominantly frozen and nonfrozen conditions. These techniques are well-suited for resolving daily FT state dynamics rather than single events or seasonally dominant transitions (Kim et al. 2011). The Stage II product applied a modified single T_b reference state STA algorithm for anomalous areas where the annual T_b frozen reference state exceeded the T_b non-frozen reference state; these areas are assigned a low QA value and represent less than 1% of the FT-ESDR domain. These areas include portions of northern Africa, Ethiopia and central Mexico, and generally encompass dry climate areas where other environmental factors, including seasonal wetting events, result in large T_b changes similar to FT transitions. The alternative single STA reference state FT classification was found to markedly improve FT-ESDR classification accuracy for these areas, even though these areas were still assigned a low QA value.

III. Ancillary data for FT-ESDR

We used daily surface air temperature records from global model reanalysis and in situ WMO weather station networks for respective FT algorithm calibration and verification of FT-ESDR accuracy. Global meteorological reanalysis data were used to define the STA FT thresholds and the global FT-ESDR domain; the FT-ESDR domain (Fig. 1) was defined as all vegetated land areas where seasonally frozen air temperatures are a major constraint to ecological processes (Kim et al. 2011).

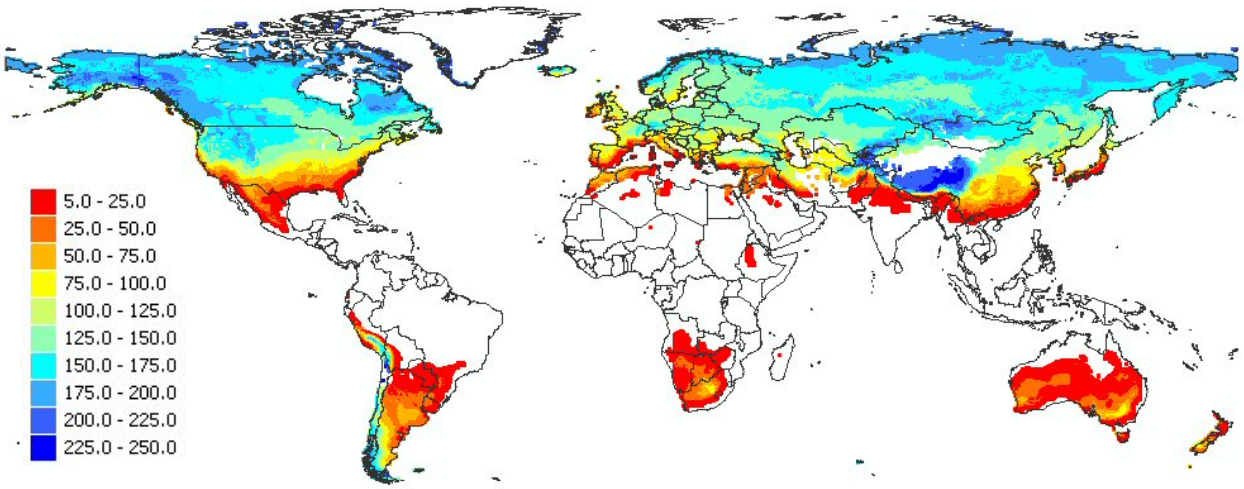

***Figure 1**: The global FT-ESDR domain defined from a Cold Temperature Constraints Index (CCI, days yr^{-1}) and GMAO MERRA (0.5 degree) reanalysis based daily T_{mn} over a 7-year (2000-2006) period; the FT-ESDR domain includes all vegetated land areas where the CCI ≥ 5 days yr^{-1}.*

The QA metrics employed provide an indicator of FT product quality for each grid cell within the FT-ESDR domain (Fig 2). The dynamic QA information includes uncertainty associated with use of reanalysis temperature data to define STA FT thresholds; this metric was defined from the annual pixel-wise standard deviation of classified non-frozen periods derived from four global reanalysis based air temperature records, including NCEP/NCAR, NCEP2, ERA-Interim and MERRA. The dynamic QA information also includes the number of days per year with SMMR and SSM/I T_b data gaps and flagged precipitation events (Ferraro et al., 1996), and the average number of days yr^{-1} with reanalysis air temperatures within $\pm 3^{o}$C of 0.0°C. The static QC information includes the potential effects of fractional open water cover (Fw) defined from the finer scale (1-km resolution) MODIS 17-class IGBP global land cover product (Friedl et al., 2002); the static QC metric also accounts for complex topography (GLOBE, 1999) and heterogeneous land cover conditions defined from the 1-km resolution global land cover classification and DEM.

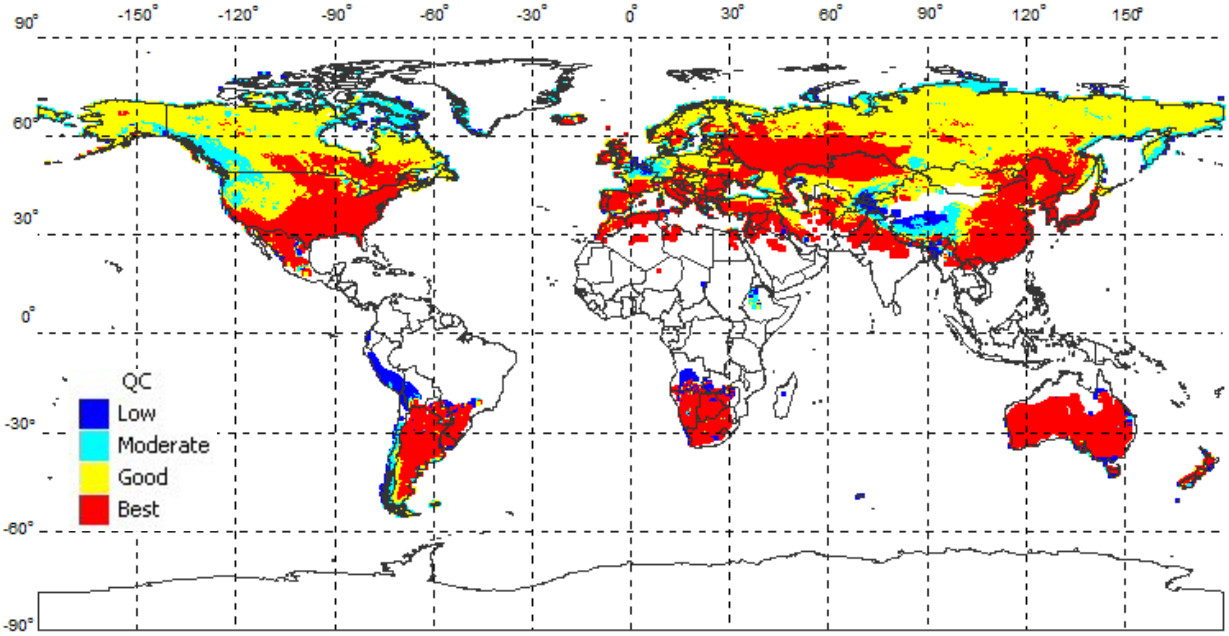

Figure 2*: A FT-ESDR quality assessment (QA) was developed to identify regions of relative high to low quality of F/T classification results in relation to general climate and landscape features; the QA map ranges from relative low (estimated spatial classification accuracy < 70 %) to best (estimated accuracy > 90 %) quality categories; areas in white are outside the FT-ESDR domain.*

IV. Data Format:

Each grid cell is projected in a global EASE-Grid format (Armstrong & Brodzik, 1995; Brodzik and Armstrong 2002) at 25km spatial resolution, with 1383 columns and 586 rows consisting of 8-bit byte data type, for a total of 810438 pixels per daily data product. An ESRI projection file is included with the GEOTIFFs to aid in viewing the data in ArcMap. The geographical range of the FT-ESDR product is global, extending from -179.9999^{o} to 179.9999 ^{o} longitude and from -86.7167^{o} to 86.7167^{o} latitude.

V. File Naming Convention:

Each daily FT product consists of 3 separate files: morning overpass (AM), afternoon overpass (PM) and combined daily AM and PM (CO) classification results. The FT product naming protocol follows these conventions:

[InstrumentLabel]_[Channel][Polarization]_[OverpassCode]_FT_[Year]_day[DOY].bin

For example, the file "SSMI_37V_CO_FT_2007_day365.bin" represents SSM/I sensor, 37 GHz, vertically polarized T_b based FT classification for composite daily conditions for day (calendar year) 365.

The FT data are stored in unsigned 8-bit integer data format as follows:

Classification		Browse Image Color Table		
	FT DN	R	G	B
Frozen (AM/PM frozen)	0	000	000	255
Thawed (AM/PM thawed)	1	255	000	000
Transitional (AM frozen and PM thawed)	2	168	168	000
Inverse Transitional (PM frozen and AM thawed)	3	076	230	000
No FT status available	251	255	255	255
Non-cold constraint area, but unmasked	252	255	255	255
Masked (permanent ice, non-vegetated and urban area)	253	255	255	255
100% open water	254	255	255	255
Fill value	255	255	255	255

VI. Data Organization and Volume:

The daily FT data is organized in this collection first by instrument label, and then by year (1979-2010), with the AM, CO, and PM granules stored in each year directory. Each daily FT dataset is stored in a raw unsigned 8-bit image of 1383 columns and 586 rows in row-major-order (ANSI C style) with no header. In addition to the primary FT data, detailed metadata is also provided that includes a total classification accuracy summary for the FT-ESDR domain on a daily basis, and a spatially contiguous QA/QC relative data quality map on an annual basis. [TBD – update with new volume merics <jmg.>] The FT-ESDR dataset consists of a total of 11688 daily global 25km resolution granules representing 8.8Gb per overpass code (AM, PM, and CO) for a total of 26.6Gb for all 3 FT products and all 32 years. Each year's data volume per

overpass code is approximately 285Mb. For fast downloading, we also provide yearly zipped FT binary files in the “DAILY_TAR_ARCHIVES” directory whose volume is approximately 10.5Mb per year and overpass code.

VII. Example FT Figures:

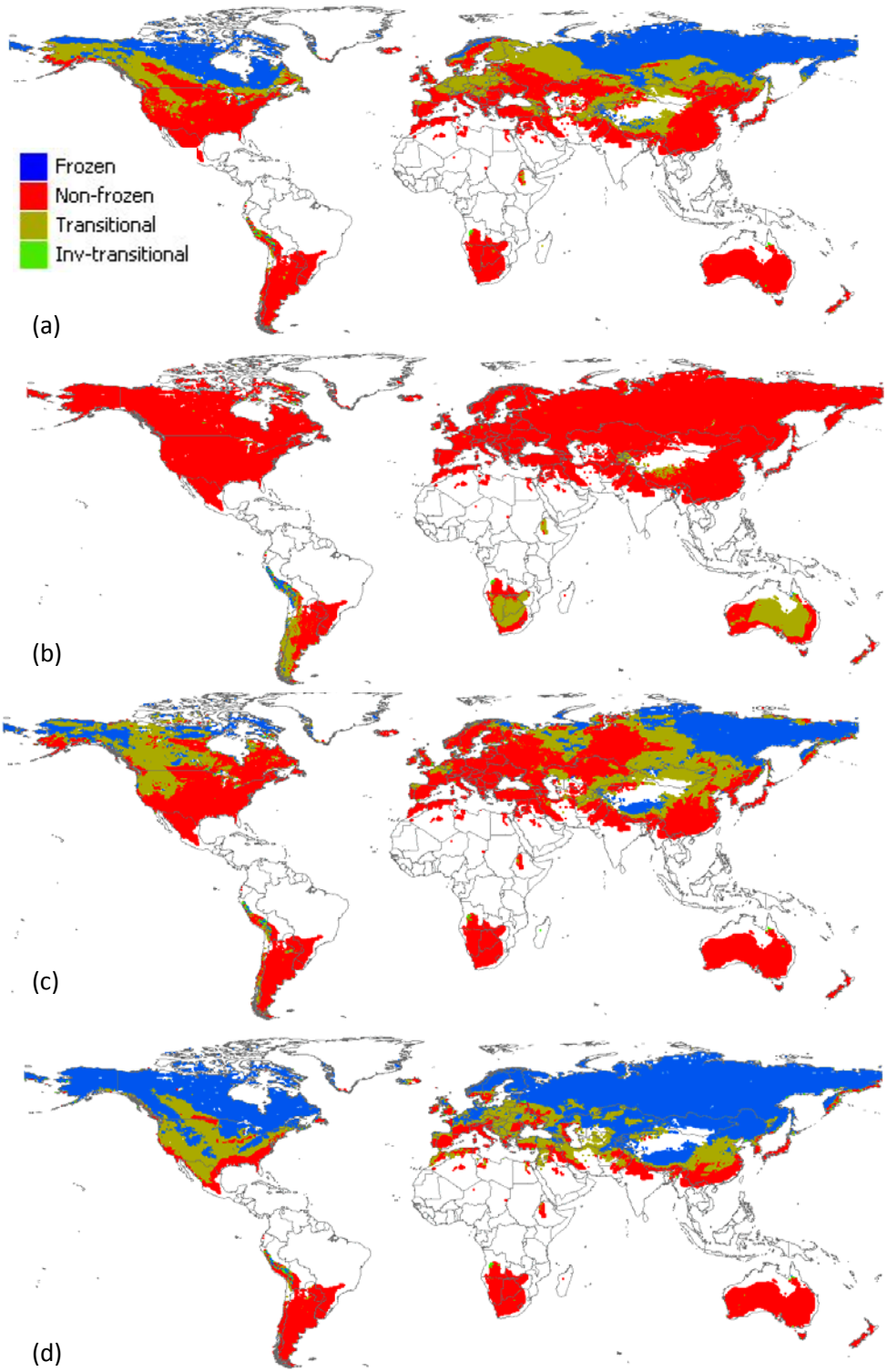

***Figure 3**: Selected daily combined (CO) SSM/I FT classification results for 2004, where: (a) DOY (Day of Year) =100, (b) DOY=200, (c) DOY=300, and (d) DOY=360; areas in white are outside the FT-ESDR domain.*

VIII. References:

Armstrong, R. L. and M. J. Brodzik. 1995. An Earth-Gridded SSM/I Data Set for Cryosphere Studies and Global Change Monitoring. *Advances in Space Research*. 16, 155-163

Brodzik, M. J. and R. L. Armstrong. 2002. EASE-Grid: A versatile set of equal-area projections and grids. In M. Goodchild (Ed.), Discrete Global Girds. Santa Barbara, California USA: National Center for Geographic Information and Anlaysis.

Ferraro, R. R., F. Weng, N. C. Grody, and A. Basist. (1996). An eight-year (1987-1994) time series of rainfall, clouds, water vapor, snow cover, and sea ice derived from SSM/I measurements. *Bulletin of the American Meteorological Society*, 77(5), 891-905

Friedl, M. A., D. K. McIver, J. C. F. Hodges, X. Y. Zhang, D. Muchoney, A. H. Strahler, C. E. Woodcock, S. Gopal, A. Schneider, A. Cooper, A. Baccini, F. Gao, and C. Schaaf (2002). Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment*, 83, 287-302

GLOBE Task Team and others (Hasting, D. A., P. K. Dunbar, G. M. Elphingstone et al.). (1999). The global land one-kilometer base elevation (GLOBE) digital elevation model, version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80305-3328, U.S.A. Digital data base on the World Wide Web (http://www.ngdc.noaa.gov/mgg/toto/globe.html) and CD-ROMs.

Jones, L.A., and J.S. Kimball, 2010. Daily Global Land Surface Parameters Derived from AMSR-E, Version 1.1. Boulder Colorado USA: National Snow and Ice Data Center. Digital media (http://nsidc.org/data/nsidc-0451.html).

Kim, Y., J.S. Kimball, K.C. McDonald and J. Glassy, 2010. MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 1.1 [1988 to 2007]. Boulder Colorado USA: National Snow and Ice Data Center. Digital media (http://nsidc.org/data/nsidc-0477.html).

Kim, Y., J. S. Kimball, K. C. McDonald, and J. Glassy. 2011. Developing a Global Data Record of Daily Landscape Freeze/Thaw Status using Satellite Microwave Remote Sensing. *IEEE Transactions on Geoscience and Remote Sensing.* 49, 3, 949-960.

Kim, Y., J.S. Kimball, K. Zhang, and K.C. McDonald, 2012. Satellite detection of increasing northern hemisphere non-frozen seasons from 1979 to 2008: Implications for regional vegetation growth. *Remote Sensing of Environment* 121, 472-487.

McDonald, K.C, and J.S. Kimball, 2005. Hydrological application of remote sensing: Freeze-thaw states using both active and passive microwave sensors. Encyclopedia of Hydrological Sciences. Part 5. Remote Sensing. M.G. Anderson and J.J. McDonnell (Eds.), John Wiley & Sons Ltd. DOI: 10.1002/0470848944.hsa059a.