Remote Sensing of Environment 176 (2016) 1–16

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

The vegetation greenness trend in Canada and US Alaska from 1984–2012 Landsat data

Junchang Ju [a,b,*], Jeffrey G. Masek [b]

[a] Universities Space Research Association, Columbia, MD 21046, USA
[b] Biospheric Science Laboratory (Code 618), NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

ARTICLE INFO

Article history:
Received 17 September 2015
Received in revised form 23 December 2015
Accepted 6 January 2016
Available online xxxx

Keywords:
Landsat
NDVI
Vegetation greenness trend
Tundra
Boreal forest
AVHRR

ABSTRACT

To assess the North American high-latitude vegetation response to the rising temperature, we derived NDVI trend for 91.2% of the non-water, non-snow land area of Canada and Alaska using the peak-summer Landsat surface reflectance data of 1984–2012. Our analysis indicated that 29.4% and 2.9% of the land area of Canada and Alaska showed statistically significant positive (greening) and negative (browning) trends respectively, at significance level $p < 0.01$, after burned forest areas were masked out. The area with greening trend dominated over that with browning trend for all land cover types. The greening occurred primarily in the tundra of western Alaska, along the north coast of Canada and in northeastern Canada; the most intensive and extensive greening occurred in Quebec and Labrador. The browning occurred mostly in the boreal forests of eastern Alaska. The Landsat-based greenness trend is broadly similar to the 8-km GIMMS AVHRR-based trend for all vegetation zones. However, for tundra, the Landsat data indicated much less extensive greening in Alaska North Slope and much more extensive greening in Quebec and Labrador, and substantially less extensive browning trend in the boreal forests that were free of fire disturbances. These differences call for further validation of the Landsat reflectance and the AVHRR NDVI datasets. Correlation study with local environmental factors, such as topography, glacial history and soil condition, will be needed to understand the heterogeneous greenness change at the Landsat scale.

1. Introduction

High-latitude regions have been warming rapidly since the last century, at a rate higher than the global average (Serreze & Barry, 2011). Warmer temperatures and the resulting local changes in growing season length, soil hydrology, and soil nutrition are expected to alter vegetation productivity, composition, and structure (Stow et al., 2004). At continental scales, satellite data since the 1980s have indicated increased vegetation productivity (greening) across northern high latitudes (Myneni et al., 1997), and a productivity decline (browning) for certain areas of undisturbed boreal forest of Canada and Alaska (Goetz, Bunn, Fiske, & Houghton, 2005). These groundbreaking remote sensing results have been corroborated by in-situ evidence. Repeat aerial photography has revealed shrub expansion in northern Alaska and pan-Arctic since 1950 (Fraser, Lantz, Olthof, Kokelj, & Sims, 2014; Sturm, Racine, & Tape, 2001; Tape, Sturm, & Racine, 2006). Plot-scale biomass measurement at multiple locations in pan-Arctic tundra shows shrub and graminoid growth since 1980s attributable to higher temperatures (Elmendorf, Henry, Walker, Hollister, et al., 2012). In the boreal forest, tree-ring measurements have indicated declining photosynthesis since 1960s, probably due to temperature-induced soil moisture deficit (Barber, Juday, & Finney, 2000; Peng, Ma, Lei, Zhu, et al., 2011).

The most widely used satellite data for large-area, long-term vegetation dynamics research are the Normalized Difference Vegetation Index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRR) sensors, due to the longevity of the record and its routine global coverage. While 1-km AVHRR NDVI datasets based on the Local Area Coverage data are available for some countries (e.g., for Canada, see Pouliot, Latifovic, & Olthof, 2009), global scale AVHRR NDVI datasets have been created from the original 4-km Global Area Coverage (GAC) data, by different research groups, with different approaches to correcting the artifacts in the GAC data; the Global Inventory Modeling and Mapping Studies (GIMMS) NDVI developed at the NASA Goddard Space Flight Center was found most suitable for vegetation dynamic study (Beck et al., 2011). Useful as it is for global scale applications, the coarse pixel size of the AVHRR NDVI data (typically 8 km) does not allow for a direct association of sensor signal with fine-scale local surface conditions such as land cover composition and fire/insect disturbances.

As a complement, Landsat imagery provides a long-term, medium-resolution data record of global land observations, despite less frequent coverage. In particular, the 30-m Landsat data have been available since

* Corresponding author at: Universities Space Research Association, Columbia, MD 21046, USA.
E-mail address: junchang.ju@nasa.gov (J. Ju).

http://dx.doi.org/10.1016/j.rse.2016.01.001
0034-4257/

1982, from Landsat 4–5 (1982–2011), Landsat-7 (1999–present) and Landsat 8 (2012–present). The Landsat spatial resolution is appropriate for studying anthropogenic and natural changes (Townshend & Justice, 1988), and it balances the requirements of fine-scale information and large area coverage (Roy et al., 2008). Landsat data are precisely georeferenced, consistently calibrated and, with a greater number of spectral bands, surface reflectance can be derived more reliably compared to AVHRR. Due to the long 16-day revisit cycle from one Landsat, it is impossible to use Landsat data for seasonal vegetation dynamics study for many parts of the world, although Landsat data from multiple years can be combined to derive an average seasonal phenology (e.g., Melaas, Friedl, & Zhe, 2013). It is, however, feasible to use the long-term Landsat data record to study the interannual variability for a certain season, e.g., during summer time. An increasing number of local investigations have used all the historical 30-m Landsat data, over a few Landsat path/row locations, to study the interannual Arctic vegetation dynamics in North America, e.g., in forest-tundra transition zones in Canada (Olthof et al., 2008), along a forest-tundra transect in Quebec, Canada (McManus et al., 2012), at a few tundra sites around Hudson bay (Fraser, Olthof, Carrière, et al., 2011), in the coastal tundra of western Canada (Fraser, Olthof, Carrière, Deschamps, & Pouliot, 2012), in the boreal forest of Alaska (Baird, Verbyla, & Hollingsworth, 2012), in the tundra of northern foothills of the Alaska Brooks Range (Raynolds, Walker, Verbyla, & Munger, 2013).

Using an approach similar to that used by the aforementioned local studies, this work aims to provide a spatially complete view of the vegetation greenness change for all of Canada and Alaska by calculating per-pixel NDVI trend from all available 1984–2012 peak-summer Landsat-5 and -7 surface reflectance data. By incorporating observations from overlapping scenes, we obtain up to 160 valid NDVI values for certain areas from this 29-year period for establishing the mid-Summer greenness trend. In data preparation, we also found and empirically corrected a minor discrepancy between Landsat-5 and Landsat-7 NDVI. The Landsat-based greenness trend was assessed with respect to land cover type and fire history, and also compared with trend based on the most recent GIMMS AVHRR NDVI dataset, NDVI3g (Pinzon & Tucker, 2014).

2. Data and methods

Our study area consists of all of Canada and Alaska (exclusive of the Aleutian Islands). The land cover type map based on circa-2000 Landsat data is shown in Fig. 1. The land cover type map for the region was assembled from three sources: land cover of northern Canada by Canadian Centre for Remote Sensing (CCRS) (URL1, Northern Canada land cover), land cover of forested area of Canada by Canadian Forest Service (URL2, Canadan forest land cover), and National Land Cover Data of Alaska by the United States USGS (URL3, Alaska land cover). As temperature exerts the primary control of vegetation distribution in this region, vegetation abundance increases generally from north to south. The Canadian Arctic is mostly barren or sparsely vegetated. Graminoid-dominated tundra extends along the northern parts of Alaska, Yukon, Northwest Territories, Manitoba, Ontario, and around the main water body of Hudson Bay to northern Quebec. Further south, tall-shrub-dominated tundra exists as a transitional ecosystem with the boreal forests to its south. Extensive wetlands of graminoids and forests are present south of Hudson Bay between the tundra and forest zones. South of the forest zone is potentially the prairie zone, which was largely converted to farmland during the past few centuries. The tundra and boreal forests dominate the study area and are the land cover experiencing most noticeable change attributable to climate change.

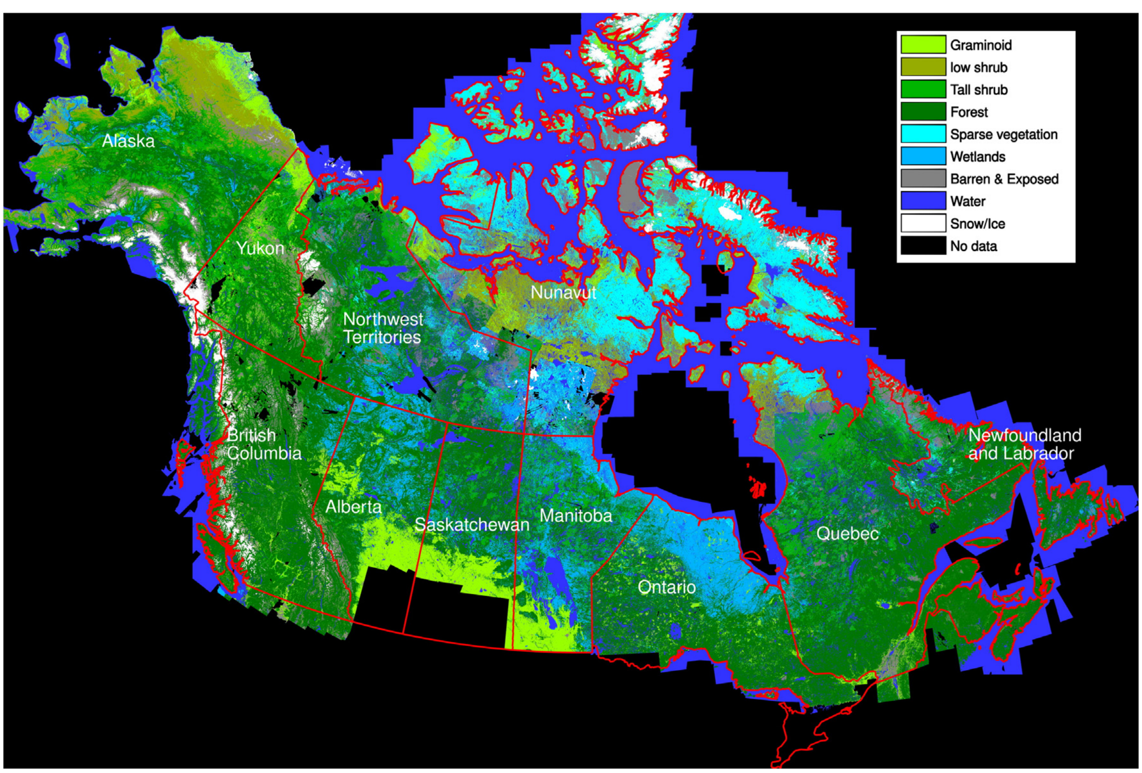

Fig. 1. Land cover type map of Canada and Alaska. This map was created by harmonizing and mosaicking land cover datasets from three sources: the Northern Land Cover of Canada dataset by the Canadian Centre for Remote Sensing, the Earth Observation for Sustainable Development of Forests (EOSD) dataset by the Canadian Forest Service, and the 2001 National Land Cover Dataset (NLCD) for Alaska by USGS. The source land cover maps were all derived from circa 2000 Landsat imagery. The harmonization used a scheme developed by McManus et al. (2012), and the regional maps were reprojected and mosaicked into the Albers equal area conic projection of Canada with central meridian at −96° and standard parallels at 50° and 70°. The land cover type information for the grassland and cropland areas in southern Alberta and Saskatchewan is not available.