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Estimating COCOM Natural Background Dormancy

Alexis L. Coplin and Charles C. Ryerson   April 2015

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Cover photo: *upper left*, verdant deciduous trees, White Mountain Forest, New Hampshire (courtesy of the Natick Soldier Systems Center); *upper right*, thermally-driven dormant deciduous trees, Colorado (courtesy of the Natick Soldier Systems Center); *lower left*, verdant herbaceous cover, Fort Hunter-Liggett, California (courtesy of S. McIntosh, Natick Soldier Systems Center); *lower right*, Moisture-driven dormant herbaceous cover, Fort Hunter-Liggett , California (courtesy S. Shoop, Cold Regions Research and Engineering Laboratory)

Estimating COCOM Natural Background Dormancy

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Final Report

Abstract

Seasonal change, expressed as phenological stage, controls color and tex-
ture of natural vegetation as it cycles through greenup, verdancy, senes-
cence, and dormancy. For the Army Product Manager Soldier Clothing
and Individual Equipment (PM SCIE) Phase IV Camouflage Effort, we
quantitatively estimated the number of days between the onset of dorman-
cy and the onset of greenup in 25 countries over a wide range of climates
and latitudes. Global land cover was lumped into Arid, Transitional, and
Woodland types; and dormant periods were determined for the latter two
cover types. Phenological stage transition dates were mapped from the
500 m resolution MODIS Land Cover Dynamics Product (Friedl 2012a)
derived from the Enhanced Vegetation Index. We found that the mean
length of dormancy (MLD) varies with climate and with cover type. High-
er latitude seasonal change is predominantly thermally controlled, and
lower latitude change is predominantly moisture-controlled. Thermally
controlled seasons exhibit less-variable MLDs than moisture-controlled
seasons. It is unclear exactly what our results mean with regard to plant
appearance as few validation field studies have been conducted in many
climate and cover types. Considering the scale of the analysis and the de-
sired generalization of the results, our study resulted in reasonable MLD
values.

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Preface

The research described in this report was funded by the U.S. Army Natick Soldier Research, Development and Engineering Center (RDEC), and Product Manager Soldier Clothing and Individual Equipment (PM SCIE) Phase IV Camouflage Effort.

The work was performed by Alexis Coplin (Biogeochemical Sciences Branch, Dr. Justin Berman, Chief) [*] and Dr. Charles Ryerson (Terrestrial and Cryospheric Sciences Branch, Rae Melloh, Acting Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Loren Wehmeyer was Acting Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

The MODIS (Moderate Resolution Imaging Spectroradiometer) MCD12Q2 data used for this work were obtained through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), U.S. Geological Survey Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/get_data). The authors thank Eli Deeb for assistance developing and applying a UNIX script for data retrieval and both Eli Deeb and Steve Newman for general advice regarding working with MODIS data. The authors also thank Scotlund McIntosh, Natick Soldier RDEC, and Tim Carey, ERDC-CRREL, for reviewing this report.

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[*] Alexis Coplin left ERDC-CRREL in May 2014 and worked at VHB in South Burlington, VT, at the time of publication.

Acronyms and Abbreviations

AFRICOM	U.S. African Command
AOI	Area of Interest
CENTCOM	U.S. Central Command
COCOM	Combatant Command
CRREL	Cold Regions Research and Engineering Laboratory
DOY	Day of the Year
ERDC	U.S. Army Engineer Research and Development Center
EROS	Earth Resources Observation and Science
EUCOM	U.S. European Command
EVI	Enhanced Vegetation Index
GIS	Geographic Information System
GLC2000	Global Land Cover 2000
HDF-EOS	Hierarchical Data Format–Earth Observing System
ITCZ	Intertropical Convergence Zone
LP DAAC	Land Processes Distributed Active Archive Center
MCD12Q1	Moderate Resolution Imaging Spectroradiometer Land Cover Type Product
MCD12Q2	Moderate Resolution Imaging Spectroradiometer Land Cover Dynamics Product (since 2009)
MLD	Mean Length of Dormancy
MOD12Q2	Moderate Resolution Imaging Spectroradiometer Land Cover Dynamics Product (prior to 2009)
MOD44W	Land–Water Mask Derived from the Moderate Resolution Imaging Spectroradiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MRT	MODIS Reprojection Tool

NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NORTHCOM	U.S. Northern Command
PACOM	U.S. Pacific Command
PM SCIE	Product Manager Soldier Clothing and Individual Equipment
RDCE	Research, Development and Engineering Center
RDECOM	U.S. Army Research, Development and Engineering Command
SD	Standard Deviation
SOUTHCOM	U.S. Southern Command
USGS	U.S. Geological Survey

1   Introduction

The Product Manager Soldier Clothing and Individual Equipment (PM SCIE) started the Phase IV Camouflage Effort in 2009 to improve the performance of soldier uniform camouflage patterns Army-wide. Phase IV of the program-developed methodologies for selecting an "operationally and scientifically validated" camouflage pattern that will perform effectively in a variety of anticipated areas of interest (AOIs) worldwide. The general methodology for the Phase IV program was detailed to industry camouflage developers in 2010 (Bacon 2010).

The primary goal of the Phase IV program was to select a family of industry-submitted camouflage patterns that would be effective in most AOIs. In an effort to ensure that testing of pattern effectiveness occurred in representative environments, projects used available geospatial data and subject matter expertise to characterize the natural backgrounds in 25 countries by mapping climate, physiography, and land cover. Ryerson et al. (2012a, 2012b, 2013a, 2013b, 2013c, 2013d, 2013e), Coplin et al. (2012), Scott et al. (2013), Hanlin and Rogers (2013), and Hanlin et al. (2013) detail this work.

The appearance of a natural background is largely a function of the local terrain and vegetation (Ryerson et al. 2012b). While terrain shape, texture, and color may dominate the natural background in an arid environment with little to no vegetation, the appearance of natural backgrounds in vegetated environments is controlled by vegetation type, size, growth stage, color, and texture. Seasonal change, where it occurs, is an important control of natural vegetation color and texture and is expressed in a plant's phenological stage. Phenology means literally to show or to appear, from the Greek word "phainestai" (Koch et al. 2006). In the context of this report, phenology refers to recurring plant lifecycle stages with the timing of these stages related to weather and climate (Weltzin 2011).

Growing season length is a commonly derived product of observing phenological metrics and refers to the time between leaf out, or greenup, of vegetation and maturity (Koch et al. 2006). Our interest in vegetation phenology is in the appearance of plants and how they might change the

color, density, and texture of natural backgrounds throughout their growth cycles. In most plants, leaf out and senescence, the latter being the period after plants have ended their mature, verdant stage, are relatively short periods. Plants generally spend most of their time in a mature, verdant stage or in dormancy. Plants often change appearance dramatically when transitioning from a verdant state to a dormant state, losing their leaves, changing leaf color, or curling leaves. Dormancy can occur because of vernalisation (temperature), photoperiodism, seasonal or periodic moisture availability, disease, and cropping (Samach and Coupland 2000; Rathcke and Lacey 1985). According to Rohde and Bhalerao (2007), dormancy in plants is the ability to cease activity in tissue responsible for growth.

The current study is part of a larger effort to characterize natural background environments in support of the Army's Phase IV Camouflage efforts (Ryerson et al. 2012b; Scott et al. 2013). The objective of the research presented in this report is to explain methodology used to quantitatively estimate the length of dormant periods experienced by natural land cover in AOIs. We hypothesized that length of dormancy could be estimated by measuring the number of days between the onset of dormancy and the onset of greenup, the antithesis of measuring growing season. The length of dormancy was ultimately used for choosing test locations and weighting pattern performance in verdant and dormant environments.

2 Background

2.1 Historical natural background characterization

Ecosystem phenology is currently an intense area of study because it is an indicator of climate change (Weltzin 2011; Zhao et al. 2013). Most recent studies use multi-spectral satellite imagery (Hanes et al. 2014); however, before satellite imagery was available and climate change was a global concern, there was interest for camouflage and other military operations in how phenology affects the appearance of natural backgrounds and how their colors change over time. One such study that considers phenology and is closely related to the natural background effort was conducted by the U.S. Army during the 1950s and 1960s (Chambers and Dalrymple 1956; Chambers 1967).

The Quartermaster Research and Development Center of the Environmental Protection Research Division at Natick, Massachusetts, published a report entitled *Color Regions of the World* (Chambers and Dalrymple 1956), and later an atlas entitled *World Color Regions Atlas* (Chambers 1967). For these publications, geographers coordinated with the Army Corps of Engineers Engineer Research and Development Laboratory to "assist planners in providing better camouflage protection to increase the efficiency of logistical operations in any area of the world" (Chambers and Dalrymple 1956). The *World Color Regions Atlas* maps natural landscape color regions by month with 9 standardized colors defined using the Munsell color system (Chambers 1967; Chambers and Dalrymple 1956). The standard colors are white, tan, green, olive green, olive drab, earth red, earth brown, forest green, and partly white, the latter consisting of white and the local background color.

The atlas contains 72 maps: 12 monthly maps for North America, South America, Asia, Africa, and Europe. The maps were drafted using the following three principles (Chambers 1967):

1. Terrain color at any time is a function of illumination, viewing conditions, and blending of many colors in the background.

2. The optimum camouflage color is governed by the current and local terrain coloration.
3. Regions with similar climate, terrain, and cover have similar color independent of location.

The *World Color Regions Atlas* was constructed in part from maps published in the 1953 *Goode's World Atlas* (Goode and Espenshade 1953). Maps from *Goode's World Atlas* included natural vegetation, agricultural regions, and soils. Clark University provided climatic data of the world, which helped to determine seasonal changes in color. Though some methodological details in their report (Chambers and Dalrymple 1956) are unclear, they used a mean monthly temperature of 0°C and 19 mm of monthly precipitation to determine the threshold for snow covered (white) areas and a mean monthly temperature of 5°C and monthly precipitation of 26.7 mm to determine the threshold for partially snow covered areas. The 5°C temperature also served as the thermal boundary between dormant vegetation and greenup. When mean monthly temperature reached 15.1°C, vegetation transitioned from the greenup stage to verdant. Neither the atlas (Chambers 1967) nor the explanatory report (Chambers and Dalrymple 1956) specified temperatures for the beginning of senescence and the beginning of dormancy. In addition, in tropical regions, such as the Sahel of Africa where moisture availability rather than temperature causes phenological change, neither the report nor the atlas (Chambers and Dalrymple 1956; Chambers 1967) specified precipitation thresholds for dry versus moist.

Despite the missing moisture criteria and generalized snow cover criteria, the spatial and temporal thoroughness of the atlas is evident in the maps. Figure 1 shows December colors in Asia. All of northern Russia, for example, is number 6, Earth Brown, indicating needle-leaf deciduous forest and tundra during the dormant or dry season, barren areas, bare rock and shallow, high mountain soils (Chambers 1967). The vertical stripes indicate a probability of more than two weeks of snow cover during the month. During July, this area is primarily color 3, indicating broadleaf deciduous trees, needle-leaf evergreen trees, needle-leaf deciduous trees, grasses, and other herbs during the growing season.

Figure 1. Asia color regions in December (Chambers 1967). Legend of colors by number as defined in Table 1. (This map is reduced from an oversize page size.)
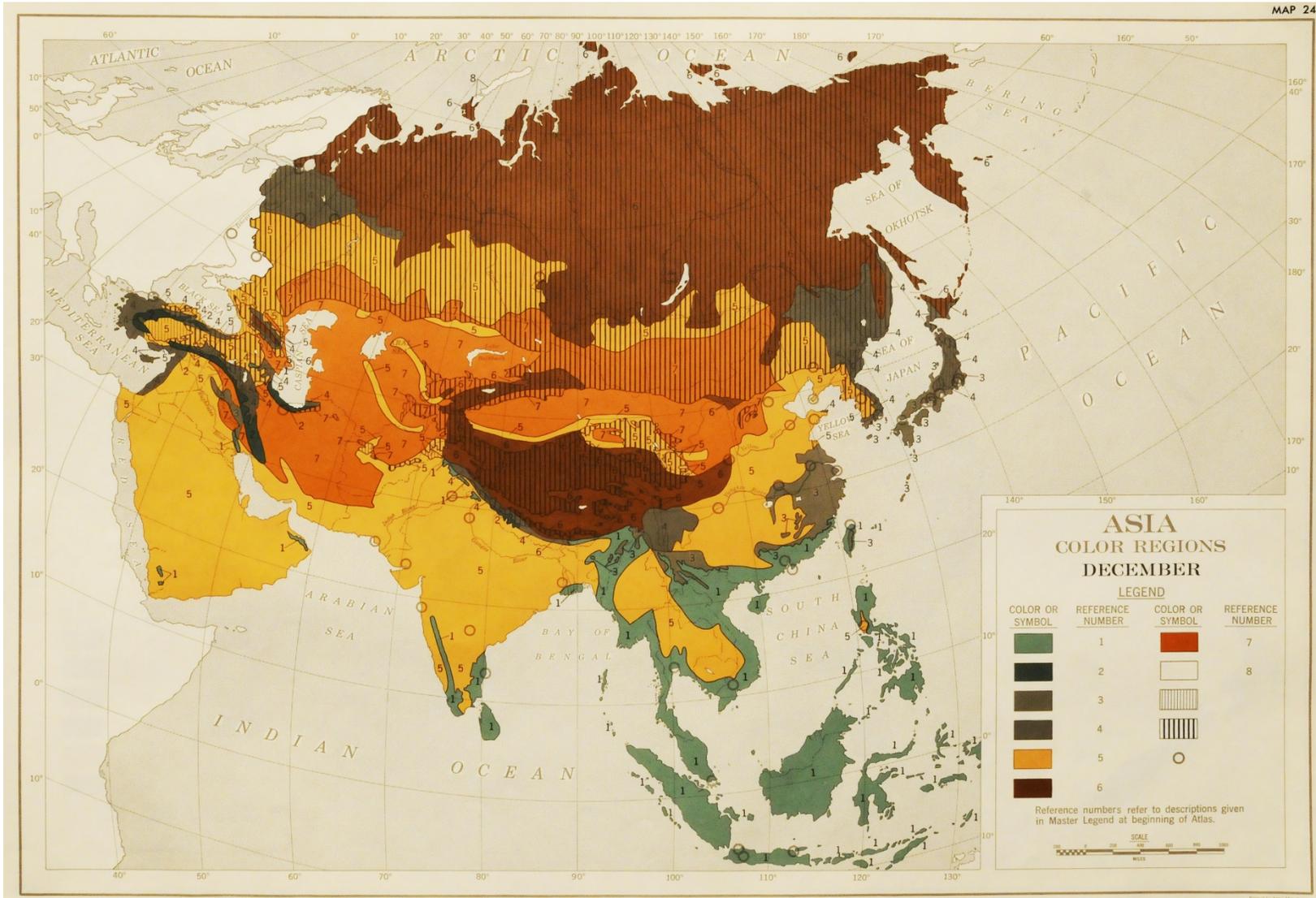
Table 1. Map legend for Figures 1 and 2 (Chambers 1967).

Color Number	Physical Features
1	Broadleaf evergreen and broadleaf deciduous trees, grasses, and herbs in the growing season
2	Mixed forests of broadleaf deciduous and needle-leaf evergreens in the growing season
3	Broadleaf deciduous trees, grasses and other herbs, and needle-leaf evergreen and deciduous trees during the growing season
4	Mixed forests of broadleaf deciduous and needle-leaf evergreens during dormant season, but tundra during the growing season
5	Broadleaf deciduous trees, grasses and other herbs, and needle-leaf evergreen and deciduous trees during dormant or dry season, and desert alluvial deposits, sand, and thin mountain soils
6	Needle-leaf deciduous trees and tundra during dormant or dry season, barren areas, bare rock, and shallow mountain soils
7	Mountainous and cold desert areas with sierozem, chestnut, reddish chestnut, reddish brown, and lateritic soils
8	Snow, white sand, and salt flats
Light vertical stripes	Less than 2 weeks of snowfall during the month
Bold vertical stripes	More than 2 weeks of snowfall during the month

Figure 2 shows Africa in January and July. The geographic shift in colors is due to movement of the Equatorial Depression and the Intertropical Convergence Zone (ITCZ), which bring moisture, greening the forest and savanna, or drying when they leave, depending upon the season. The *World Color Regions Atlas* illustrates the monthly change well. It also shows that there is considerable generalization as most of Africa is signified as colors 1 or 5, except for northern Algeria in January, which is 3 and 4.

Figure 2. Africa in January (*left*) and July (*right*) (Chambers 1967). See Table 1 for the legend.
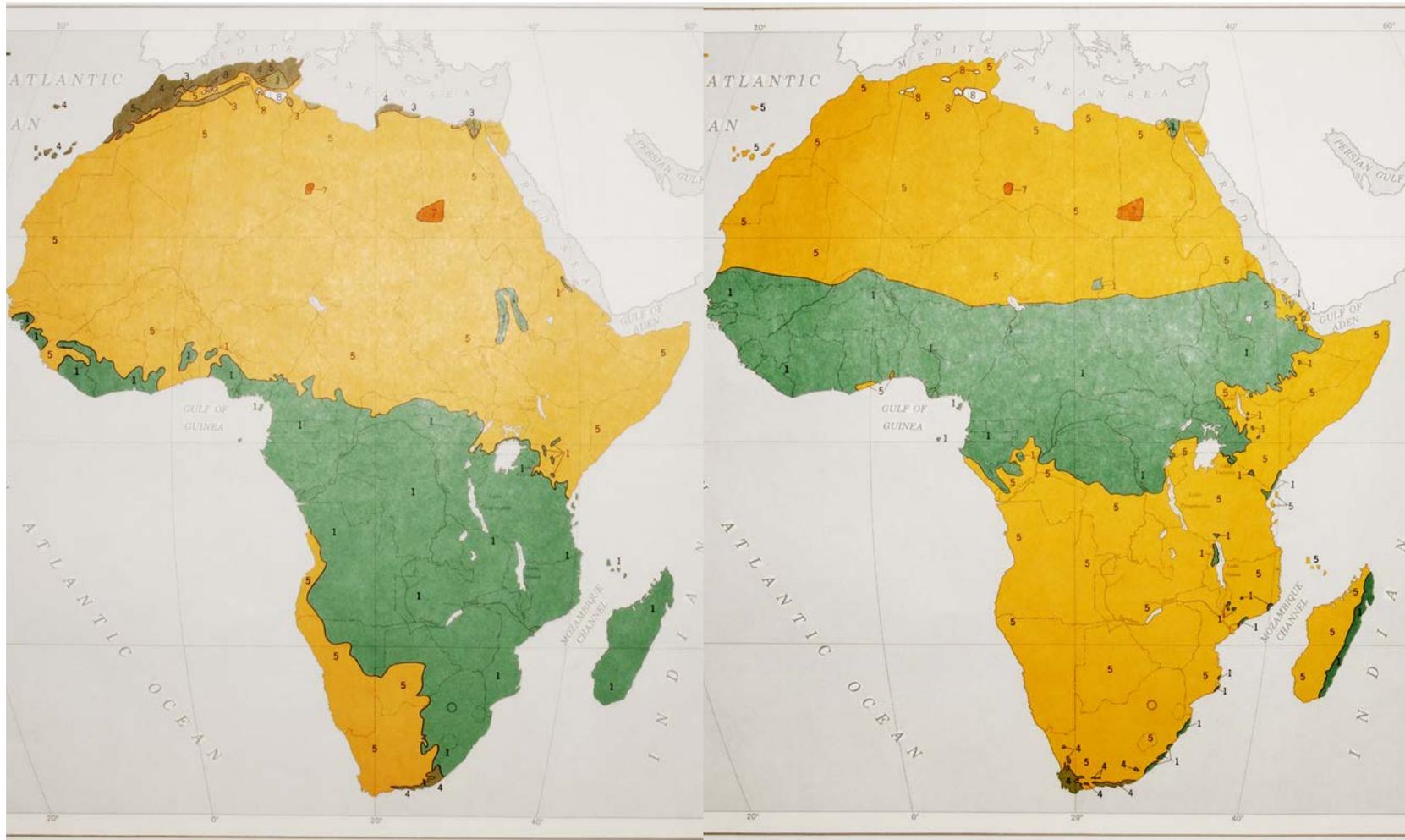
The atlas authors validated the color atlas through spot fieldwork in the Middle East, Panama, Africa, and the western United States. To map the phenological change, they used small-scale maps and climatic data, the best available technology when the color atlas was made (Chambers and Dalrymple 1956; Chambers 1967). Although we can use this atlas to estimate dormant periods for our current AOIs, more recent land-cover information and satellite data provide a more accurate and representative estimate of dormant period length.

2.2   Current phenology work

Currently, phenological work is using satellite multispectral imagery and vegetation indexes to assess change over time. White et al. (2005) used 10-day composite, 8 km Pathfinder Advanced Very High Resolution Radiometer Normalized Difference Vegetation Index (NDVI) datasets from 1982 through 1999 (excluding 1994). They conducted a wavelet analysis on NDVI values to identify areas with an annual cycle in at least 15 of the 17 years of data. They then clustered pixels using NDVI and climate data and created 500 global phenoregions that, when tested, identified areas with known annual phenological change. White et al.'s (2005) specific interest was to identify optimal areas for monitoring phenological response to climate. This required strict selection of areas that would respond only to climate with no other factors present that may induce phenological response. Therefore, they eliminated areas with fewer than 100 pixels and those areas with a high percentage of crop areas, barren areas, urban areas, and anywhere that change may be due to non-climatic causes, reducing the clusters from 500 to 136 phenoregions (White et al. 2005).

Our requirement was to characterize the visual appearance of dormant versus verdant areas and to identify when and where dormancy occurs. Therefore, we initially used White et al.'s (2005) phenoregion maps for identification of areas with change. Though we knew that all of the change may not be climatically induced, we wished to be as spatially complete as possible. Though effective in showing areas with change, their 8 km pixel maps are of low resolution and, more importantly, do not indicate dormant period duration (Figure 3).

Figure 3. Map from White et al. (2005) showing areas of phenological change in Africa. The map of 500 phenoregions initially created in their work is available as a KMZ file and viewable in Google Earth, as shown here. The colors represent different phenoregions.
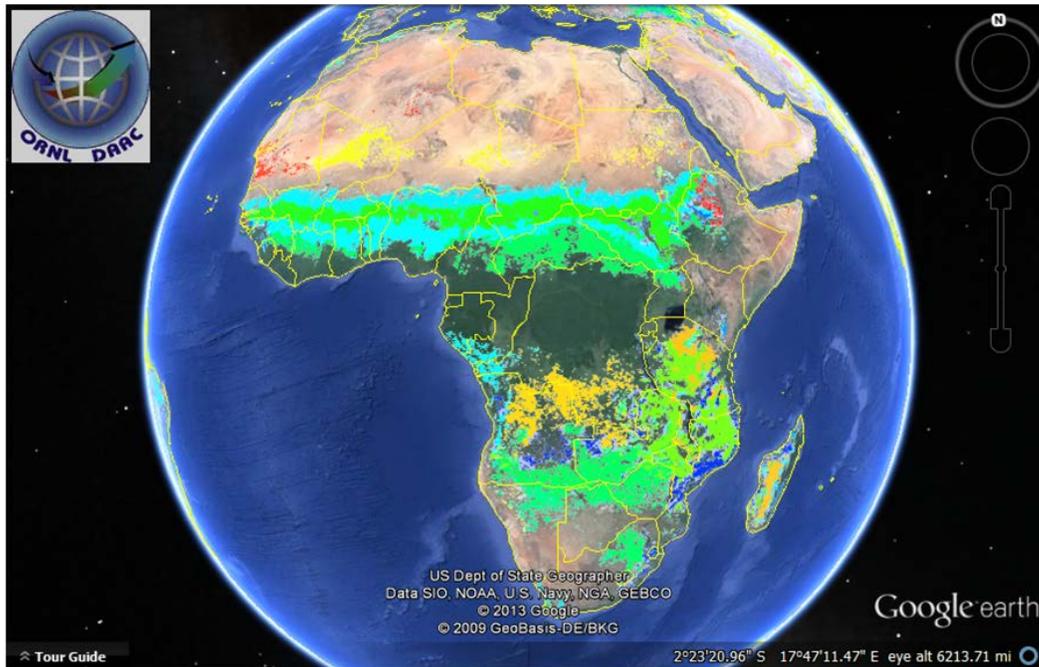
In addition to locations of phenological change, we wanted to know for how long natural cover was dormant. This would allow computation of a time-versus-area weighting for dormant periods in the AOI (Ryerson et al. 2012a, 2013a, 2013b, 2013c, 2013d, 2013e).

NASA (National Aeronautics and Space Administration) has created global animations of NDVI that show seasonal changes in vegetation by sequencing average monthly NDVI for 2004 (NASA/Goddard Space Flight Center Scientific Visualization Studio 2009) (Figure 4). The animation used shows one frame per day and repeats through the annual cycle 6 times as the Earth rotates in the video, allowing a complete yearly sequence of NDVI for each continent, though it emphasizes the northern hemisphere (Figure 4). The animation allows rough estimates to be made for verdant or dormant period duration for most terrestrial locations. The NASA NDVI information was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) that flies on the Terra and Aqua satellites. The images, from 1 January 2004 through 31 December 2004, are colored to represent the health of the vegetation cover. However, we could not locate specific information about interpreting the color changes in the animation (Figure 4).

Figure 4. January and July images from the NASA NDVI animation showing Africa and Europe at two extremes of NDVI (NASA/Goddard Space Flight Center Scientific Visualization Studio 2009).
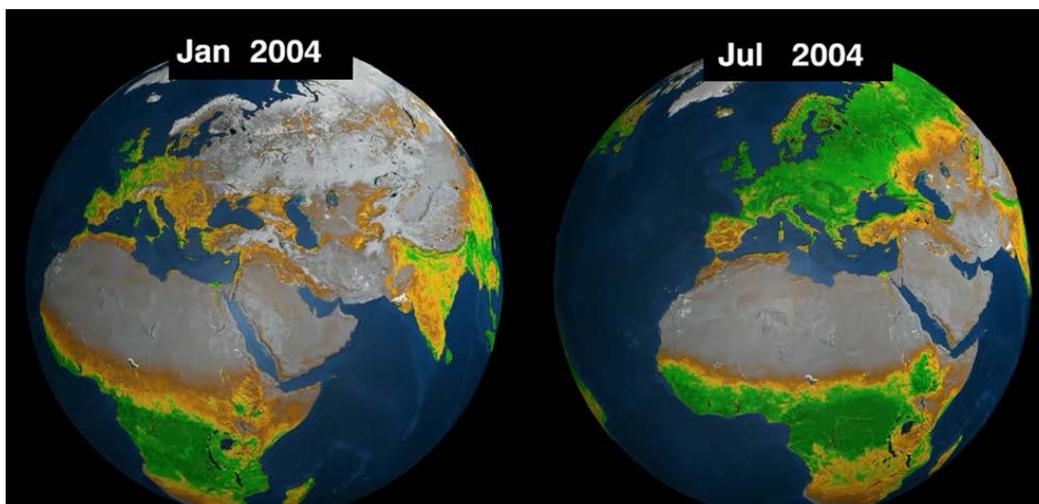
Figure 4 shows January and July 2004 for Africa and Europe. In Africa, the comparison shows that transitions between verdant and dormant vegetation are expressed as latitudinal change as the seasonal position of the sun changes and, therefore, the location of the Equatorial Depression, the ITCZ, and areas of rainfall or drought. Europe and Scandinavia show the effects of seasonal temperature change on verdancy and dormancy with much higher NDVI values in July compared to January.

Using the monthly NASA NVDI animation, we estimated the number of months per year that were verdant. As NASA did not specify the absolute meaning of the colors in the animations, we compared seasonal changes in known areas to the NASA NDVI color changes. Verdant and dormant periods on the NDVI maps appeared to correspond well to local periods of verdancy and dormancy observed on the ground, such as in the Eastern United States.

We did not include in this analysis areas that are evergreen, such as the Congo Basin and Amazon Basin tropical rainforests. We weighted the dormant period lengths by the area of deciduous woodland and transitional cover to obtain final answers. We estimated that deciduous Woodland areas were 27% dormant, when weighted for dormant season length and area of coverage, and Transitional areas 56% dormant. These values were used as an intermediate solution to the Phase IV program's needs. How-

ever, as we describe in the next sections, we found an improved phenology product and developed a new methodology.

3   Data Descriptions

The natural background work conducted at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) heavily relied on the Global Land Cover 2000 (GLC2000) database for land-cover characterization purposes (European Commission 2003). This database includes 22 land-cover classes and has a spatial resolution of approximately 1 km, representing global land cover during the year 2000 (Figure 5). To better meet the needs of the Army's camouflage efforts, 19 of the 22 GLC2000 land-cover classes were lumped into 3 broad, environment categories— Woodland, Transitional, and Arid—as shown in Figure 6. This study did not consider areas designated as "no data," "water bodies," "snow and ice," and "artificial surfaces and associated areas." The spatial boundaries of the generalized Woodland and Transitional categories were used to define the study areas within each Combatant Command (COCOM) for the natural background dormancy results. Although many arid regions within our study areas have sparse vegetation that experiences measurable growth cycles, including periodic green-up, we assumed that verdant periods in arid regions would have highly variable timing and would likely be very short-lived. This would be problematic for analysis and prediction of when dormancy might occur (Botta et al. 2000; Peñuelas et al. 2004; Reynolds et al. 2004; Kwarteng et al. 2009; Ghazanfar 1997). Additionally, vegetation, especially verdant vegetation, is not considered to be a dominant natural background feature for camouflage purposes in arid environments (Ryerson et al. 2012b); therefore, we do not present dormancy results for land-cover classes considered to be Arid.

Because of the nearly global study area, we needed phenology information with global coverage that included spatial and temporal resolution similar to that of land-cover data. Another key requirement was that the data be easy to access and that it was available at no-to-low cost.

Figure 5. Map of GLC2000 displaying all 22 land-cover classes.

Artificial surfaces and associated areas	Mosaic: Tree Cover / Other natural vegetation	Sparse herbaceous or sparse shrub cover	Tree Cover, needle-leaved, deciduous
Bare Areas	No Data	Tree Cover, broadleaved, deciduous, closed	Tree Cover, needle-leaved, evergreen
Cultivated and managed areas	Regularly flooded shrub and/or herbaceous cover	Tree Cover, broadleaved, deciduous, open	Tree Cover, regularly flooded, fresh water
Herbaceous Cover, closed-open	Shrub Cover, closed-open, deciduous	Tree Cover, broadleaved, evergreen	Tree Cover, regularly flooded, saline water
Mosaic: Cropland / Shrub and/or grass cover	Shrub Cover, closed-open, evergreen	Tree Cover, burnt	Water Bodies
Mosaic: Cropland / Tree Cover / Other natural vegetation	Snow and Ice	Tree Cover, mixed leaf type	

Figure 6. Map of GLC2000 with land-cover classes re-colored to show Woodland (*green*), Transitional (*orange*), and Arid (*gray*) categories.
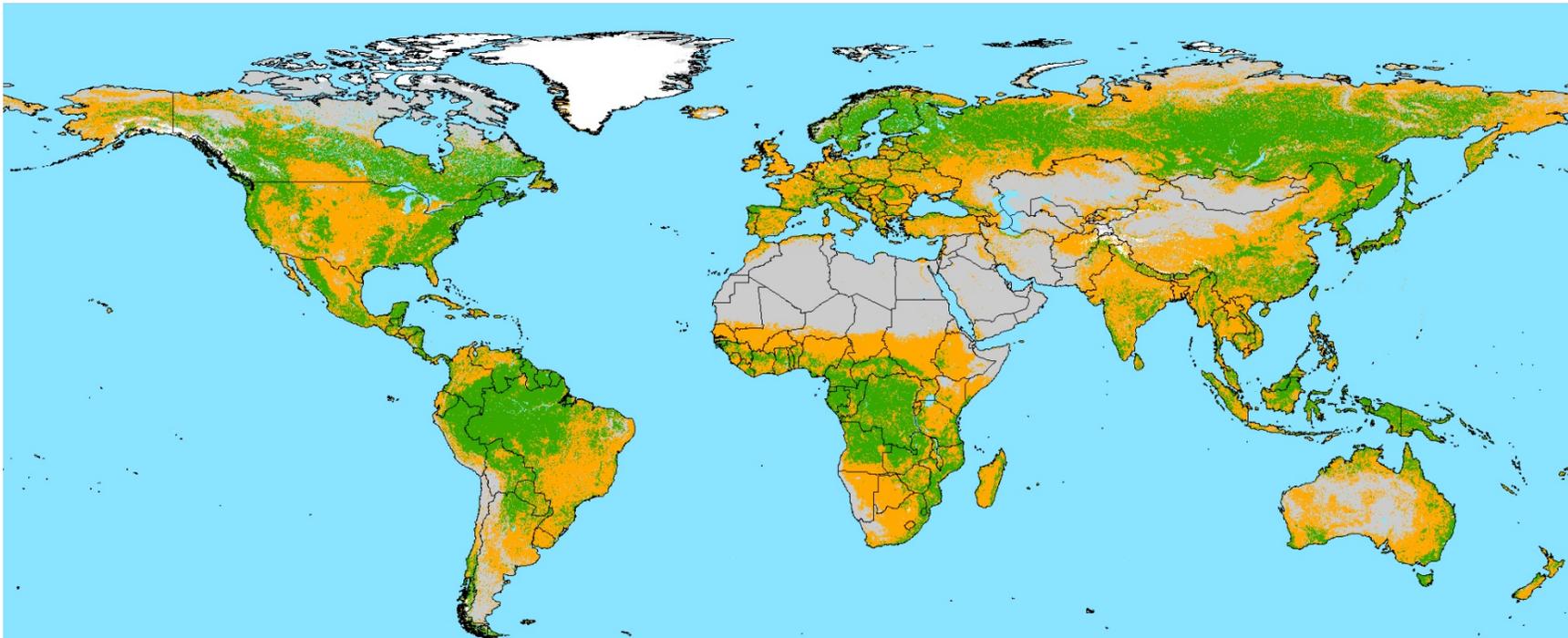
Bare Areas	Mosaic: Tree Cover / Other natural vegetation	Tree Cover, broadleaved, deciduous, closed	Tree Cover, needle-leaved, deciduous
Cultivated and managed areas	Regularly flooded shrub and/or herbaceous cover	Tree Cover, broadleaved, deciduous, open	Tree Cover, needle-leaved, evergreen
Herbaceous Cover, closed-open	Shrub Cover, closed-open, deciduous	Tree Cover, broadleaved, evergreen	Tree Cover, regularly flooded, fresh water
Mosaic: Cropland / Shrub and/or grass cover	Shrub Cover, closed-open, evergreen	Tree Cover, burnt	Tree Cover, regularly flooded, saline water
Mosaic: Cropland / Tree Cover / Other natural vegetation	Sparse herbaceous or sparse shrub cover	Tree Cover, mixed leaf type	Water Bodies

This effort used Version 005 of the MODIS Land Cover Dynamics Product (MCD12Q2) to determine dormant season length in the AOIs. MCD12Q2 provides global coverage of yearly estimates for the timing of vegetation phenology at 500 m resolution. It uses both Aqua and Terra MODIS Enhanced Vegetation Index (EVI) input data to identify vegetation growth, maturity, and senescence during a given year. The MCD12Q2 algorithm identifies phenophase transition dates by fitting logistic functions to time series of smoothed EVI data. Transition dates are identified as local maxima and minima in the rate of change of curvature of the fitted logistics function (Figure 7) (Friedl and Tan 2006). MCD12Q2 removes gaps in the input EVI time series that are due to atmospheric interference (i.e., cloud cover, aerosols, etc.) or snow and ice cover by using a three-date, moving-window average and smoothes the series by using a three-point, median-value, moving-window technique (Friedl 2012a; Zhang et al., 2006). Moving windows composed of five consecutive observations are used to identify sustained periods of EVI increase and decrease. This technique also requires that the local maximum curvature change rate in EVI be at least 70% of the annual maximum and that the change in EVI must exceed 35% of the annual amplitude. This requirement excludes transient variations in EVI and avoids inaccurate detections of transitions (Friedl 2012a; Zhang et al. 2003).

Figure 7. Schematic illustrating how MCD12Q2 identifies phenological transition dates. The solid line represents an idealized time series of EVI, and the dashed line represents the derived curvature change rate. The circles indicate four phenological transition dates: (*A*) onset of greenness increase, (*B*) onset of greenness maximum, (*C*) onset of greenness decrease, and (*D*) onset of greenness minimum (Friedl and Tan 2006)
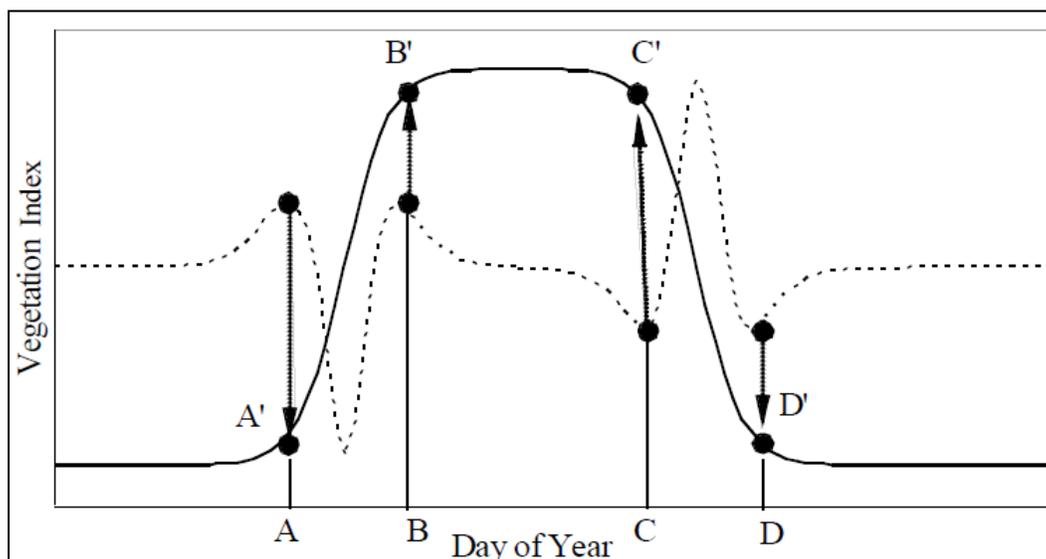
The NASA/USGS (U.S. Geological Survey) Land Processes Distributed Active Archive Center (LP DAAC) makes MCD12Q2 freely available to the public. The LP DAAC serves MODIS data products in Hierarchical Data Format–Earth Observing System (HDF-EOS) format and sinusoidal projection, which requires manipulation prior to image analysis in a geographical information system (GIS). Of eight scientific datasets included in the MCD12Q2 data, we used the following four: Onset_Greenness_Increase (OG_Inc), Onset_Greenness_Maximum (OG_Max), Onset_Greenness_Decrease (OG_Dec), and Onset_Greenness_Minimum (OG_Min). There are two layers for each dataset, representing the first full growth cycle and a potential second growth cycle (see Figure 8 for illustrations), resulting in eight layers total. Because we were singularly interested in determining the length of the primary period of dormancy, this study used only the primary growth cycle layers for the OG_Inc and OG_Min, which represent the onset of vegetation greenup and dormancy, respectively. The primary growth cycle in the database is the first that occurs within a year. The OG_Inc and OG_Min data layers are 16-bit unsigned integer raster files where the units of a given pixel are days since 1 January 2000 with a background value of 32767. So, for example, the valid range in pixel values for data from 2001 is 367 through 731 days.

Prior to presenting methodology and results, it is important to emphasize how variable timing of the seasons is across the planet. Because of this variability, remote detection of complete growth cycles can be quite complicated, even with the high temporal resolution and relatively high spatial resolution of the MODIS data. While the MCD12Q2 algorithm is capable of recording up to two full vegetation cycles at each pixel, the current structure of the algorithm and data is best suited for Northern Hemisphere seasonal dynamics (Friedl 2012a; Ganguly et al. 2010). Figure 8 illustrates several idealized examples of vegetation growth cycles within a 12-month period.

Figure 8. Illustration of vegetation growth cycle patterns: (*a*) a single, complete growth cycle; (*b–d*) two partial cycles; (*e*) two complete growth cycles; and (*f–h*) one complete cycle and two incomplete cycles. The x-axis is "day of the year" (Friedl and Tan 2006).
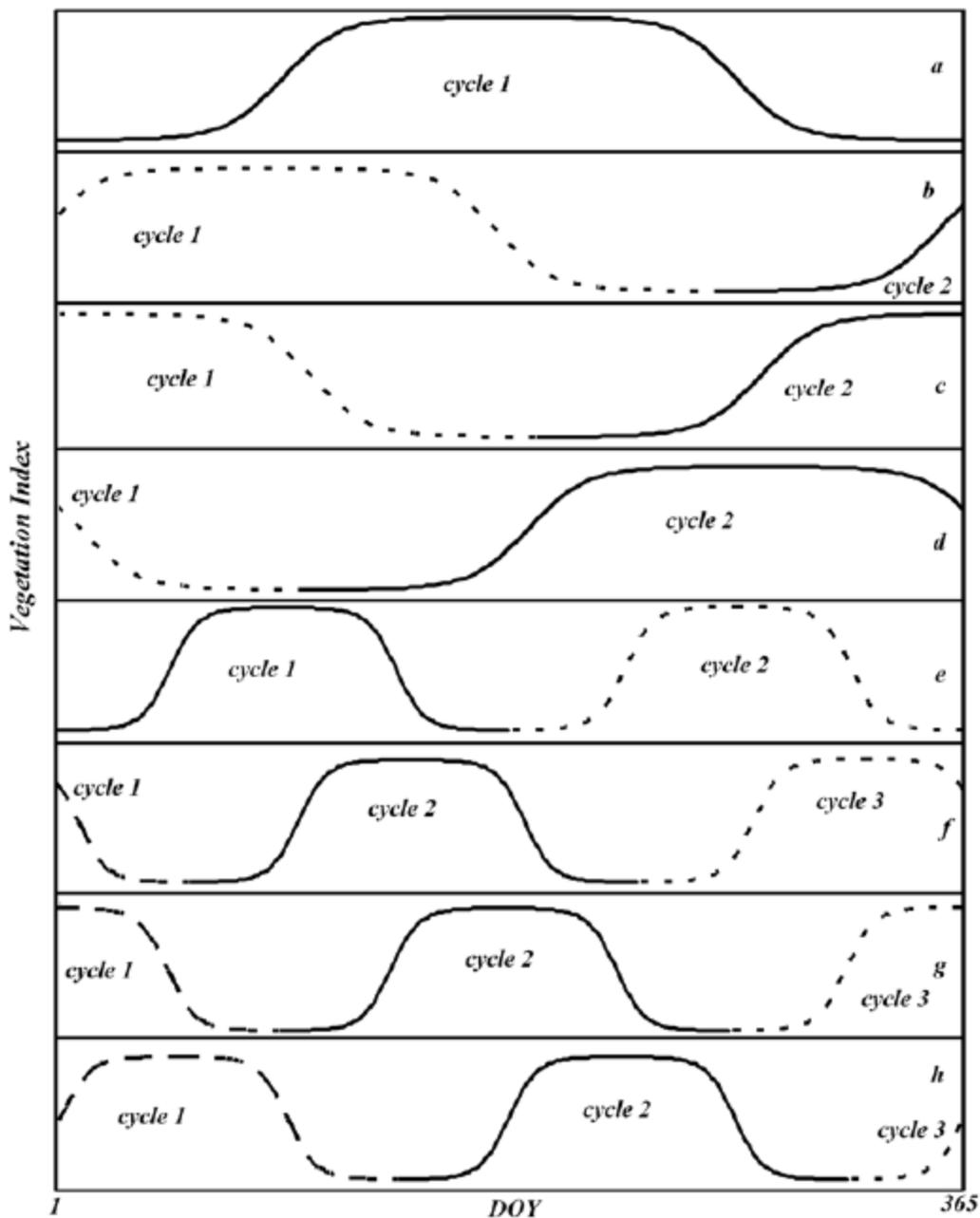
We also used a second MODIS product, the land–water mask derived from MODIS (MOD44W), to prevent the analysis from including water bodies. The MOD44W product has a spatial resolution of 250 m and is a composite of over 8 years of Terra observations and over 6 years of Aqua observations. Data values identify cells as water or land.

4   Methodology

4.1   Data acquisition

We acquired from the LP DAAC Data Pool gridded 10° × 10° tiles of the MCD12Q2 dataset for collection years 2001 through 2009. We grouped and processed tiles by COCOM in the interest of computational efficiency. Because of the large number of tiles that were required, we used a batch retrieval script to download the required data efficiently. We also acquired from the LP DAAC Data Pool tiles of the MOD44W product.

Prior to analysis, we pre-processed MCD12Q2 and MOD44W data by using the MODIS Reprojection Tool (MRT), version 4.0. The desired data layers for each COCOM for a given year were mosaicked, reprojected to the Geographic projection and WGS84 datum, and converted to GEOTIFF format using the nearest neighbor resampling technique.

4.2   Analysis

Further processing and analysis were done using ESRI's ArcGIS software (ArcMap and ArcCatalog), version 10.0. When working with the MCD12Q2 data layers, we ran Spatial Analyst Tools in batch mode due to the high volume of annual files. First, the background value of 32767 was removed (using the Extract by Attributes tool) from all yearly OG_Inc and OG_Min layers in preparation for raster subtraction. The OG_Inc and OG_Min raster layers were used as input, and the extraction clause was the following SQL expression: "Value" <32767.

Next, we created dormant season length raster files for each COCOM. Our methodology accommodated two different dormant season patterns: dormant seasons that occur within a given calendar year and dormant seasons that overlap two consecutive calendar years—like the winter season in the Northeastern U.S (see examples *a* and *c* in Figure 8). In the absence of EVI time series, this was accomplished by first determining the temporal relationship between the OG_Inc and OG_Min dates for each year by using the "Greater Than" raster math tool. The "Greater Than" tool identified cells where cell values in the first input raster, OG_Min, were greater (i.e., occurred later in the year) than cell values in the second input raster,

OG_Inc. The output raster contained cell values of 1 where input 1 was greater than input 2 and cell values of 0 where input 1 was not greater than input 2. This output raster was used as an extraction mask to separate cells where the OG_Min date occurred earlier in the year than the OG_Inc date from cells where OG_Inc occurred earlier than the OG_Min. If the OG_Min date in a given year occurred earlier than the OG_Inc date, the dormant season length was estimated by subtracting the OG_Min raster of that year from the OG_Inc raster of the following year. If the OG_Min was less than the OG_Inc for a given year, the OG_Min was subtracted from the OG_Inc from the same year. Raster subtraction was accomplished using the "Minus tool" in the Raster Math Toolset. This process resulted in 8 raster files for cases where OG_Min was greater than OG_Inc and 9 raster files where OG_Min was less than OG_Inc. The resulting pixel values represented the number of days between the OG_Min and OG_Inc, or in other words, the length of annual dormancy.

The dormant season raster files were then used as input for the Cell Statistics tool with "MEAN" selected as the overlay statistic. The pixels in the resulting output raster represented the mean length of dormancy (MLD) in days. This process was repeated with "STD" selected as the overlay statistic, which resulted in a second output raster representing the standard deviation of the input values.

To ensure a reasonably accurate representation of average local dormant season lengths, we removed from the mean raster files all pixel locations with fewer than four input values. The first step in identifying pixel locations with fewer than four input values was to apply the "Is Null" tool to each of the input raster files. This tool assigns a value of 1 to input pixels that have no data value and a value of 0 to cells that have any other value. The output raster files from the "Is Null" tool can then be used as inputs for the "Equal to Frequency" tool. An input value raster is also required for this tool, so a constant raster with a value of 0 and the same dimensions as the rasters was created. This tool evaluates on a cell-by-cell basis the number of times the values in a set of raster files are equal to another raster: in this case, the number of times the value "0," the value that represents an input value other than "no data," occurs in each cell. The output raster's values ranged from 0 to 8. Values greater than or equal to 4 were selected and used as a mask to select the final assessment areas in the MLD raster and in the standard deviation raster.

At this stage, the two MLD and the two standard deviation rasters representing each of the potential seasonal patterns were mosaicked together, respectively, by using the "Mosaic to New Raster" tool. The mosaic files were then integerized and subjected to a series of extractions to attain results for our specific AOI. The GLC2000 land-cover classes identified as either Woodland or Transitional were used to mask the MLD and standard deviation data, respectively. Raster statistics, including mean and standard deviation, are automatically calculated during processing and reported for our AOIs in the results. Data coverage was reported as a percentage of coverage by dividing the total number of pixels in the final MLD and standard deviation rasters by the total number of pixels in a constant raster created for the AOI with water pixels removed. Standard deviation rasters were created primarily to illustrate spatial trends in yearly variability. The standard deviation values reported in the results are those automatically calculated for the MLD rasters, representing the spatial variability in MLD over a given AOI.

5 Results and Discussion

5.1 Analysis results

Table 2 shows MLD summary statistics for Woodland and Transitional areas for the countries of interest in each COCOM. Again, these values reflect observations made between 2001 and 2009. Notably, vegetation in EUCOM (U.S. European Command) experiences the longest MLDs of any COCOM, with 245 days for Woodland cover and 258 days for Transitional cover. The EUCOM countries assessed were Russia, Georgia, and Azerbaijan, with Russia representing 99% of the land cover of the three countries. Woodland vegetation in AFRICOM (U.S. African Command) experiences the shortest MLD at 95 days and represents the countries of Sudan, South Sudan, Eritrea, Ethiopia, Somalia, Kenya, and the Democratic Republic of Congo. SOUTHCOM (U.S. Southern Command) has the shortest Transitional cover MLD of 159 days, representing Colombia, Venezuela, Brazil, Guatemala, Cuba, and Haiti.

Standard deviation (SD) in Table 2 refers to the deviation of MLD spatially within the countries analyzed for each COCOM. For example, EUCOM Woodland and Transitional cover have the smallest standard deviation, 22 and 36 days respectively, for the three-countries analyzed. The AFRICOM countries assessed have the largest standard deviation for Woodland and Transitional cover, 55 and 78 days respectively, among the COCOMs for the countries analyzed.

Table 2. Summary statistics by COCOM.

	Woodland					Transitional				
	Mean Length of Dormancy (Days)	Mode	SD	Percentage of Year Dormant	Data Coverage (%)	Mean Length of Dormancy (Days)	Mode	SD	Percentage of Year Dormant	Data Coverage (%)
AFRICOM	95	49	55	26	4	190	Low: 56,Hi1: 219, Hi2: 278	78	52	20
CENTCOM	139	117	48	38	2	163	191	52	45	27
EUCOM	245	245	22	67	43	258	High:271, Low:225	36	71	35
NORTHCOM	173	177	43	47	14	179	185	43	49	18
PACOM	203	218	36	56	10	211	231	41	58	33
SOUTHCOM	191	198	41	52	6	159	Hi:213, Low:51	70	44	5

EUCOM also had the highest percentage of data coverage for both Woodland and Transitional cover. Woodland areas in AFRICOM, CENTCOM (U.S. Central Command), and SOUTHCOM and transitional areas in SOUTHCOM all had very low data coverage at 6% and less. The standard deviation for transitional areas in AFRICOM and SOUTHCOM were both very high at 78 and 70 days, respectively. For woodland vegetation, the modal length of dormancy for AFRICOM, 49 days, varied widely from the mean, 95 days. For transitional vegetation, AFRICOM, EUCOM, and SOUTHCOM all exhibited multi-modal distributions; and in the cases of AFRICOM and SOUTHCOM, the variability in modal values was quite large.

Our results show that MLD varies with climate and with cover type. In higher latitudes, seasonal change is predominantly thermally controlled; and in lower latitudes, it is predominantly moisture-controlled. Areas with thermally controlled seasons exhibited less-variable MLDs than areas with moisture-controlled seasons. For example, EUCOM, the COCOM with the greatest area of thermally driven seasonal change, had the smallest standard deviations for both Woodland and Transitional cover compared to the other COCOMs (Table 1). PACOM (U.S. Pacific Command) also had relatively small standard deviations, in part, we believe, because China is a highly continental, mid-latitude country; and thus its climate is largely thermally controlled

The two COCOMs that are dominated by moisture-controlled seasonal change are AFRICOM and SOUTHCOM. AFRICOM Woodland and Transitional areas have the highest variability in MLD of any COCOM. Transitional areas in SOUTHCOM also exhibited a high MLD standard deviation while the woodland areas had a smaller standard deviation. The analyzed CENTCOM countries, Iraq, Iran, Afghanistan and Yemen, and the only NORTHCOM (U.S. Northern Command) country analyzed, Mexico, all cover the northern Tropics to the southern mid-latitudes where both moisture and temperature are controlling phenological factors. Their Woodland and Transitional cover standard deviations generally fell between the standard deviations of the purely thermal- and purely moisture-controlled areas.

SOUTHCOM also had the lowest data coverage of any COCOM, which may be a reflection of the high amount of tropical evergreen vegetation present.

Tropical evergreen vegetation may not exhibit enough change in EVI throughout the year for the conservative MCD12Q2 algorithm to recognize phenophase transition dates. Ganguly et al. (2010) state that the algorithm does not produce a result if input data are missing during transition periods or if the change in EVI over time is slight. Ganguly et al. (2010) also state that low data coverage is common and acceptable in areas where the amplitude of seasonal EVI is low, such as in tropical evergreen areas and nearly barren arid regions.

Researchers have noted thermal- versus moisture-control patterns in numerous ecological studies comparing phenology to climate. For example, Potter and Brooks (1998) observed that three climatic indices were related to global NDVI patterns: degree-days, annual precipitation total, and annual moisture index accounted for 70%–80% of the geographical variation in NDVI seasonal extremes in 1984. The monthly timing of NDVI extremes was associated closely with patterns of maximum and minimum temperature and precipitation, with 1–2 month lag times as the seasons changed. Botta et al. (2000) state quite explicitly that leaf onset in temperate and high latitudes is mainly dependent on temperature whereas, at low latitudes, leaf onset is controlled by water availability.

As described, thermally controlled areas have less variability in inter-annual seasonal trends, and thus less variability in MLD, than do areas with moisture-controlled seasonal change. Moisture-driven areas experience greenup when wetting occurs and senescence when prolonged drying occurs. Dates signifying the beginning of the dormant season, during the drying phase and at the end of senescence, generally had the largest variability. Dates signifying the end of the dormant season, when rains return and the soil is again wetted, had smaller variability. We show examples of this, later, in Sudan and South Sudan.

The beginning of the dormant season may be more variable because soil dries more slowly than it wets. Wetting occurs from rainfall, which usually occurs as distinct, relatively short-period events. Drying occurs through moisture infiltration and evapotranspiration and is typically a slower event, with lower elevation areas, even on a small scale, drying most slowly. In addition, a mix of plant species will show delayed dormancy for deeper-rooted plants when compared to shallow-rooted plants. During precipitation, the soil wets at the surface; and then moisture migrates

deeper depending on the soil properties and amount and rate of rainfall. This allows shallow-rooted plants to benefit first though deeper-rooted plants can also draw moisture from near the surface. Therefore, there could be less variability in vegetation response at the end of dormancy, when rains begin, than during the beginning, when drying occurs.

Ehleringer at al. (1991) observed that annual, succulent, and herbaceous plants with shallower roots in desert areas of Utah were most dependent upon intermittent summer precipitation for their moisture source. Woody perennial plants with deeper roots were able to use winter, spring, and summer precipitation and did not respond as dramatically to shifts in precipitation frequency and amount.

5.2 Thermal- versus moisture-control examples

5.2.1 EUCOM

Russia is largely a high-latitude country, but it also spans about 40° latitude and about 170° longitude. Despite its great size, MLD is relatively uniform over the country except in its extreme lower-latitude corners (Figure 9, *A–C*). Aside from southeastern Russia near Kamchatka, the duration of dormancy increases from the southwest to north-central Siberia. Dormancy lasts only 150 to 225 days in southeastern Russia and in southern European Russia north to the Gulf of Finland. In the southwest, most of the cover is Transitional cultivated land and mosaics of cropland, tree cover, and other natural vegetation, with the exception of the Greater Caucasus, which is largely forested. The Vladivostok area has a relatively short dormant period because of its oceanic and relatively southern location. Dormant season length increases to about 300 days per year near the Arctic Ocean coast of central Siberia.

Figure 9, *A1–C*1, shows the spatial variability (the standard deviation) within the annual input data. There is a noticeable increase in variability (around 50 days) in southwest Russia, in the steppe area bordering the Caspian Sea. This may be evidence of increased variability in vegetation phenology in moisture-controlled climates. Smaller variance in the timing of the beginning and end of dormant seasons is observed in thermally controlled portions of Russia (Figure 8, *A1–C1*). In the north and east, variability decreases to fewer than about 25 days. In addition to the strong thermal control, species diversity is smaller than in moisture-controlled

areas. The more homogeneous species composition may allow dormancy to begin and end more uniformly.

5.2.2 AFRICOM

Phenology is largely moisture-controlled in the African nations. Figure 10 shows that seasonal moisture and aridity are controlled primarily by movement of the sun and, subsequently, movement of the ITCZ and the Equatorial Trough. Rainfall in much of equatorial Africa follows the high sun period, which occurs in the summer months in the respective Northern Hemisphere or Southern Hemisphere. Variance in MLD in this area may be due to irregularity of the drying period that brings the beginning of dormancy; but it may also be due to the timing of moisture return, which during some years can be delayed or weak and may provide only spotty rainfall (Ryerson et al. 2013b).

Moisture-controlled MLD, as a pattern and as a process, is best understood through an examination of Sudan and South Sudan together. This is because they cover a large latitudinal spread in tropical climates that are defined by the amount and duration of precipitation. Woodland and Transitional vegetation MLD increases dramatically from southwest South Sudan, where it is fewer than 50 days annually, to where sparse herbaceous and sparse shrub cover transitions to barren desert in central Sudan (Figure 10). Dormant season length is over 300 days per year along the barren margins of the Sahara Desert in Sudan (Ryerson et al. 2013b).

A short period when rain occurs in the summer is the only opportunity that grasses and shallow-rooted shrubs have to green. There is considerable variability in precipitation amount year to year; and in some years, dormancy may reach over 360 days. Higher elevations in the Marrah Mountains in Darfur in western Sudan and the Nuba Mountains near the Sudan and South Sudan border catch additional moisture by causing air to lift, producing localized orographic precipitation, or fog, that adds moisture through interception and dripping from leaves. In these mountains and somewhat farther south where precipitation increases, MLD decreases to about 200 to 225 days annually (Ryerson et al. 2013b).

Figure 9. Maps of the mean MLD in days (*top row*) and standard deviation in days (*bottom row*) for input data from 2001 to 2009 in Russia. *A* and *A1* show all data; *B* and *B1* show Woodland areas; and *C* and *C1* show Transitional areas. White areas within Russia represent areas either without subject vegetation or without good quality temporal data.
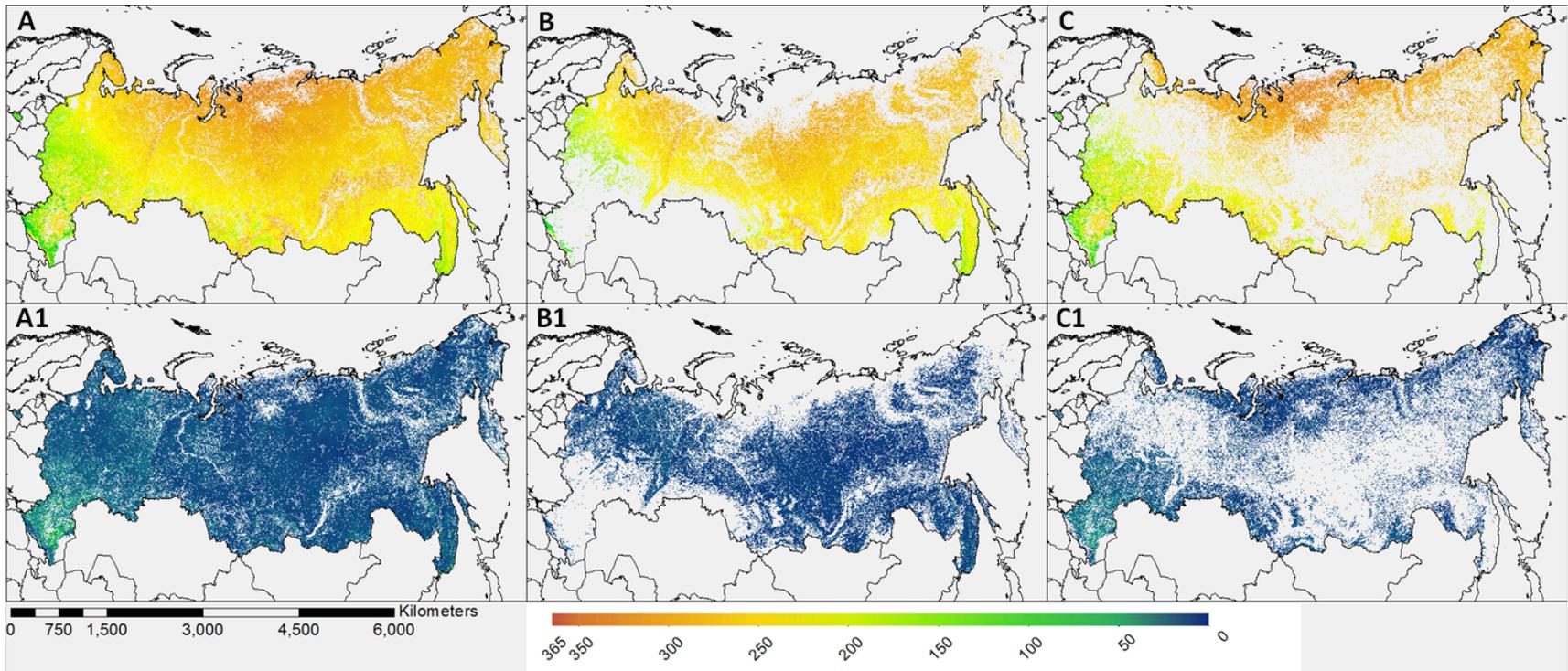
Figure 10. Maps of MLD in days (*top row*) and standard deviation in days (*bottom row*) for input data from 2001 to 2009 in Sudan and South Sudan (country borders predate South Sudan's independence). *A* and *A1* show all data, *B* and *B1* show Woodland areas, and *C* and *C1* show Transitional areas. White areas within Sudan and South Sudan represent areas either without subject vegetation or without good quality temporal data.
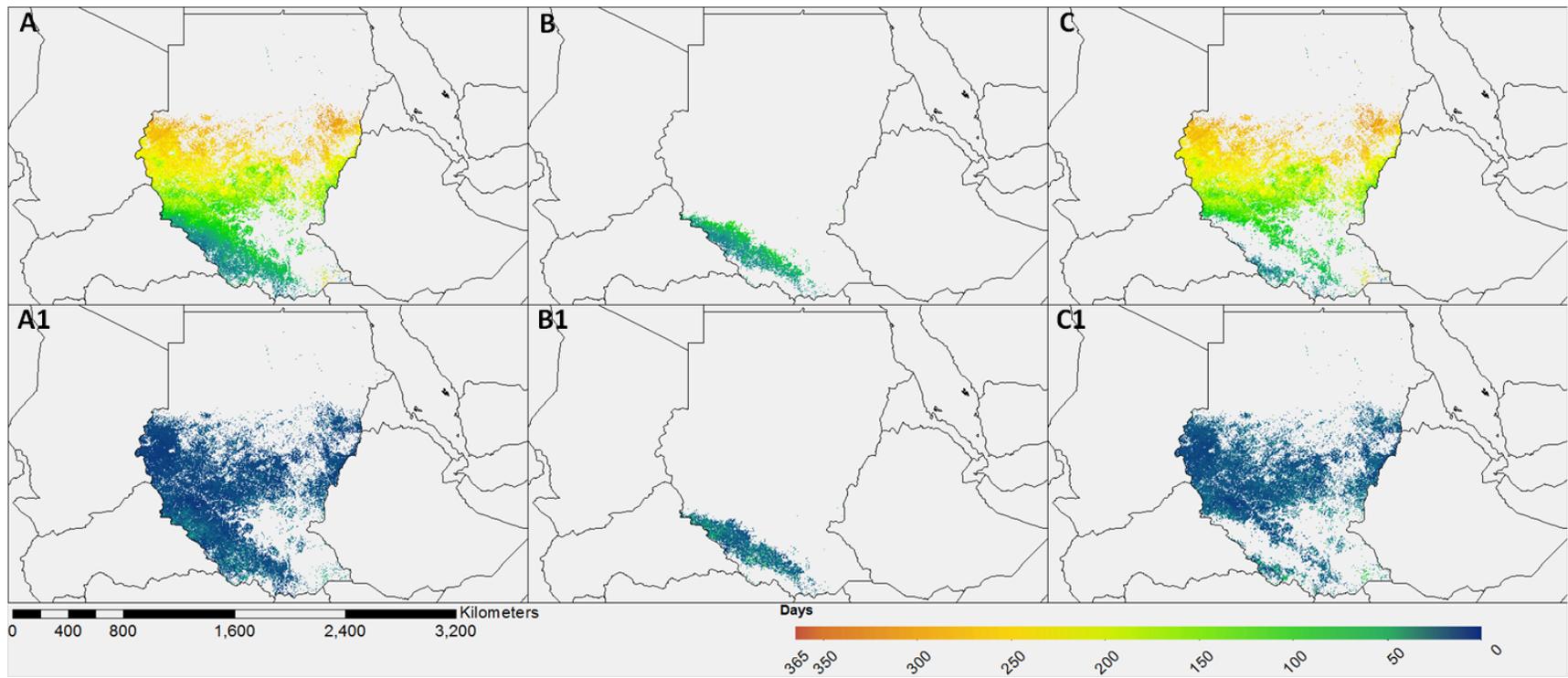
South Sudan is often very wet during the summer and dry during the winter. Dormant seasons in South Sudan range from about 200 to 225 days per year near the Sudan border, to 150 to 175 days annually along the perimeter of the Sudd marsh, to only 25 to 50 days annually on the Ironstone Plateau in the southwest (Figure 10). Within the Sudd marsh area in north-central South Sudan, there is no indication of dormancy, suggesting that there is no dormant period, perhaps due to the high soil moisture. As a further illustration of the role of moisture in dormant season length, the number of dormant days locally increases to about 250 in a small arid area immediately north of the Kenya border in southeast South Sudan (Figure 10) (Ryerson et al. 2013b).

Area devoted to Woodland cover is nearly all on the Ironstone Plateau in southwest South Sudan, along the Central African Republic border and along the upper reaches of the White Nile at the southern end of the Sudd marsh. Along the northeast edge of the Ironstone Plateau, dormant periods are about 150 days. Within the Ironstone Plateau, dormancy decreases to the southwest to a minimum of about 25 days as the conditions to support tropical rainforest, with sufficient moisture in all months to support plant growth, become more dominant (Ryerson et al. 2013b).

5.2.3 SOUTHCOM

The tropical rainforest in SOUTHCOM is perennially green, which results in absent-to-sparse data availability as there is no definitive seasonal change. According to GLC2000, 43% of the vegetation in Brazil is tropical rainforest. Phenology in SOUTHCOM, and specifically Brazil, is largely moisture controlled as in AFRICOM; but patterns are more complex (Figure 11). There is a wide range of MLD in Brazil, ranging from fewer than about 100 days in the southern panhandle to as much as 250 to 300 days in portions of the Amazon Basin.

Figure 11. Maps of MLD in days (*top row*) and standard deviation in days (*bottom row*) for input data from 2001 to 2009 in Brazil. *A* and *A1* show all data, *B* and *B1* show Woodland areas, and *C* and *C1* show Transitional areas. White areas within Brazil represent areas either without subject vegetation or without good quality data.
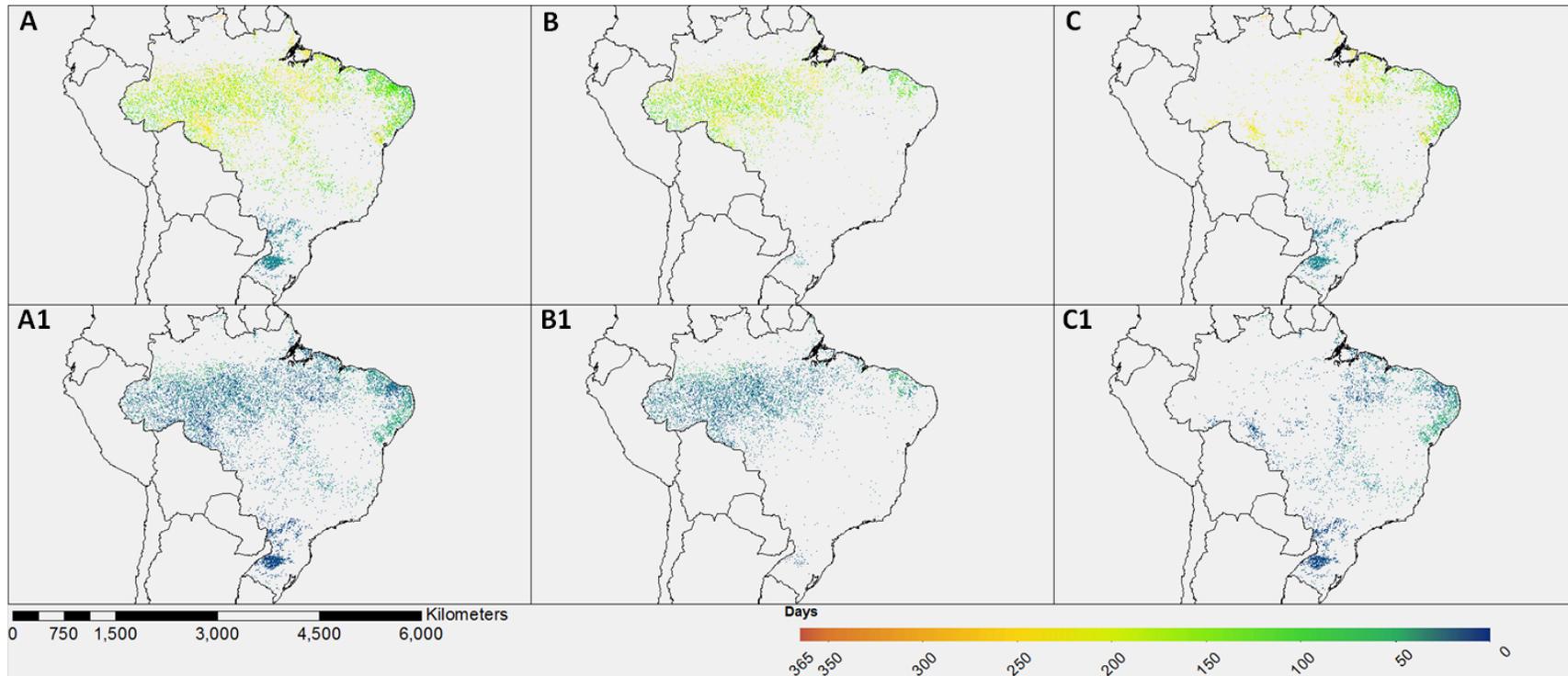
There are very sparse phenological signals in the Amazon Basin north of the Amazon River. This may be due to the prevalence of tropical rainforest in the area, which typically has no identifiable dormant period, though there are arguments that periods of decreased leaf area index for approximately a month are not uncommon in tropical rainforest (Myneni et al. 2007). Throughout the southern side of the Amazon Basin, MLD ranges from 50 to 100 days to over 250 days. Most of the area is tropical rainforest, and MLD in these areas is a mix of the range of durations stated. However, in some areas there are mosaics of cropland, tree cover, and other natural vegetation; and they show a more consistent MLD of 250 to 300 days. These areas are near the Bolivia border and near the Amazon River and in the Amazon River delta area on the northern edge of the Amazon Highlands (Ryerson et al. 2013e).

We do not know why the tropical rainforest area south of the Amazon River has such a wide range of MLD. One reason could be the methods of analyzing land cover versus MLD. The GLC2000 land cover classification was made using pixels of 1 km² area; however, we computed MLD by using imagery with a 0.5 km² resolution. Therefore, the MLD analysis could be resolving variability in phenology that is not apparent in the coarser resolution GLC2000 land-cover classification. That is, the smaller pixels of the MODIS data could be detecting sub-pixel variability in GLC2000 land use. This may be why the MLD in tropical rainforest areas is not consistently a single duration. The MLD analysis may be detecting openings in the rainforest, such as cropland, where MLD is longer during dry periods (Ryerson et al. 2013e).

In the horn of Brazil, MLD ranges from fewer than 50 days, especially in scattered areas deep in the highlands and in a narrow strip along the coast, to durations ranging from 150 days to over 250 days. This area is a semi-arid steppe climate, so the mix of long and short MLD may be due to mixtures of deep-rooted shrubs and trees that remain green longer during drought and shallower-rooted grasses that have longer dormant periods. This area also shows relatively high values in variability regarding the input data (Figure 11, *A1–C1*). The most dramatic change in MLD in Figure 11 is within the panhandle of Brazil, in the subtropics. Here, MLD is only 50 to 100 days. The phenology signals are strongest in areas of deciduous shrub cover, grassland, and cultivated and managed land (Ryerson et al. 2013e).

Mapping the MLD of Woodland and Transitional cover separately has value for determining whether the dormant period signals are due to either type of vegetation cover alone. Overall, Figure 11 shows that the Woodland and Woodland-Transitional patterns in the southern Amazon Basin are similar. However, there is little Woodland data in the Brazilian Highlands, in the southern horn of Brazil, and in the panhandle of Brazil, suggesting that Transitional cover may cause the dormant season lengths for those areas. In the latter area, much of the signal could be from grasses as this is grazing land.

5.3 Assumptions and sources of error

Perhaps the most important assumption made in this study is that a minimum vegetation index is a good indicator of the onset of vegetation dormancy and that vegetation dormancy equates to a change in vegetation appearance from primarily green during verdancy to primarily not green (i.e., browns, tans, and grays) for dormancy. While this is less of an assumption than a widely observable fact for deciduous vegetation, it is a huge assumption for evergreen and tropical vegetation. That is, it is unclear exactly what our results mean with regard to plant appearance. It is likely to be different for different species, physiognomic categories, and climates. Ganguly et al. (2010) conducted studies at Hubbard Brook and at Harvard Forest, both New England broadleaf deciduous forests relatively close to one another, about 200 km apart, which describe vegetation appearance during phenological transition dates. However, these forests are in the same thermally controlled climate, so variability is likely less than in moisture-controlled regions. Also, temperate deciduous forests are generally less species-diverse than tropical ecosystems.

Our study made a second major assumption, that MLD could be represented by a single annual dormant period despite the possibility of multiple growth seasons. For example, some tropical areas experience multiple wet and dry periods per year as the ITCZ moves overhead and poleward and then returns on its migration to the opposite hemisphere. Additionally, seasonal crop rotation in agricultural areas often results in multiple growth cycles in a given year. We made this assumption to simplify data analysis in the face of limited time, resources, and known issues with the MCD12Q2 data. Because pixels can contain incomplete cycles in a given data year (e.g., OG_Inc, OG_Max, and OG_Dec, but no OG_Min for a given pixel in a given year) (Friedl 2012b), creating a methodology that accommodated more than one annual dormant period for extensive areas

was beyond the research team's capabilities and resources. The consequences of assuming a single dormant period are overestimation or underestimation of MLD, primarily in agricultural areas and regions where phenological change is controlled by moisture availability. Unfortunately, there is currently no quantitative way to identify areas where either MLD overestimation or underestimation likely occurred.

Because of the massive scale of the natural background effort (25 countries) and the need for results to be highly generalized, this study did not consider the effects of specific vegetation disturbances, such as disease, insect outbreaks, and fire. However, it is important to mention that such disturbances can occur over very short periods of time, can have drastic effects on the appearance of natural backgrounds, and would certainly contribute to both inter-annual and spatial variability in the phenology results. For example, a widespread fire could result in an abnormally timed OG_Min; and the following OG_Inc would likely be representative of whatever recovered vegetation grows back first rather than the established land cover documented by GLC2000.

As observed by Ganguly et al. (2010), land-cover type often exerts strong control on phenology and thus provides an appropriate means of generalizing phenology results. However, it is important to recognize that presenting phenology results in this manner introduces additional potential error to satellite data as the data resolution is already generalized over a 500×500 m area. Depending on geographic location, vegetation type and species distribution throughout an area this large are often heterogeneous. As such, the value of a given pixel reflects an integrated value of the different vegetation types represented within.

Another potential source of error was using GLC2000 defined Woodland and Transitional areas to present the phenology results. The GLC2000 dataset has a known accuracy of about 70% (Neumann et al. 2007), has coarser spatial resolution than the MODIS data, and is representative of only the year 2000. The MODIS Land Cover Type Product (MCD12Q1) may be a more appropriate dataset for future phenological classification efforts. The MCD12Q1 dataset is a yearly product with the same resolution as the MCD12Q2 data.

Efforts to validate MODIS data by using ground measurements are still ongoing due to challenges in scaling ground measurements, geo-location

uncertainties, field-instrument calibration, and limited ability to sample ground data over comparable lengths of time and space to that of the satellite (Ganguly et al. 2010). Recent studies, such as Hmimina et al. (2013), using ground-based measurements to evaluate the effectiveness of using MODIS data to predict vegetation phenology have found that effectiveness is strongly affected by the location and the types of vegetation being assessed. Hmimina et al. (2013) found that among five biomes—temperate deciduous forests (beech and oak), evergreen forest, tropical rainforest, African savanna, and successional cropland—MODIS-derived phenological estimates are the most accurate for deciduous forests and the least accurate for tropical rainforests.

Considering the assumptions and potential sources of error, our analytical methods used the best data available from MODIS and NASA, data that is being used to track climate-change-induced phenology changes. The most complete natural background analysis to date that included seasonal change in vegetation appearance was conducted over 50 years ago by using climate data and world atlas information (Chambers and Dalrymple 1956). The current database and algorithms, and the assumptions necessary, provide the best information available for determining the portion of a year when vegetation appearance changes from that of a verdant background to that of a dormant background. Clearly, additional research is necessary to address the assumptions and sources of error discussed.

6   Conclusion

In this study, the MODIS Land Cover Dynamics Product (MCD12Q2) allowed us to present quantitative estimates for the mean length of dormancy experienced by Woodland and Transitional areas in all vegetated areas of interest. Our estimates for MLD provided insight regarding the appearance of vegetation, one of the main components of natural backgrounds, thus providing the Phase IV effort with valuable decision aides. Despite our assumptions and potential sources of error in the MCD12Q2 data and in our methodology, estimating MLD by measuring the number of days between the onset of dormancy (OG_Min) and the onset of greenup (OG_Inc) resulted in reasonable MLD values, considering the scale of the analysis and the desired generalization of the results.

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14. ABSTRACT

Seasonal change, expressed as phenological stage, controls color and texture of natural vegetation as it cycles through greenup, verdancy, senescence, and dormancy. For the Army Product Manager Soldier Clothing and Individual Equipment (PM SCIE) Phase IV Camouflage Effort, we quantitatively estimated the number of days between the onset of dormancy and the onset of greenup in 25 countries over a wide range of climates and latitudes. Global land cover was lumped into Arid, Transitional, and Woodland types; and dormant periods were determined for the latter two cover types. Phenological stage transition dates were mapped from the 500 m resolution MODIS Land Cover Dynamics Product (Friedl 2012a) derived from the Enhanced Vegetation Index. We found that the mean length of dormancy (MLD) varies with climate and with cover type. Higher latitude seasonal change is predominantly thermally controlled, and lower latitude change is predominantly moisture-controlled. Thermally controlled seasons exhibit less-variable MLDs than moisture-controlled seasons. It is unclear exactly what our results mean with regard to plant appearance as few validation field studies have been conducted in many climate and cover types. Considering the scale of the analysis and the desired generalization of the results, our study resulted in reasonable MLD values.

15. SUBJECT TERMS		
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Enhanced Vegetation Index	MODIS	Season
	Moisture	Thermal

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