

## Assessment of the MODIS Leaf Area Index Product (MOD15) in Alaska

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The Moderate Resolution Imaging Spectroradiometer (MODIS) Leaf Area Index (LAI) Product (MOD15A2) was evaluated for the growing seasons of 2000 through 2004 in Alaska. The LAI estimate may be affected by three factors not directly related to canopy leaf area: snow melt, cloud contamination and conifer forest versus broadleaf shrub canopy type. Increases in MODIS LAI values occurred during the snowmelt period, prior to leaf flush along an elevation gradient in central Alaska. This false LAI increase prior to broadleaf budburst could lead to an overestimate of growing season length based on the MODIS LAI product. During the spring greenup period, there were temporal dips in MODIS LAI estimates for up to 57% of the pixels. This decrease in MODIS LAI value was likely due to cloud contamination, despite use of the MODIS quality control information to select pixels that were cloud-free. The MODIS LAI algorithm may be sensitive to variation in near-infrared reflectance due to canopy type rather than leaf area. For example, coniferous boreal forests typically have a higher LAI than shrub tundra. However, the maximum seasonal LAI estimate from the MODIS product was consistently higher from shrub tundra areas compared to coniferous boreal forest areas. There was a strong correlation of the MODIS LAI estimate with MODIS near-infrared reflectance among conifer and broadleaf shrub frames. This could lead to overestimates of LAI in areas where coniferous forest is replaced by broadleaf shrub following wildfire in boreal forest regions.

### 1. Introduction

Leaf area index (LAI) is a biophysical variable influencing transpiration and photosynthesis at the plant canopy scale, and carbon, water and energy dynamics at the regional scale. Remotely sensed LAI estimates are available as a standard global 8-day composite product (MOD 15A2) delivered from spectral data acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) as part of the Earth Observing System (EOS).

The MODIS algorithm compares MODIS directional spectral reflectances with model-based entries for six biome types stored in a look-up-table and then derives a distribution of possible solutions. If the look-up method fails to localize a solution, a back-up method based on the relationship between the normalized difference vegetation index (NDVI) and LAI is used with a biome classification (Knyazikhin *et al.* 1999). For detailed information about the MODIS LAI product, see Knyazikhin *et al.* (1998, 1999).

Validation of global MODIS products is important to establish the accuracy of the products from different regions of the globe, and to provide feedback to improve

the data processing algorithms (Cohen and Justice 1999). It is difficult to validate directly the MODIS LAI estimates because of differences in spatial and temporal scale between the 8-day composite, 1-km MOD15A2 product and higher spatial resolution satellite sensor imagery or field-based LAI estimates. Even field-based estimates of LAI can vary substantially depending on methodology (Asner *et al.* 2003, Hyer and Goetz 2004).

The MODIS LAI product has been assessed for savannah and shrub in southern Africa (Myeni *et al.* 2002, Tian *et al.* 2002), broadleaf forest in eastern United States (Shabanov *et al.* 2003) and agricultural, tall grass prairie, broadleaf forest and boreal forest sites in North America (Cohen *et al.* 2003). The MODIS LAI product has not been adequately assessed for high latitude regions such as the tundra and boreal forest regions of Alaska. The accuracy of MODIS LAI estimates in these regions is suspect for several reasons. First, the MODIS radiative transfer and empirical backup methods of estimating LAI both depend on a biome-specific land cover type. Unfortunately, the cover type of tundra is not included in the MODIS LAI/FPAR (Fraction of Photosynthetically Active Radiation) land cover classes. Also some areas in Alaska are incorrectly classified in the MODIS land cover product as savannah or grassland. Second, the MODIS LAI algorithm backup method depends on a biome-specific empirical relationship between LAI and the NDVI. However, the relationship between LAI and NDVI is confounded by the canopy background (Nemani *et al.* 1993). NDVI can vary by as much as 0.30 units at a LAI of 1 due to different canopy background conditions (Huete *et al.* 1985, Bausch 1993). Both the empirical NDVI method and the main radiative transfer method in the MODIS LAI algorithm may be influenced by a change in canopy background during the spring snowmelt period prior to leaf flush. Third, the LAI quality control bits allow the user to screen cloud-contaminated pixels. However, the cloud detection algorithm used in the processing of MODIS data before input to the LAI algorithm may not accurately flag cloud-contaminated pixels in high latitude boreal forest and tundra regions where cloud cover can be a persistent problem (Cihlar and Howarth 1994, Hope *et al.* 1999).

## 2. Objectives

The objective of this Letter is to assess some potential problems with the MODIS LAI product for the Alaska region, by examining the pattern of LAI estimates before and after spring leaf flush across an elevational gradient, and by examining the maximum LAI in selected shrub tundra and coniferous boreal forest areas.

## 3. Methods

MOD15A2 tiles covering most of Alaska (H10V02, H11V02, H12V02) from 2000 to 2004 were acquired for the 8-day composite periods during the growing season of May to September. The Version (Collection) 4 data were reprojected from a sinusoidal projection to Albers equal area projection as 1-km pixels using the MODIS Reprojection Tool. Cloud-free pixels were selected using MODIS Quality Control (QC) bit fields (table 1). Pixels with bit values indicating cloud-free pixels and Main RT method used with best possible results (00000000 and 00000001) were selected for analysis.

Table 1. Quality control bit fields for MOD15A2 Collection 4 LAI product.

| Bit fields | QC variable   | Possible bit values  |
|------------|---------------|--|
| 0-1        | MODLAND_QC    | 00*=Best possible<br>01*=OK, but not the best<br>10=Not produced due to cloud<br>11=Not produced due to other reasons  |
| 2-2        | DEAD-DETECTOR | 0*=Detectors apparently fine from up to 50% of channels<br>1,2<br>1=Dead detectors caused >50% adjacent detector retrievals  |
| 3-4        | CLOUDSTATE    | 00*=Significant clouds not present (clear)<br>01=Significant clouds were present<br>10=Mixed cloud present on pixel<br>11=Cloud state not defined, assumed clear   |
| 5-7        | SCF_QC        | 000*=Main RT method used with best possible results<br>001=Main RT method used with saturation<br>010=Main RT method failed due to geometry, NDVI method used<br>011=Main RT method failed due to other problem, NDVI method used<br>100=Could not retrieve pixel<br>111=Non terrestrial biome |

\* indicates QC values selected in this study.

### 3.1 Spring greenup

Spring greenup in interior Alaska typically begins in mid-May and peaks in July. The change in MODIS LAI estimates during this period was assessed for a 100 km by 100 km frame near Fairbanks, Alaska. Since the LAI pixels were screened for cloud contamination by using the MOD15 quality control bits, the pattern of mean LAI values was expected to increase steadily from May until a peak LAI in July with no decreases in LAI values during the greenup period.

Spring budburst of broadleaf forest trees near Fairbanks occurs first in May on low elevation, south-facing forested slopes. The MODIS LAI estimates were expected to be low and stable until well after the broadleaf budburst period during May. The temporal pattern of MODIS LAI estimates was assessed for three 25 km × 25 km frames across an elevational gradient. The 25 km × 25 km frames were centred over a low-elevation, floodplain boreal forest, a high elevation alpine boreal forest and an alpine tundra region (table 2). The mean MODIS LAI values

Table 2. Elevation of 25 km × 25 km frames used in elevational transect.

| Frame                                  | Description             | Elevation (m) |                    |
|--|-------------------------|---------------|--------------------|
|  |                         | Mean          | Standard deviation |
| BNZ                                    | Lowlands boreal forest  |               |                    |
| Bonanza Creek LTER Site                |                         | 180           | 78                 |
| CPCRW                                  | Highlands boreal forest |               |                    |
| Caribou-Poker Creek Research Watershed |                         | 474           | 160                |
| SUMMIT                                 |                         |               |                    |
| Eagle Summit                           | Alpine tundra           | 876           | 170                |

from the low elevation frame should not have increased until well after the spring budburst dates. Increases in mean MODIS LAI were expected to occur later at the high elevation boreal forest frame and latest from the alpine tundra frame.

### 3.2 *Shrub tundra versus coniferous boreal forest*

Landsat-7 Thematic Mapper scenes from the 1990s were used to select large areas of coniferous boreal forest and shrub tundra in Alaska. The areas were selected visually by displaying scenes as colour infrared images with shrub tundra areas appearing bright red and coniferous forests appearing purple. An Alaskan fire scar database (Kasischke *et al.* 2002) was used to avoid any areas that have burned in the past 50 years. Frames (25 km) were delineated within five shrub tundra areas and five coniferous boreal forest areas throughout Alaska (figure 1). The mean maximum MODIS LAI value was extracted from each 25-km frame for the period of May to September 2000 to 2004.

## 4. Results and discussion

### 4.1 *Spring greenup*

A decrease in LAI estimates during the spring greenup periods occurred in 7–57% of the pixels (table 3). A possible reason for a decrease in LAI estimates on a pixel-basis is that the MODIS algorithm may not estimate LAI accurately for an individual pixel due to uncertainties in inputs, but the mean of multiple estimates over a multiple pixel patch may be accurate (Wang *et al.* 2004). Another possible reason for decreases in LAI estimates is cloud contamination of pixels that were supposed to be cloud-free according to the QC bit fields used in this study.

MODIS mean LAI estimates increased before leaf flush actually occurred on low elevation, south-facing slopes (figure 2). The mean LAI estimates also increased from the mid-elevation frame before spring budburst occurred at the low elevation

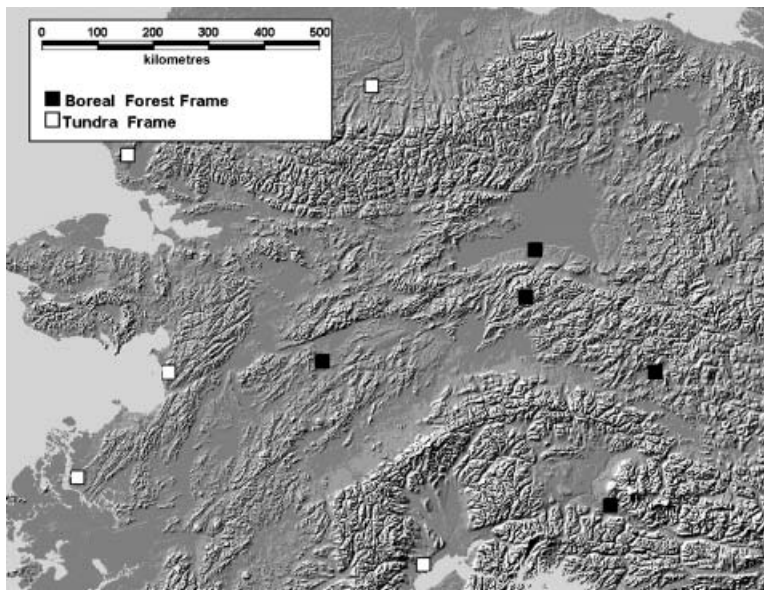


Figure 1. Spatial distribution of 25-km frames where shrub tundra and coniferous boreal forest are the dominant land cover types.

Table 3. Changes in cloud-free MODIS LAI estimate from previous composite period within a 100 km × 100 km frame near Fairbanks (frame comprised 9585 vegetated pixels).

| Julian days      | Date range     | Cloud-free vegetated pixels (%) | Decreased LAI (%) | Increased LAI (%) |
|------------------|----------------|---------------------------------|-------------------|-------------------|
| <i>Year 2000</i> |                |                                 |                   |                   |
| 137–144          | 17–24 May      | 34.8                            | 52.6              | 47.4              |
| 145–152          | 25 May–1 June  | 29.5                            | 29.2              | 70.8              |
| 153–160          | 2–9 June       | 42.1                            | 10.3              | 89.7              |
| 161–168          | 10–17 June     | 80.1                            | 20.5              | 79.5              |
| 169–176          | 18–25 June     | 75.1                            | 27.0              | 73.0              |
| 177–184          | 26 June–3 July | 38.9                            | 57.2              | 42.7              |
| 185–192          | 4–11 July      | 30.1                            | 40.7              | 59.3              |
| <i>Year 2001</i> |                |                                 |                   |                   |
| 137–144          | 17–24 May      | 57.7                            | 51.6              | 48.4              |
| 145–152          | 25 May–1 June  | 54.4                            | 52.9              | 47.1              |
| 153–160          | 2–9 June       | 63.2                            | 11.0              | 89.0              |
| 161–168          | 10–17 June     | 45.9                            | 47.8              | 52.2              |
| 169–176          | 18–25 June     | missing                         | missing           | missing           |
| 177–184          | 26 June–3 July | missing                         | missing           | missing           |
| <i>Year 2002</i> |                |                                 |                   |                   |
| 137–144          | 17–24 May      | 76.2                            | 6.8               | 93.2              |
| 145–152          | 25 May–1 June  | 88.7                            | 11.8              | 88.2              |
| 153–160          | 2–9 June       | 59.6                            | 44.5              | 55.5              |
| 161–168          | 10–17 June     | 55.0                            | 36.6              | 63.4              |
| 169–176          | 18–25 June     | 67.0                            | 35.2              | 64.8              |
| 177–184          | 26 June–3 July | 55.4                            | 47.4              | 52.6              |
| <i>Year 2003</i> |                |                                 |                   |                   |
| 137–144          | 17–24 May      | 47.9                            | 55.5              | 44.5              |
| 145–152          | 25 May–1 June  | 67.2                            | 11.9              | 88.1              |
| 153–160          | 2–9 June       | 89.2                            | 29.0              | 71.0              |
| 161–168          | 10–17 June     | 90.1                            | 15.8              | 84.2              |
| 169–176          | 18–25 June     | 87.6                            | 32.4              | 67.6              |
| 177–184          | 26 June–3 July | 58.6                            | 56.3              | 43.7              |
| <i>Year 2004</i> |                |                                 |                   |                   |
| 137–144          | 17–24 May      | 63.0                            | 18.0              | 82.0              |
| 145–152          | 25 May–1 June  | 57.2                            | 10.5              | 89.5              |
| 153–160          | 2–9 June       | 56.3                            | 40.8              | 59.2              |
| 161–168          | 10–17 June     | 51.6                            | 36.2              | 63.8              |
| 169–176          | 18–25 June     | 50.6                            | 36.8              | 63.2              |
| 177–184          | 26 June–3 July | 36.9                            | 31.5              | 68.5              |

frame. This false increase in LAI may be due to snow and ice melt during the pre-leaf flush period. Reed *et al.* (1994) found that in the Great Plains of the USA, the greatest increase in Advanced Very High Resolution Radiometer (AVHRR) NDVI occurred during the time of snow melt.

There were sometimes decreases in mean LAI estimates during the 2000–2004 spring greenup periods (figure 2). Kang *et al.* (2003) also noted decreased LAI estimates during leaf expansion periods in Korea. This decrease in LAI estimates was likely due to cloud contamination, despite the selection of ‘cloud-free’ QC bit values.

LAI typically increases across the vegetation gradient from tundra to boreal forest (Asner *et al.* 2003, Thompson *et al.* 2004). However, the mean maximum MODIS LAI values were consistently lower from the coniferous boreal forest frames relative to the shrub tundra frames (table 4), possibly due to a higher near-infrared

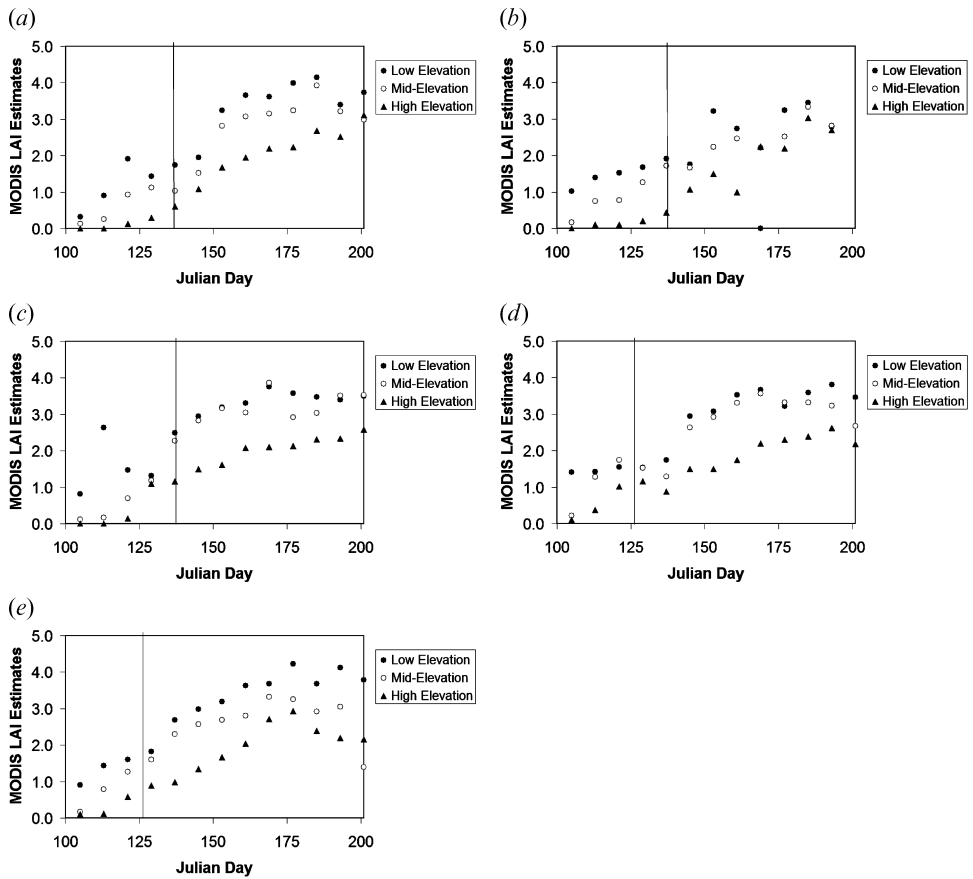


Figure 2. Mean MODIS LAI estimates from 25-km frames along an elevational gradient. Julian dates of broadleaf budburst at a low elevation site (represented by a vertical line) were (a) 2000: 137, (b) 2001: 138, (c) 2002: 138, (d) 2003: 126, (e) 2004: 126.

Table 4. Mean maximum MODIS LAI (MOD15) and near-infrared surface reflectance (MOD9) from cloud-free pixels in  $25 \times 25$  km shrub tundra and coniferous spruce frames.

| Biome         | Ecoregion               | Mean maximum LAI |      | Maximum near-infrared reflectance |       | No. of cloud-free pixels in frame |
|---------------|-------------------------|------------------|------|-----------------------------------|-------|-----------------------------------|
|               |                         | Mean (SD)        |      | Mean (SD)                         |       |                                   |
| Tundra        | Cook Inlet              | 5.3              | 0.46 | 0.41                              | 0.061 | 614                               |
| Tundra        | Arctic Foothills        | 4.8              | 0.43 | 0.38                              | 0.041 | 575                               |
| Tundra        | Seward Peninsula        | 4.7              | 0.67 | 0.37                              | 0.039 | 624                               |
| Tundra        | Subarctic Coastal Plain | 4.4              | 1.21 | 0.38                              | 0.068 | 589                               |
| Tundra        | Subarctic Coastal Plain | 5.2              | 0.46 | 0.38                              | 0.056 | 625                               |
| Boreal forest | Interior Highlands      | 3.8              | 0.71 | 0.26                              | 0.048 | 624                               |
| Boreal forest | Yukon Flats             | 3.5              | 0.83 | 0.21                              | 0.046 | 607                               |
| Boreal forest | Copper Plateau          | 4.0              | 0.77 | 0.23                              | 0.042 | 619                               |
| Boreal forest | Interior Highlands      | 4.1              | 0.79 | 0.25                              | 0.049 | 625                               |
| Boreal forest | Interior Bottomlands    | 3.6              | 0.36 | 0.23                              | 0.038 | 625                               |

reflectance from broadleaf shrub tundra relative to coniferous spruce forest. I used the MOD9 8-day composite surface reflectance product to select the maximum near-infrared reflectance from each cloud-free pixel from 2000 to 2004 growing seasons.

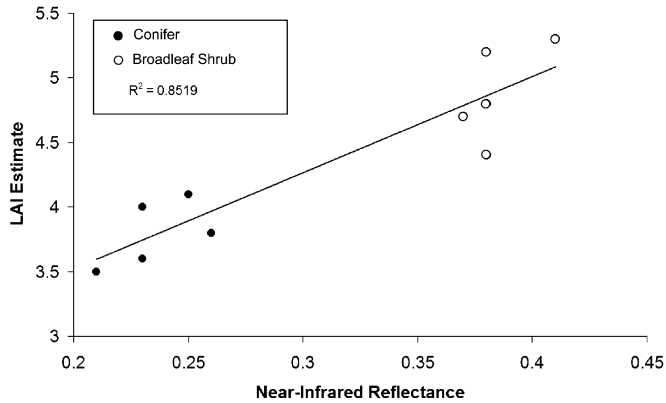


Figure 3. Mean maximum LAI estimates (MOD15) and near-infrared reflectance (MOD9) composited from 2000 to 2004 cloud-free pixels within 25 km × 25 km shrub and conifer frames.

The mean near-infrared reflectance was consistently higher in shrub tundra frames compared to coniferous spruce frames (table 4). There was a strong correlation between MODIS LAI estimates and near-infrared reflectance (figure 3). This may lead to a false increase in LAI estimates following wildfire in boreal forest regions due to the increase in near-infrared reflectance as late succession spruce stands are replaced by early succession broadleaf shrub stands.

## 5. Conclusions

The MODIS LAI product is an evolving product with future improvements anticipated. For the first time, a standard product is available globally on a regular 8-day interval. However, current problems with the LAI product may include a potential for false increase in LAI estimates due to snow melt, cloud contamination in cloudy areas such as Alaska, and higher LAI estimates in shrub tundra relative to coniferous boreal forest areas.

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