47th Annual Alaska Surveying and Mapping Conference Feb. 18-22, 2013

MODIS-derived NDVI and snow climatology for Alaska

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Introduction

The National Park Service and Geographic Information Network of Alaska (GINA) are developing two algorithms to derive NDVI and snow cover climatology for Alaska, respectively. The NDVI metrics algorithm takes as input the MODIS 7-day composite NDVI data. The date go through stacking, filtering and smoothing processes, then combined delay moving average and threshold method is applied to derive 12 NDVI metrics. Initial result shows that the satellite –derived NDVI metrics agrees on-site observation well and can be used to analyze the change of vegetation of Alaska. The snow metrics algorithm involves both data processing and the derivation of snow cover metrics. Terra MODIS snow cover daily 500m grid data (MOD10A1) are processed to reduce cloud obscuration by spatial, temporal, and snow cycle filtering methods. A total of 12 metrics are calculated. Initial snow metrics are compared with three point data sources for evaluation. Evaluation of the metrics generally shows reasonable agreement between satellite-derived metrics and point observations. Snow onset dates show less agreement than snow melt dates because of the effects of cloud cover and polar darkness in early winter.

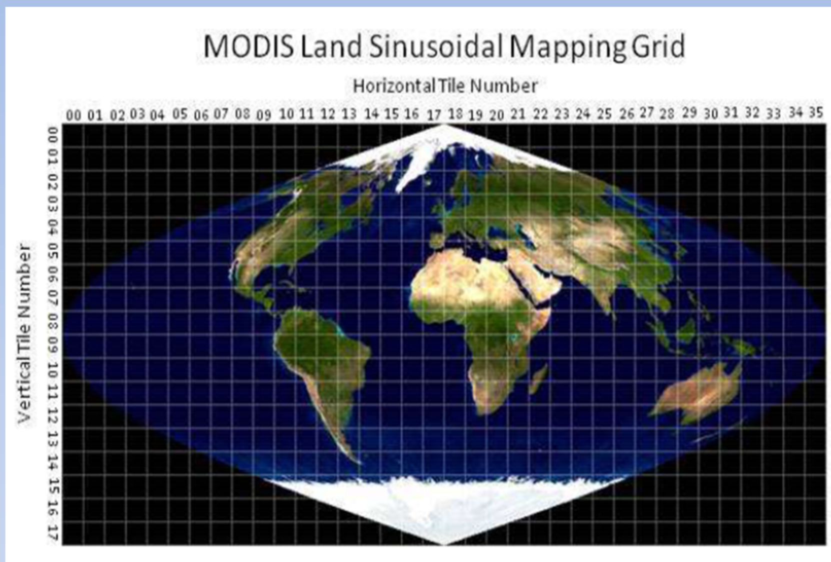
Snow metrics

1. MODIS terra daily snow cover data set

MODIS Terra Snow Cover Daily L3 Global 500m Grid data (MOD10A1)

- --- snow cover, fractional snow cover, Quality Assessment (QA), and snow albedo data
- --- 500 m resolution, 1200 km by 1200 km tile files
- --- sinusoidal map projection
- --- download from National Snow and Ice Data center (NSIDC)

Data pre-process



h06v03, h07v03, h08v03, h09v02, h09v03, h10v02, h10v03, h11v02, h11v03, h12v01, h12v02, h13v01, h13v02, h14v01, h20v01, h23v01, h23v02, h24v02, h25v02, h26v02, h26v03, h27v03, h28v03, h29v03

Fig. 1 MODIS sinusoidal mapping grid

a) download 24 tiles of files which cover all Alaska region.
b) mosaic and re-project into the Alaska Albers Projection (NAD83).
c) output the four scientific fields of snow cover, snow fraction, snow quality, and snow albedo into four single band Geotif files, respectively.

2. Snow metrics algorithm

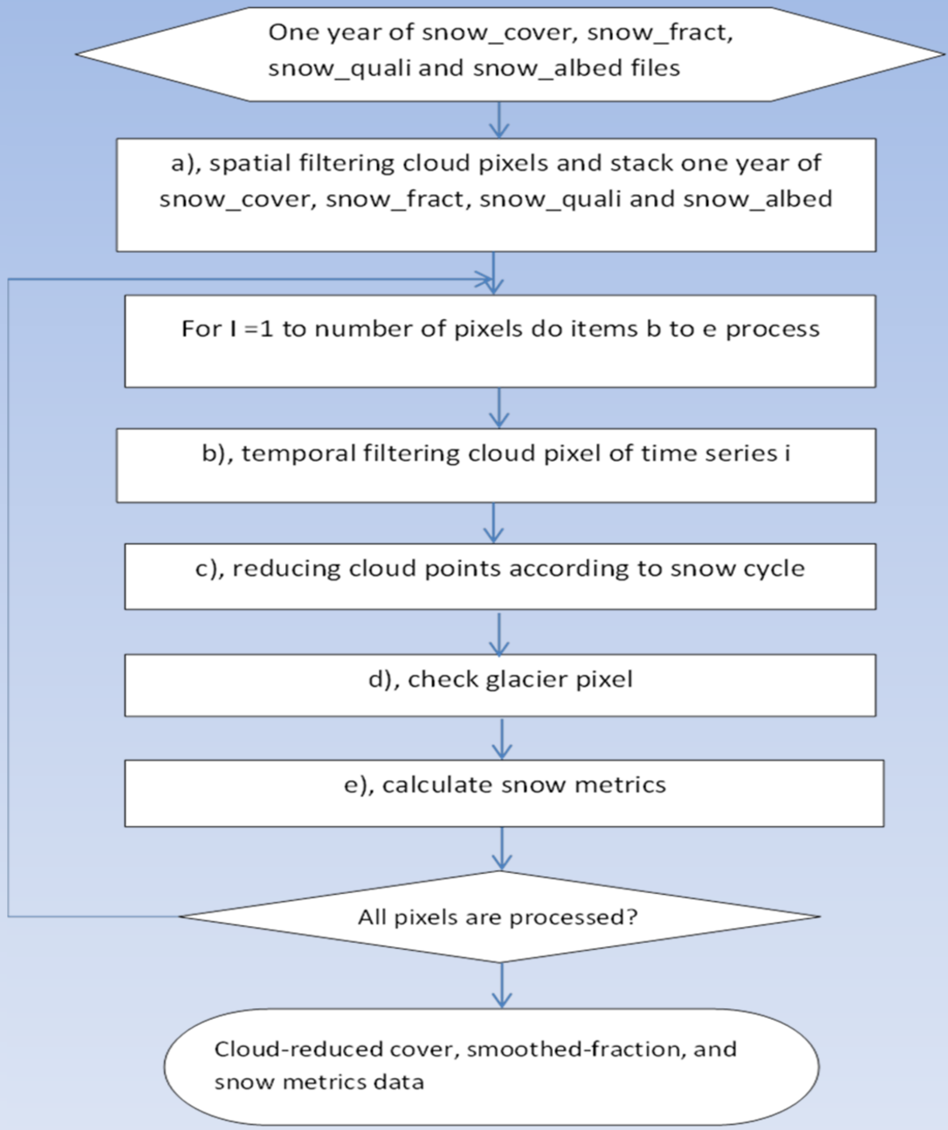
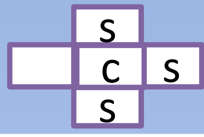


Fig.2 Snow metrics algorithm schema

12 snow metrics:
0-first_snow_day
1-last_snow_day
2-fss_range, last_snow_day-first_snow_day +1
3-longest_css_first_day
4-longest_css_last_day
5-longest_css_day_range, longest_css_last_day-longest_css_first_day +1
6-snow_days
7-no_snow_days
8-css_segment_num, the number of continuous snow season segments
9-mflag, indicate the pixel type(ocean, land or lack/river) and type of snow (no snow, broken snow, or continuous snow)
10-cloud_days
11-tot_css_days, total number of all css segments



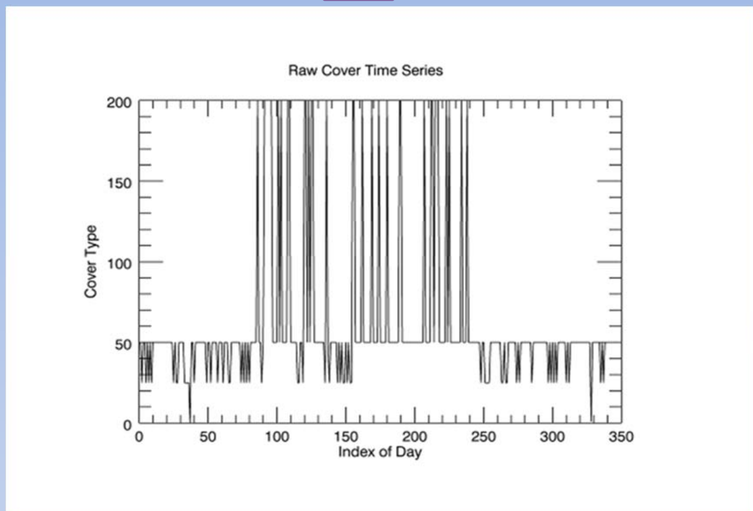


Fig.3 A snow cover time series of 2010 snow-year

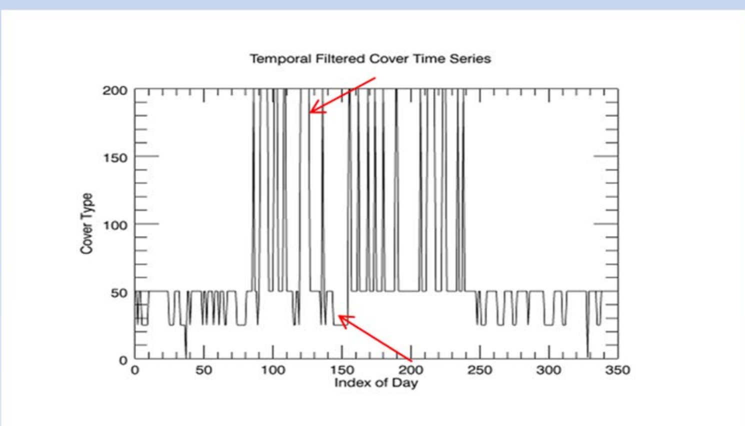


Fig. 4 Temperal filtered time series

a) spatial filtering:

Check each cloud pixel which is not at edge, if ¾ of its orthogonal neighbor pixels are snow, then re-classify the cloud pixel as snow pixel; if ¾ of them are no-snow, re-classify the cloud pixel as no-snow pixel. Then, stack the whole snow-year of files for four different types of files to get four stacked files, respectively. Fig.2 is snow cover time series after spatial filtering of cloud days.

b) temporal filtering:

If one day before and after of the cloud day are snow, re-classify the cloud day as snow day; if otherwise one day before and after of the cloud day are no-snow day, re-classify the cloud day as a no-snow day. Fig.3 illustrates the change of time series after temporal filtering of cloud days.

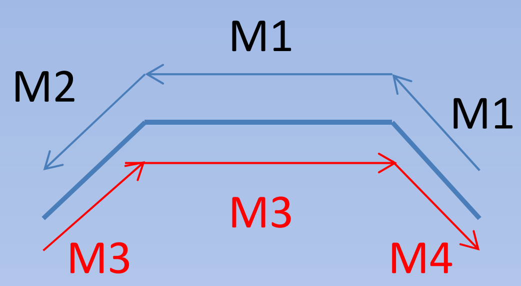


Fig.5 Three segments

c) Snow cycle filtering:
estimate snow accumulation (segment1), snow covering (segment2), and snow melt out period (segment 3) for a time series, then apply 4 different filters on the time series in following sequence.

n	c	s	c	c	c	s	s
n	c	s	s	s	s	s	s

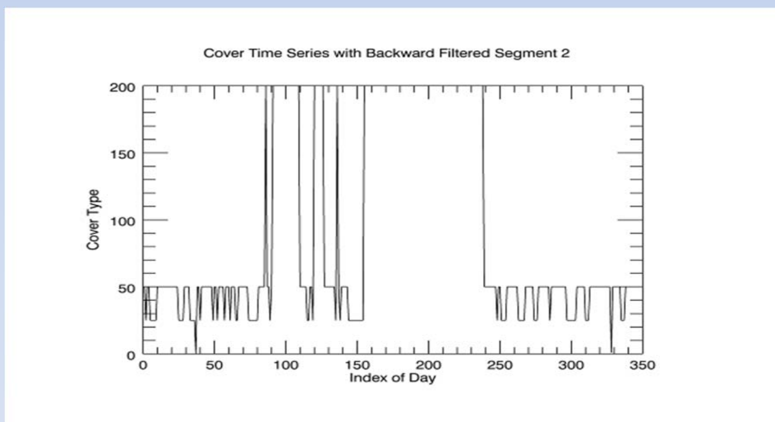


Fig. 6 M1 to segment 3

i Backward filter method 1 (M1)
This method applies to segments 2 and 3. Start from the last day of segment 3. If day i is snow day, and the preceding consecutive days (i-1,i-2,...,i-n) are cloud days, then we re-classify the preceding consecutive days (i-1,i-2,...,i-n) as snow days.

n	c	c	n	c	s	s
n	n	n	n	c	s	s

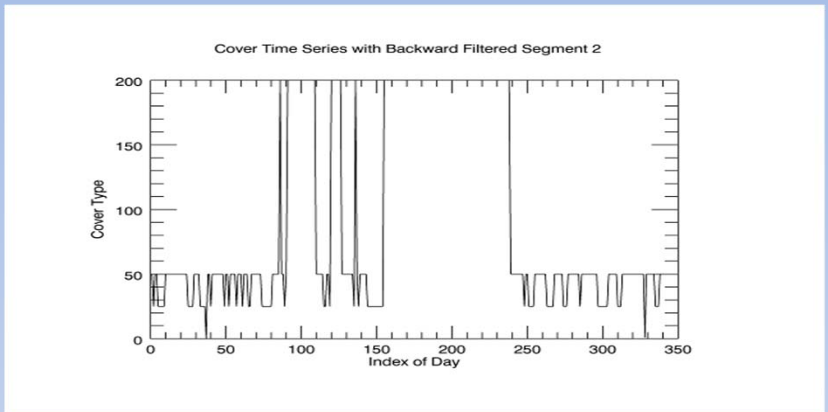


Fig. 7 M2 to segment 1

ii Backward filter method 2 (M2)

This method applies to segment 1. Starting from the last point of the segment 1, if the day i is no-snow and the preceding days (i-1, i-2,.., i-n) are cloud, then we reclassify the days as no-snow days.

n	c	c	s	c	c	s
n	c	c	s	s	s	s

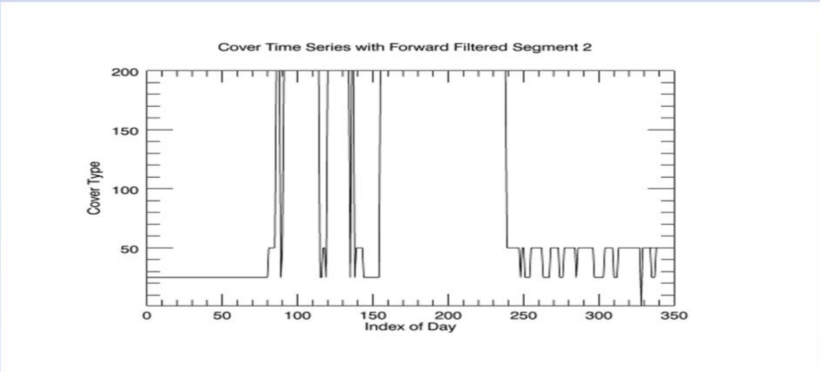


Fig. 8 M3 to segments 1 and 2

iii Forward filter method 3 (M3)

This method applies to segments 1 and 2. Staring from the first day, if the day i is snow, and the following consecutive days (i+1,i+2,...,i+n) are cloud, then we re-classify the following consecutive days(i+1, i+2,..., i+n) as snow.

s	s	n	c	c	c	n
s	s	n	n	n	n	n

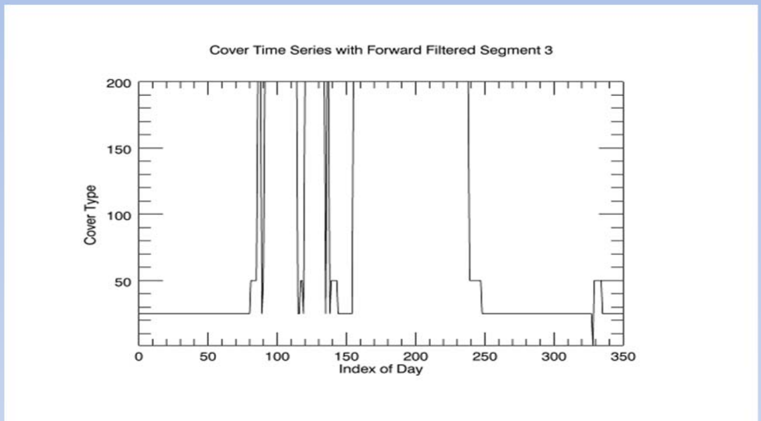


Fig. 9 M4 to segment 3

iv Forward filter method 4 (M4)
Starting from the first day of the segment 3, if day i is no-snow, and the following consecutive days (i+1,i+2,...,i+n) are cloud, then we re-classify the following consecutive days (i+1,i+2,...,i+n) as no-snow.

d) Glacial pixel Identification
If the time series does not have any no-snow, or lake, or ocean points, the time series represents a glacier pixel. For the time series of a glacier pixel, we reclassify all points of the time series as snow points.

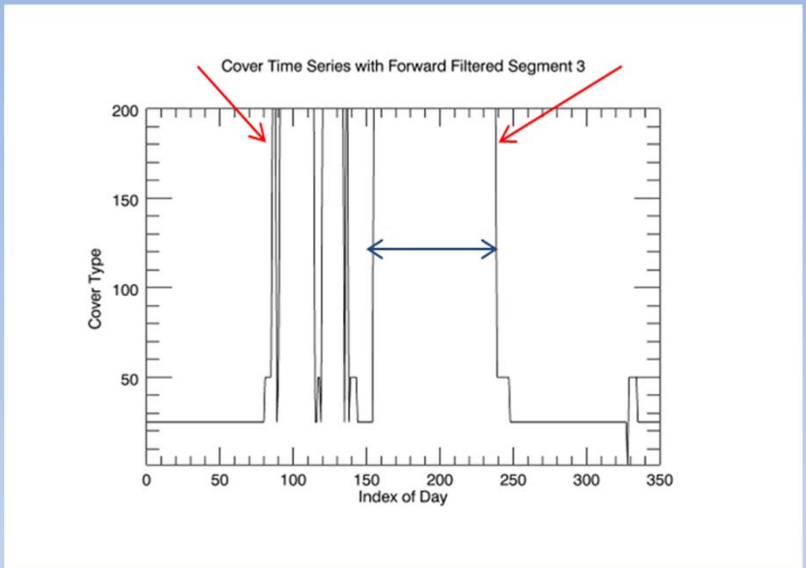
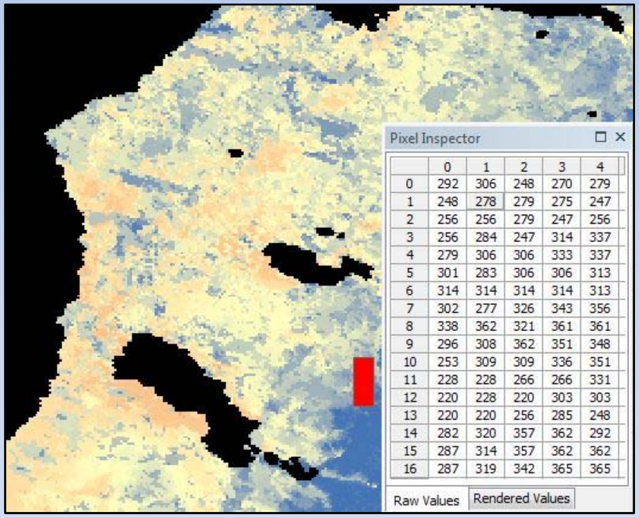


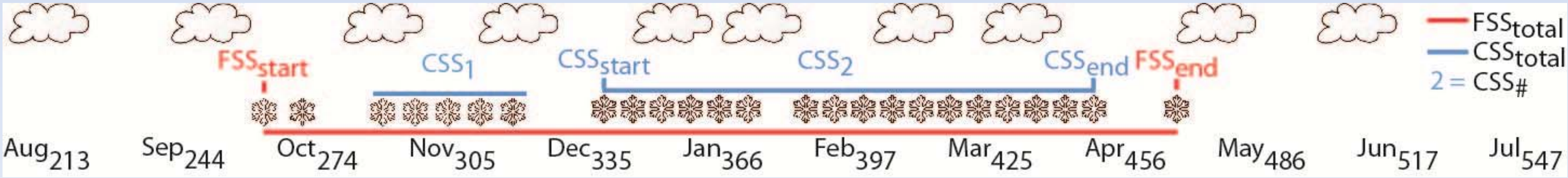
Fig. 10 Some key metrics.
Red arrows point out the first and last snow days. Blue double arrow presents the longest consecutive snow cover segment. They are three CSS segments.

Step e) calculates the snow metrics
Using snow cover to determine the type of the pixel; get snow days, no-snow days and cloud days; identifies the first and last snow days; looks for the time period with snow cover and >50 % snow fraction, within the range from the first snow and the last snow days; check the time period to find out the unbroken segments (>14 days with at most 2 days of no snow days in between); adjust the length of the segment with beginning or ending cloud days; find out how many unbroken segments are consecutive snow cover (CSS) segments ; calculate the total days of all CSS segment, and first and last days of the longest CSS segment; combine the pixel type with snow type and set metrics flag.

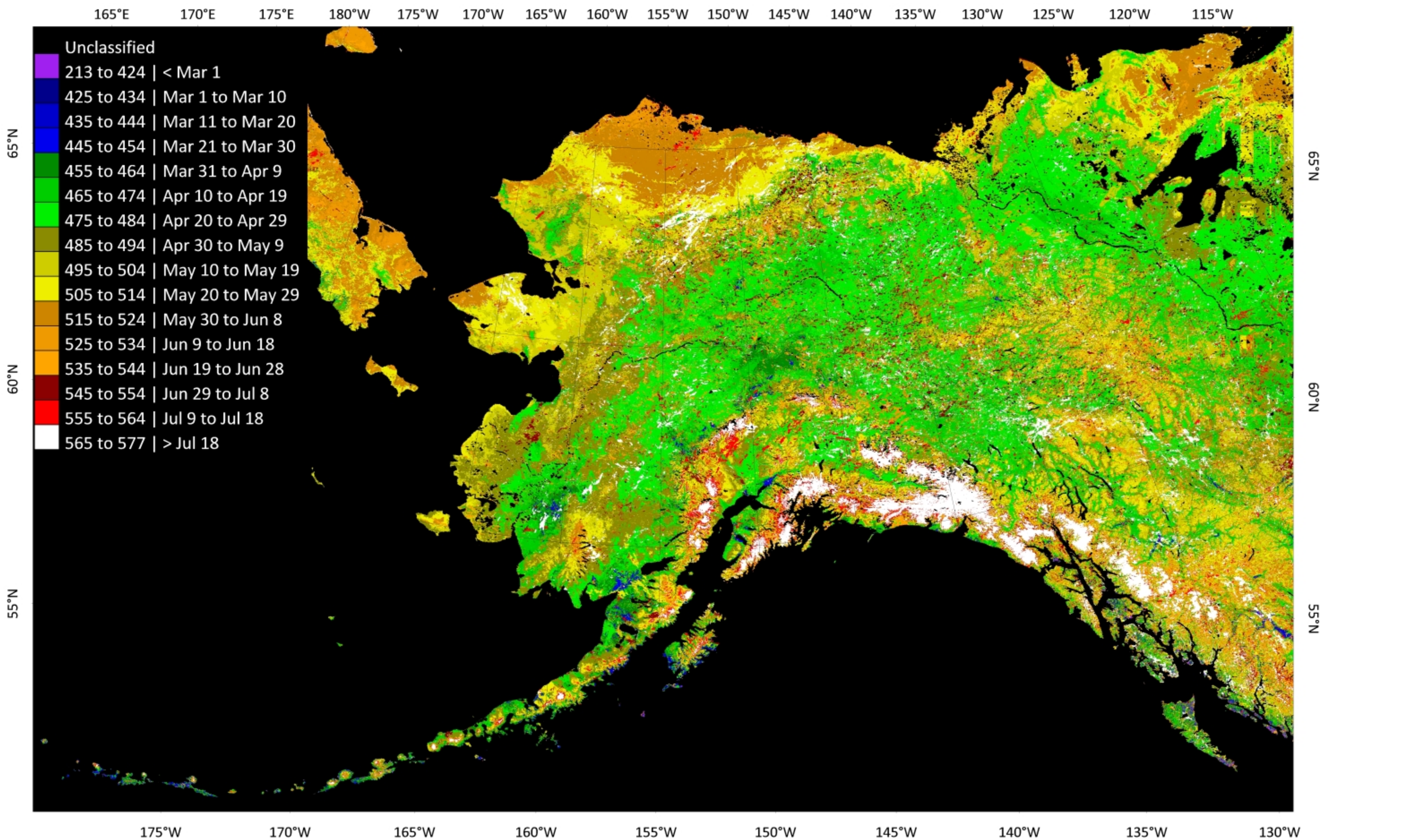
3. Results, validation and summary

- Several iterations 2009-10 snow year
- Metrics output in 12-band GeoTIFF
  - 500m resolution
- Key metrics:
  - Full snow season (FSS)
    - Start and end date, total days
  - Continuous snow season (CSS)
    - >14 days of snow, ≤2 no-snow days
    - Start and end date, total days, # segments

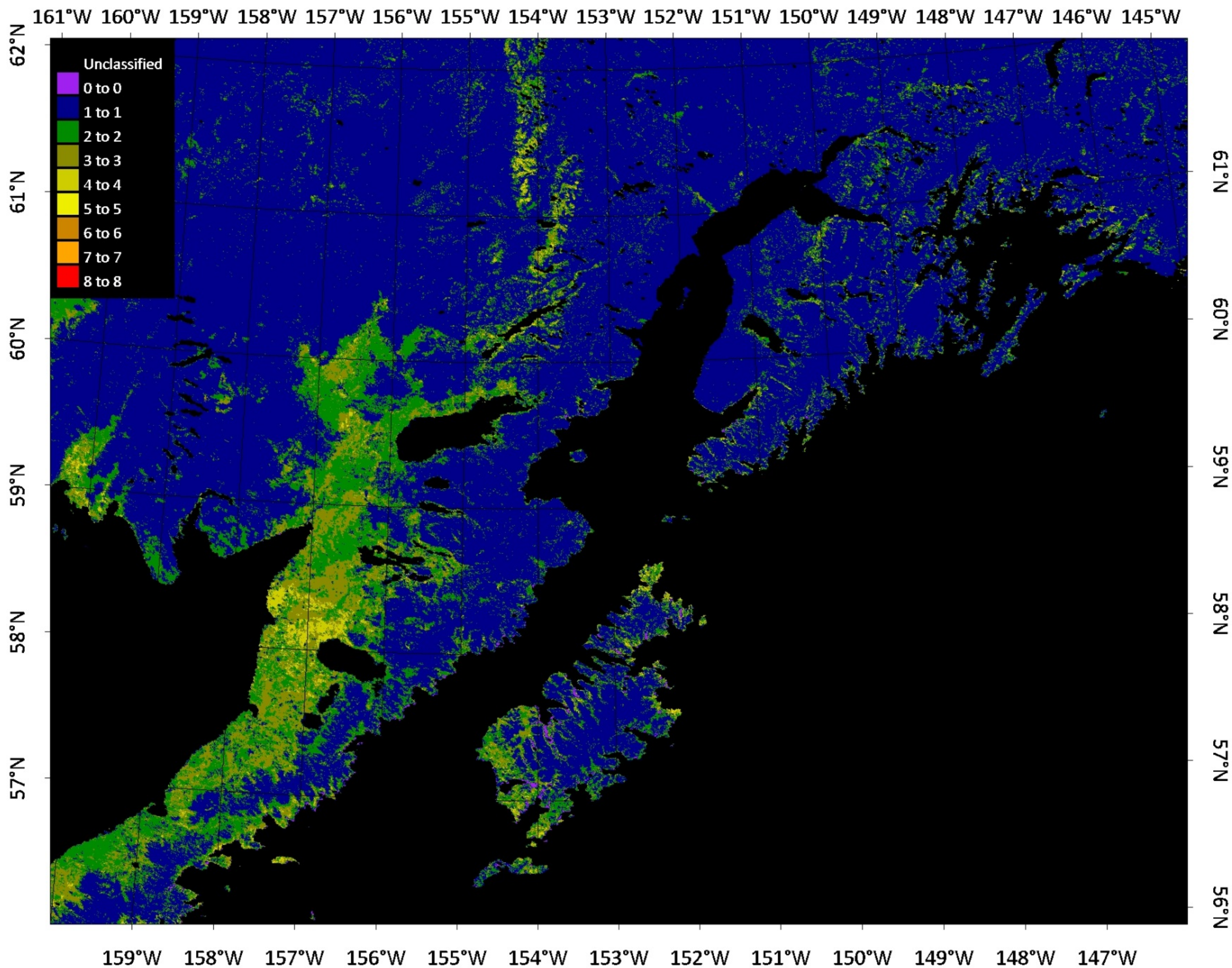




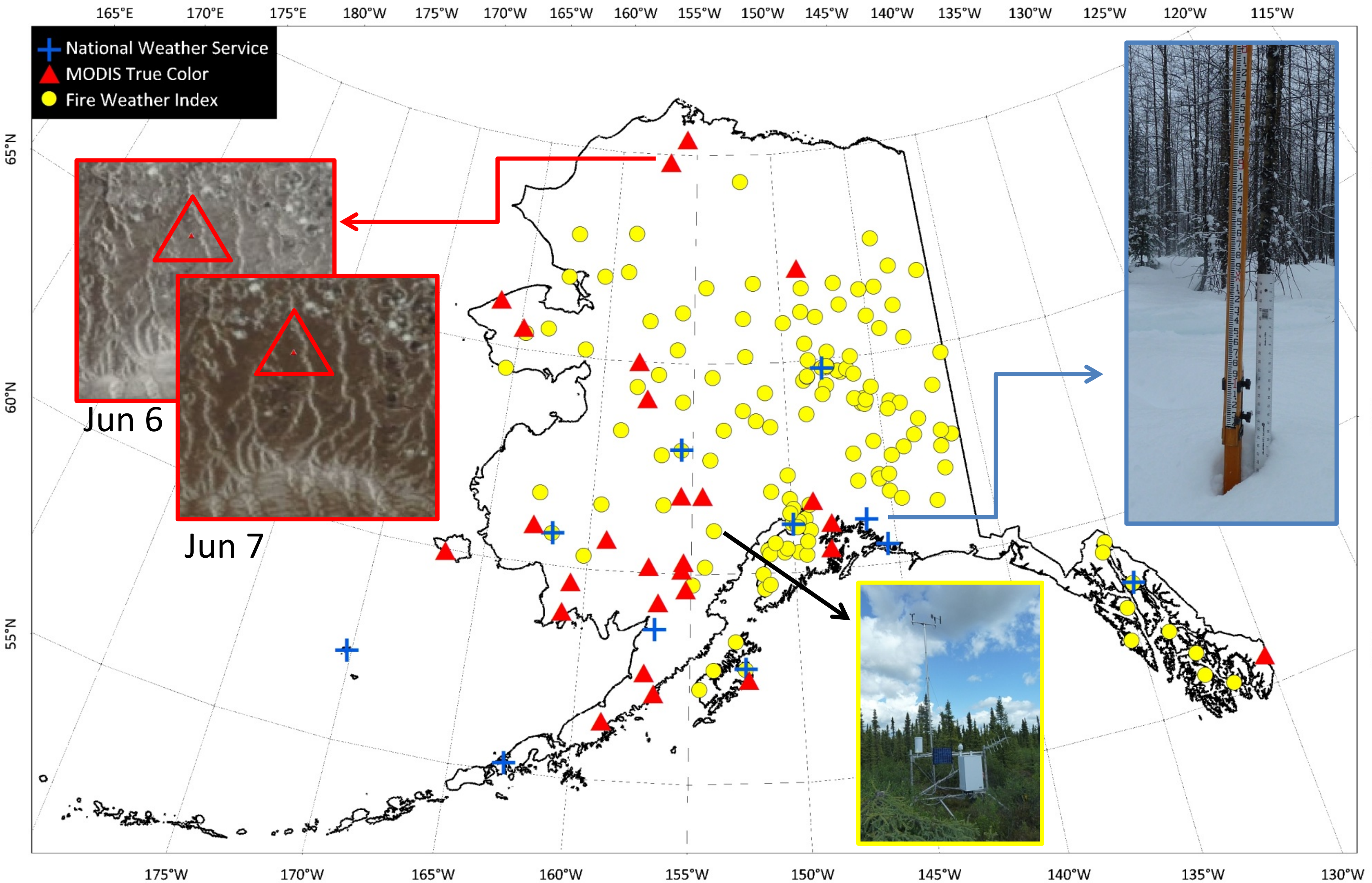
End date - Full snow season

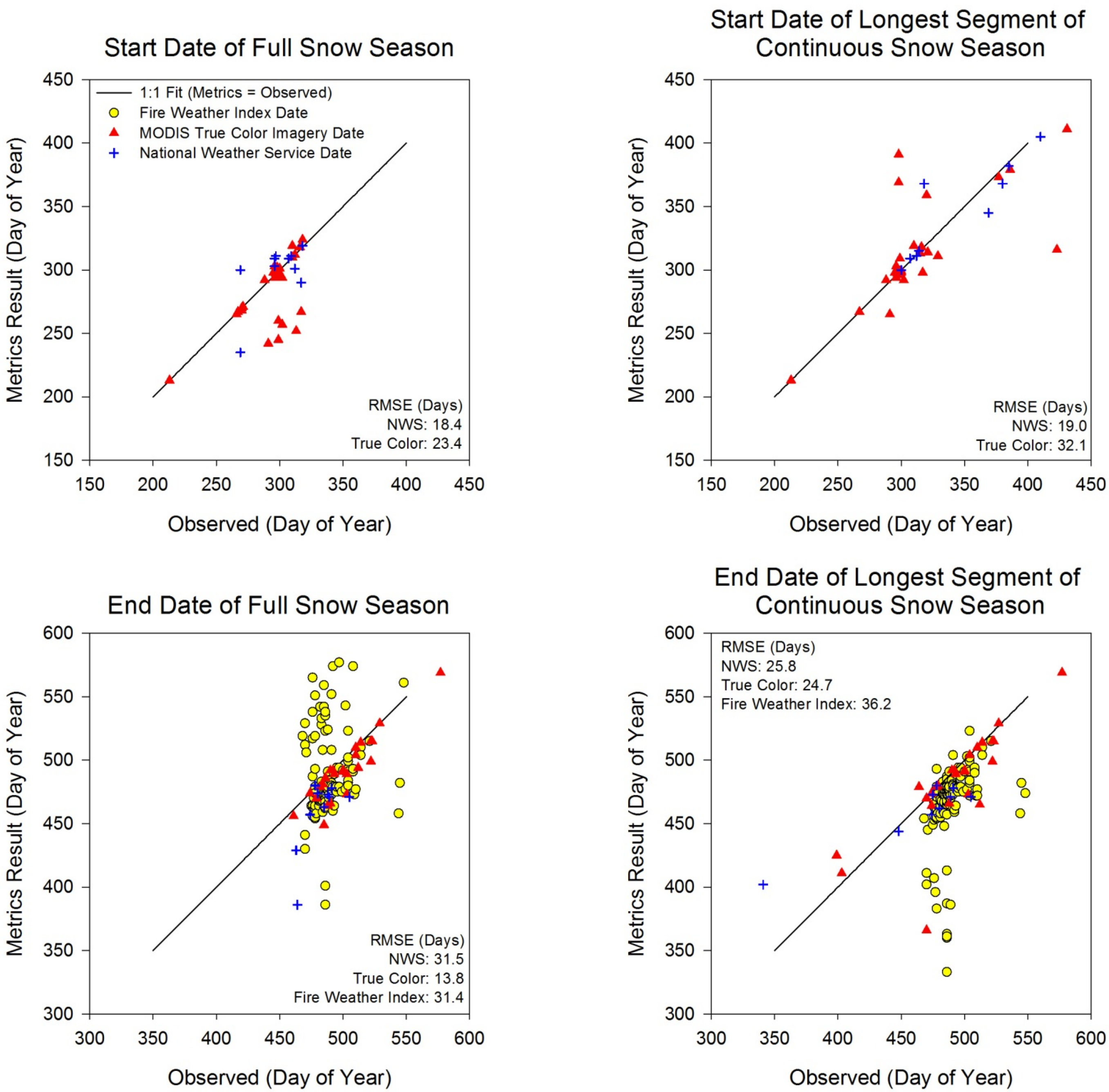


Continuous snow season segments



Evaluation – Point data




Start Date of Full Snow Season
1:1 Fit (Metrics = Observed)
Fire Weather Index Date
MODIS True Color Imagery Date
National Weather Service Date
RMSE (Days)
NWS: 18.4
True Color: 23.4
Metrics Result (Day of Year)
Observed (Day of Year)
Start Date of Longest Segment of Continuous Snow Season
RMSE (Days)
NWS: 19.0
True Color: 32.1
Metrics Result (Day of Year)
Observed (Day of Year)
End Date of Full Snow Season
RMSE (Days)
NWS: 31.5
True Color: 13.8
Fire Weather Index: 31.4
Metrics Result (Day of Year)
Observed (Day of Year)
End Date of Longest Segment of Continuous Snow Season
RMSE (Days)
NWS: 25.8
True Color: 24.7
Fire Weather Index: 36.2
Metrics Result (Day of Year)
Observed (Day of Year)

Summary and validation

- Cloud filtering methods are effective
- Forest canopy is likely still a problem
- Snow metrics are consistent with expected snow accumulation/melt patterns
- Continuous snow season metrics
  - Capture transient nature of snow cover
  - Ecologically relevant?
- Validation
  - General agreement with validation data
  - End date metrics show slightly better agreement with validation data
  - Large error ($\overline{RMSE}_{FSS(\hat{\theta} - \theta)}$ = 21 days)
- Snow metrics are easy to use!
- Next steps: process 2001-12 and share metrics

NDVI metrics

4. MODIS 7-day composite dataset

7-day composite eMODIS Alaska dataset

--- Normalized Difference Vegetation Index (NDVI) data and NDVI quality data (0-good, 1-cloudy, 2-bad, 3-negative, 4-snow, 10-fill)

--- spatial resolution: 250x250 square meters

--- NAD83/Alaska Albers (EPSG3338)

--- GeoTIFF format

--- produced by the U.S. Geological Survey's (USGS) Earth Resources Observation and Science. downloadable the USGS-EROS Data Center eMODIS website (http://dds.cr.usgs.gov/emodis/Alaska/historical/TERRA)

2. NDVI algorithm

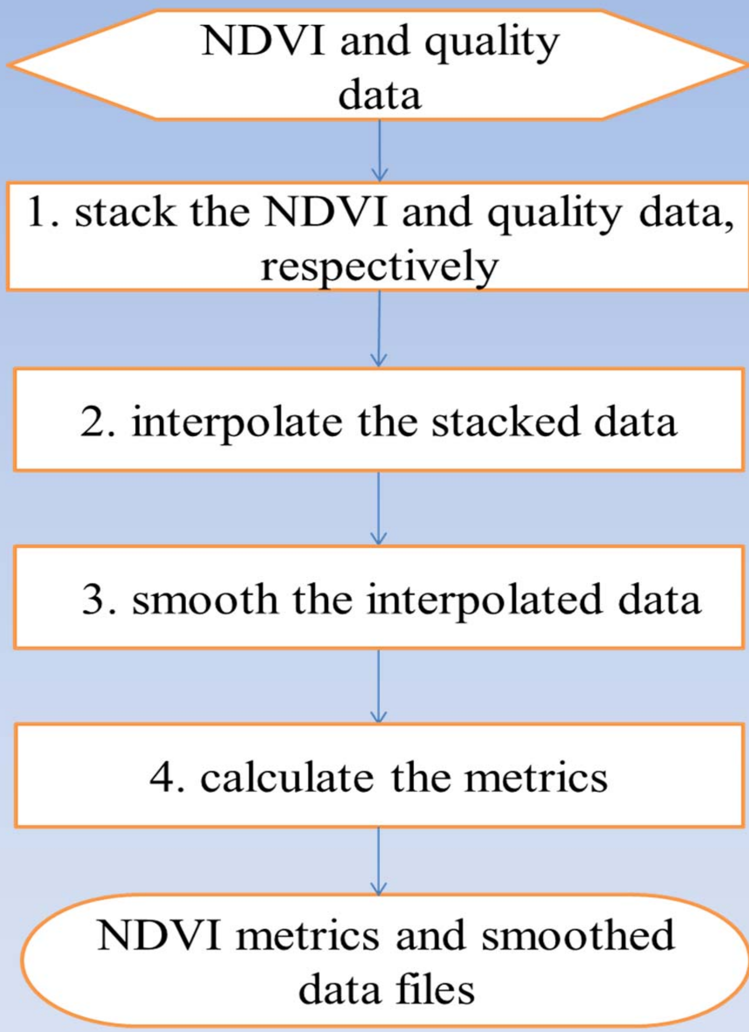


Fig.16 NDVI metrics algorithm schema

12 NDVI metrics:

1. time (Day of year) of start of greenness season (SOS)
2. value of onset of greenness
3. time of end of greenness season (EOS)
4. value of end of greenness
5. duration of greenness
6. time of maximum NDVI
7. value of maximum NDVI
8. range of NDVI
9. rate of green up
10. rate of senescence
11. time-integrated NDVI
12. metrics flag

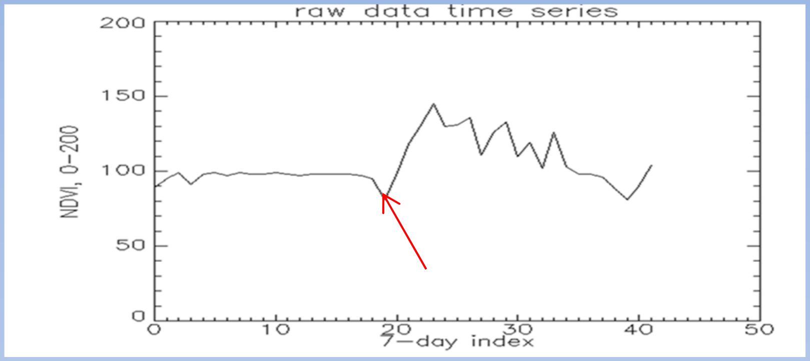


Fig.17 Raw NDVI time series

one year of 7-day composite NDVI and quality data files are stacked into the 42 layers of raster image files, respectively. Fig.17 shows the time series of at a pixel in the stacked file.

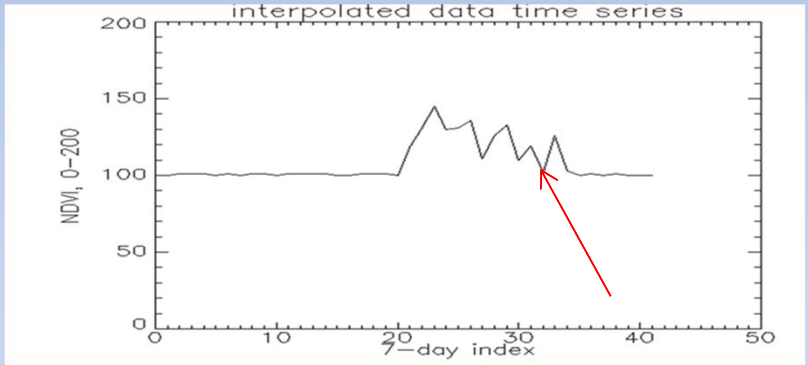


Fig. 18 Interpolated time series

bad data (e.g. < 100, one example of bad data is pointed by the red arrow in Fig. 17) in the raw time series are linearly interpolated (see Fig.18).

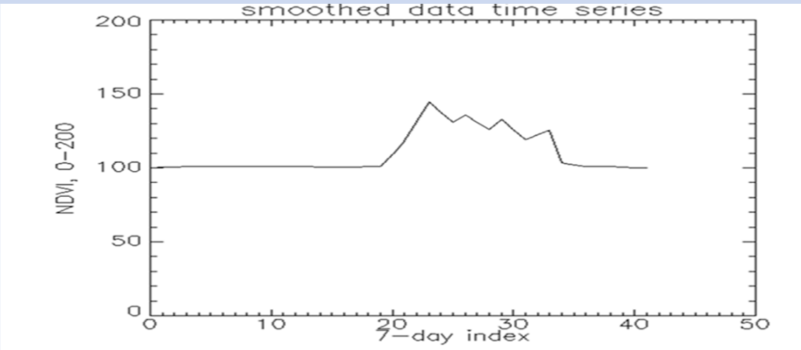


Fig. 19 Smoothed time series

Anomalously low NDVI data(one example is pointed by the red arrow in Fig.18) are taken away, and the weighted least-squares regression is applied to smooth the time series (see Fig.19).

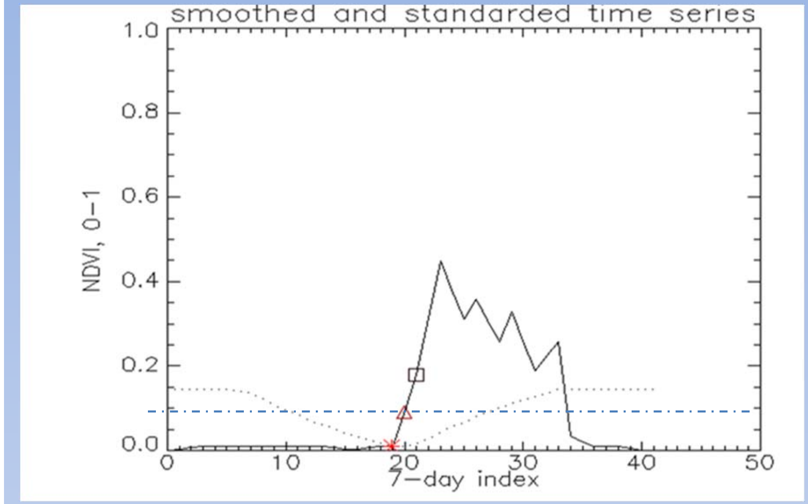


Fig. 20 Determination of start day of greenness

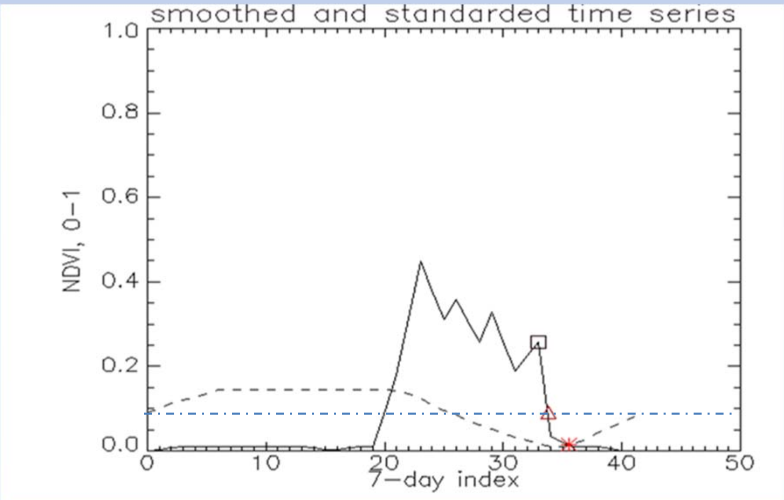


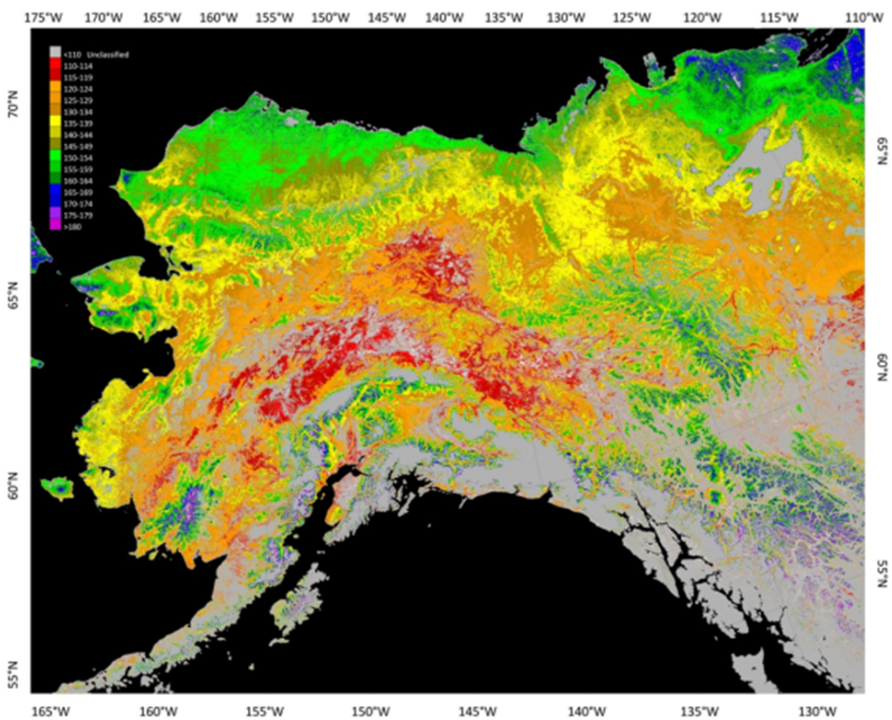
Fig. 21 Determination of end day of greenness

obtain crossover days (indicated with star signs) where the time series crossover from below to the forward delay moving average time series, and threshold day (presented in triangle sign) which is the time series crossover from below to the line with threshold value. Pick out the candidate SOS day from crossover days which is the most close to the threshold day. If the candidate day is before the threshold day, then pick threshold day as SOS day, otherwise, pick the candidate day as SOS day (See Fig. 20). In the similar way, the end day of greenness season (EOS day) is determined, as indicated in Fig.21.

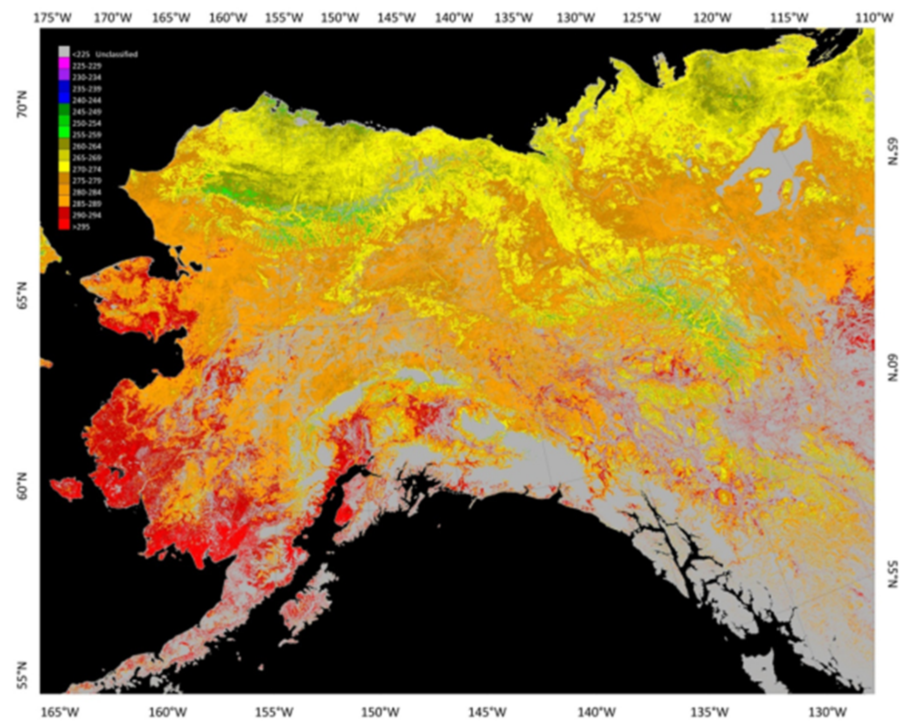
--- **combined delay moving average and threshold method**

3. Applications and summary - NDVI

Average Start of Season (2000-2011)

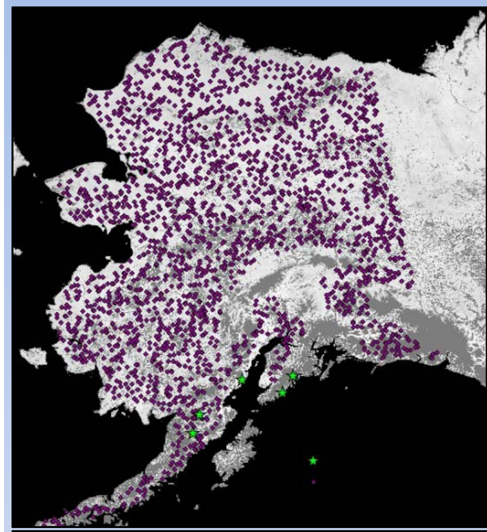


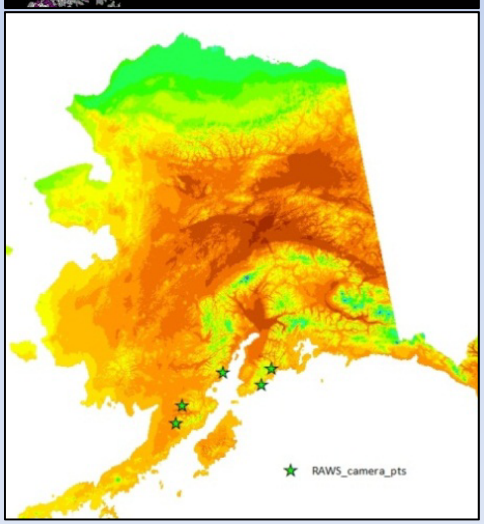
Average End of Season (2000-2011)

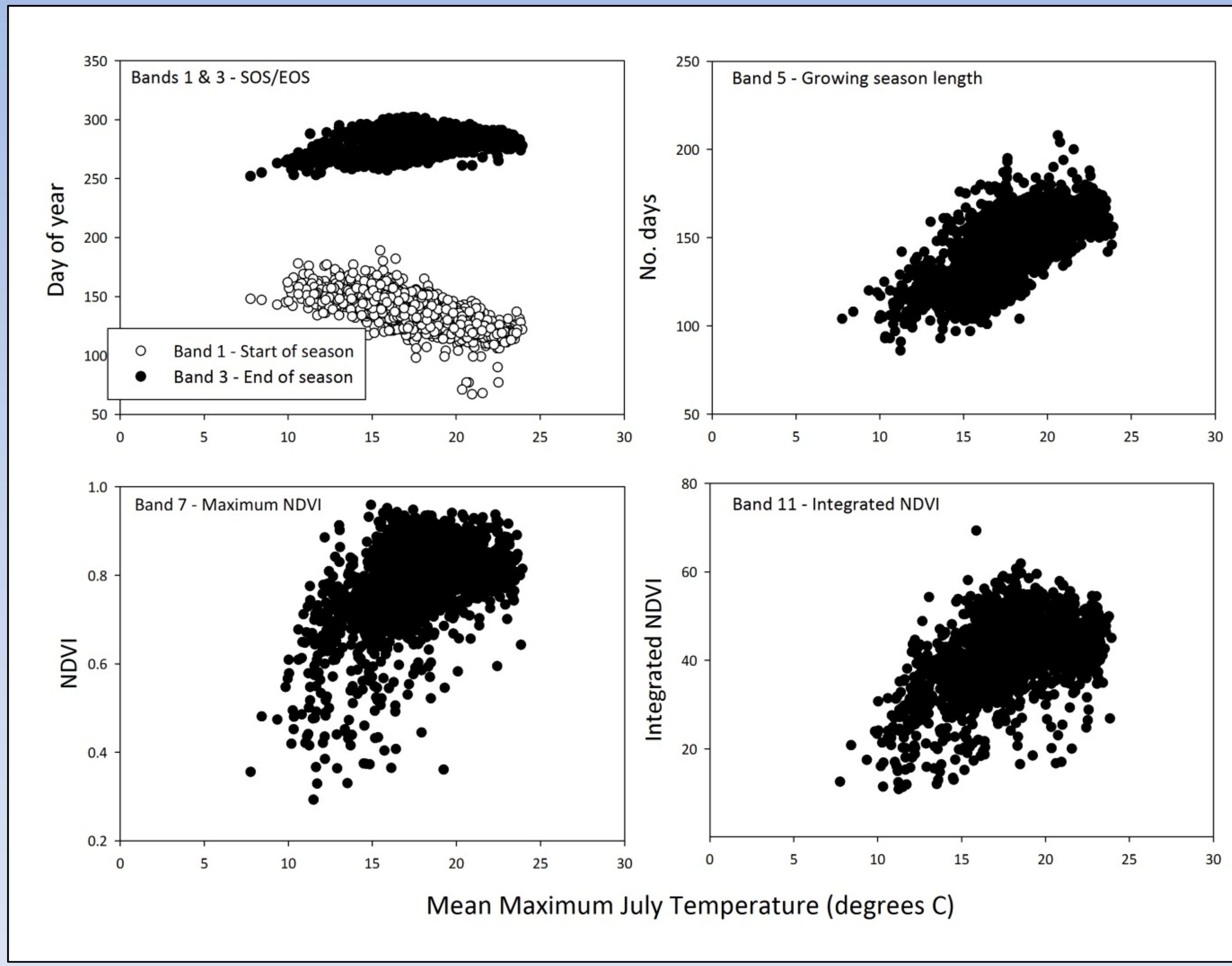


MODIS-NDVI metrics (2000-2011) available at http://ndvi.gina.alaska.edu/metrics?

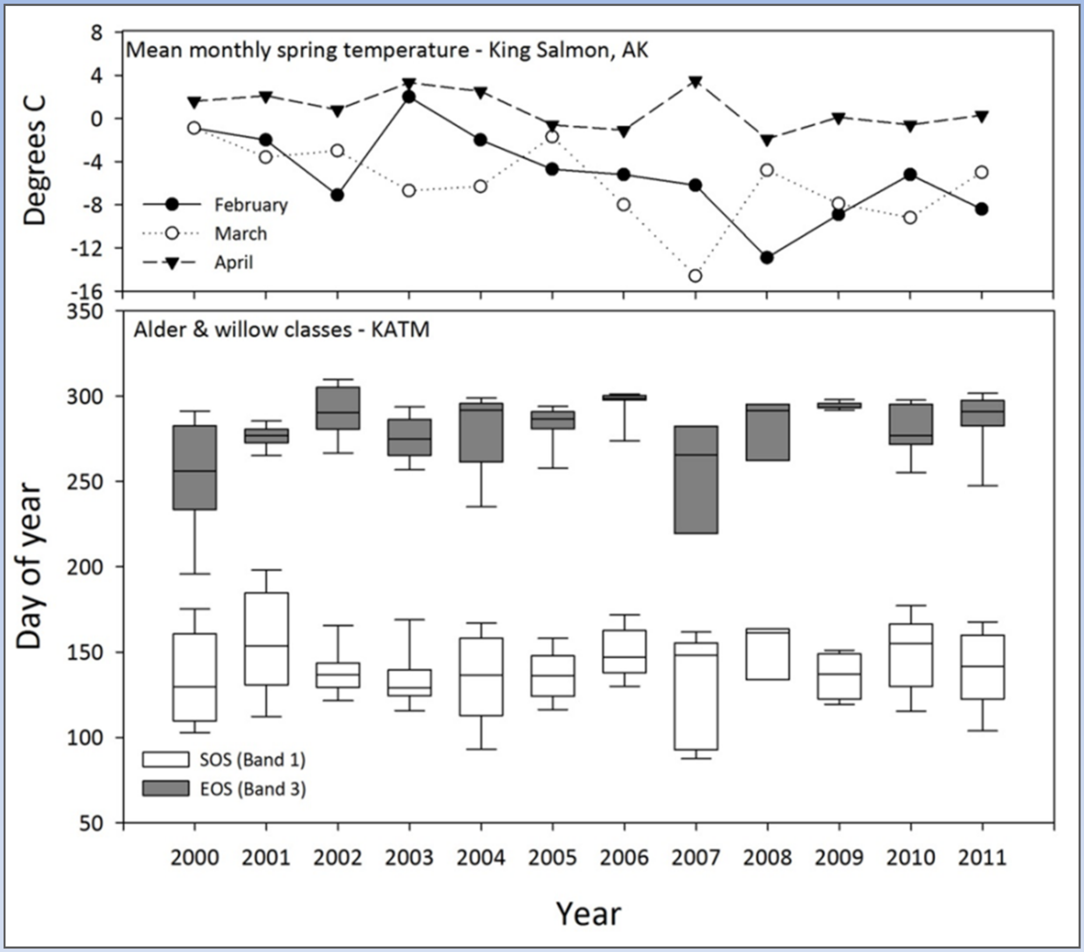
Evaluation – spatial & temporal variation in metrics

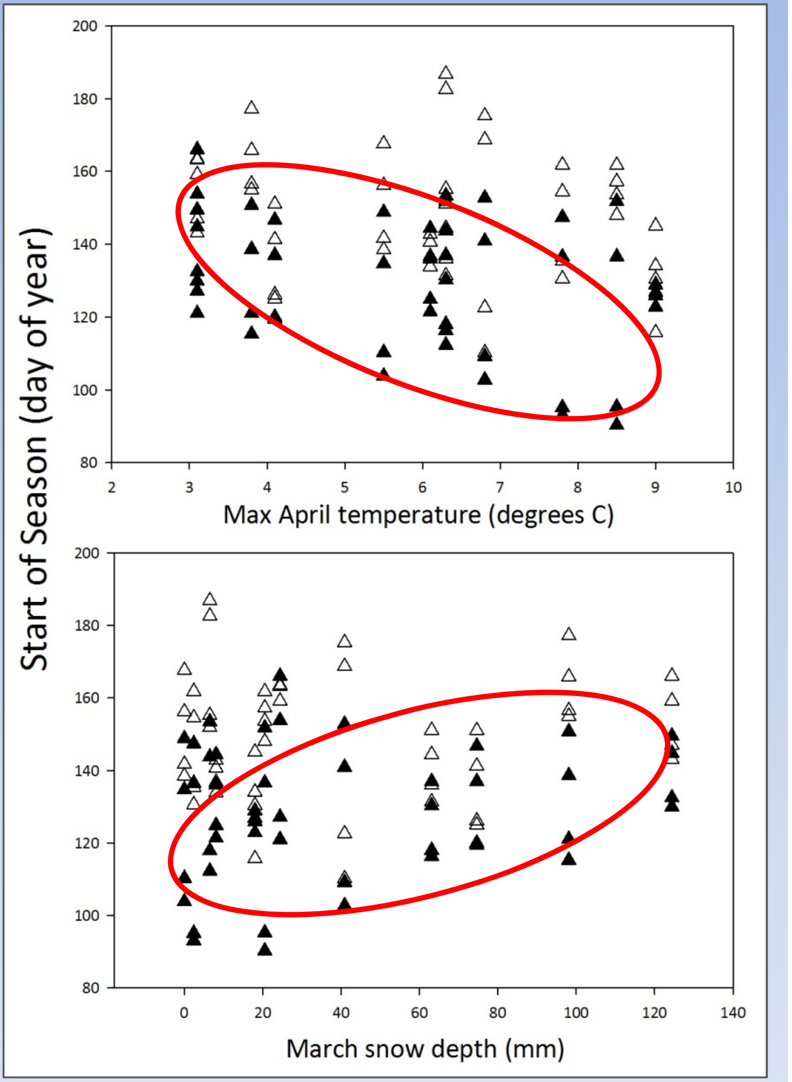






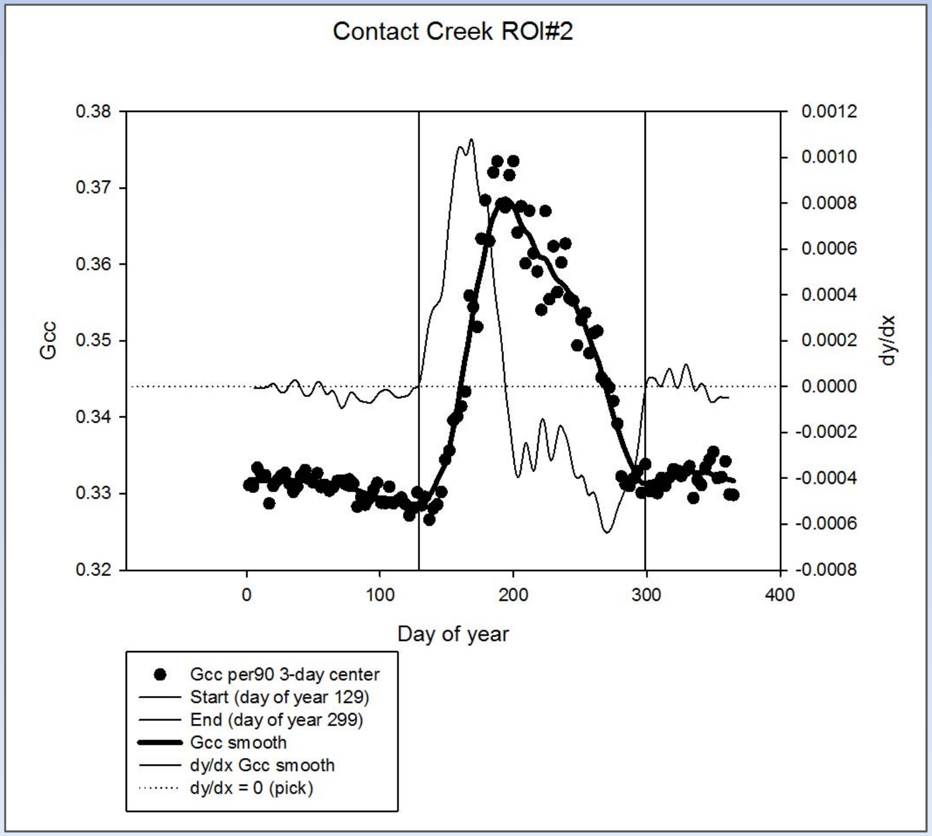
Temporal trends more meaningful than absolute values

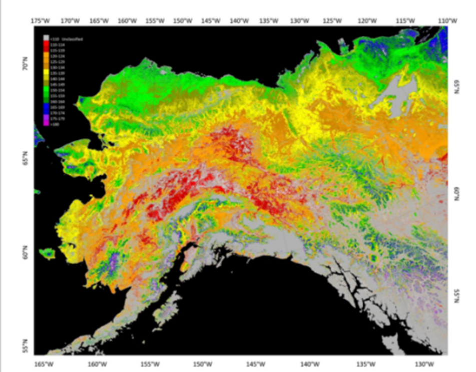


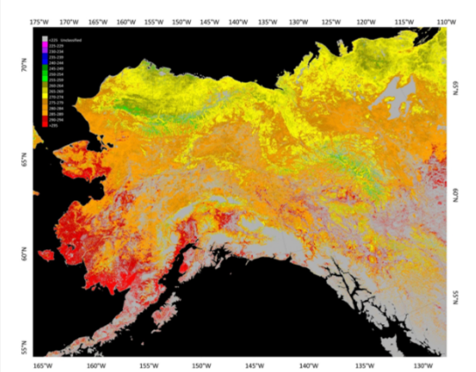


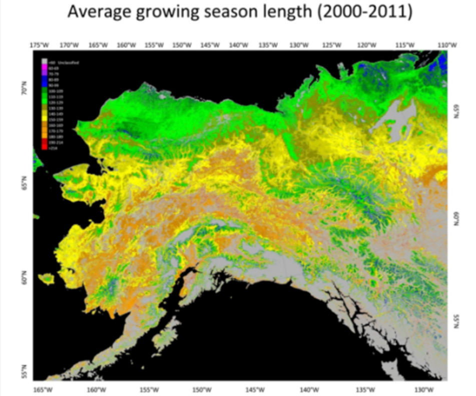
Evaluation - ground observations

- Field measurements of biomass, NDVI from North Slope in agreement with MODIS NDVI time-series
- Visible green-up lags MODIS start of season (≤30 d)
- Maximum NDVI, EOS consistent with phenology




Average SOS (2000-2011)


Average EOS (2000-2011)


Average growing season length (2000-2011)

Summary

- SOS/EOS values are consistent with phenological patterns on the ground, but MODIS-derived SOS lags visible green-up by up to 30 days in some areas

- NDVI metrics are inherently variable; however, spring temperature and snow depth influence growing season length, primarily through effects on SOS

- MODIS-NDVI metrics are available for 2000-2011 through the WCS feed at GINA (http://ndvi.gina.alaska.edu/metrics?).

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Acknowledgments

Support for this project was provided by the National Park Service, Inventory & Monitoring Program, Anchorage, Alaska.

Thank You !