Phenological changes of Russian northern forests inferred from analysis of 230m MODIS LAI time series data from 2000 to 2018

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IKI RAN, Moscow, Russia, November 12, 2019

Research highlights

- The objective is to evaluate changes in vegetation green biomass over Northern high latitudes of Russia (>60^0 N).
- The data are time series of 230m IKI MODIS LAI product for 2000-2018, generated based on recent advances in stochastic radiative transfer modeling and improved data pre-processing techniques, implemented at IKI.
- The approach is to analyze whole seasonal LAI profile at the pixel level to fully understand impact of climate change and various disturbances (burns, logging, etc.)

Outline

1) Background information on trend analysis

2) Algorithms and data sets

3) LAI trend analysis

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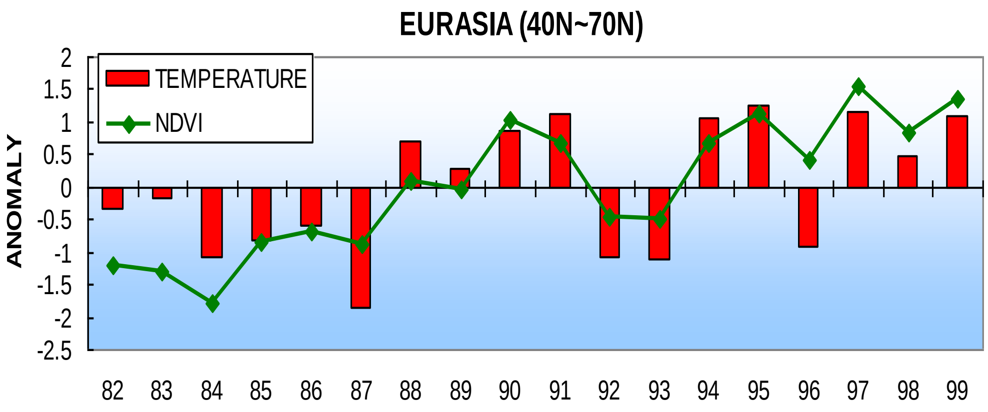
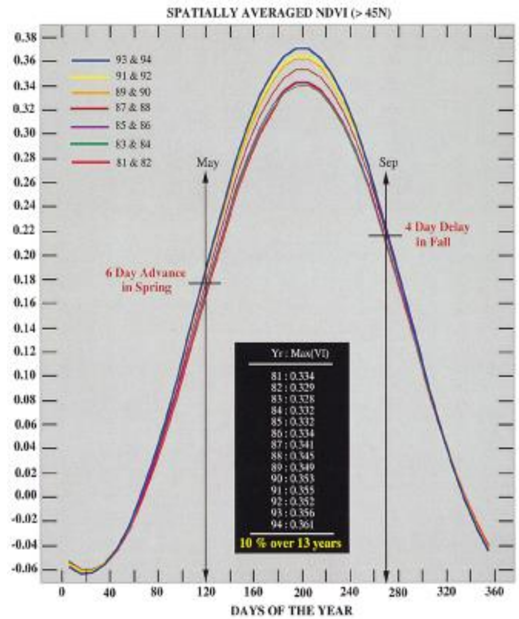
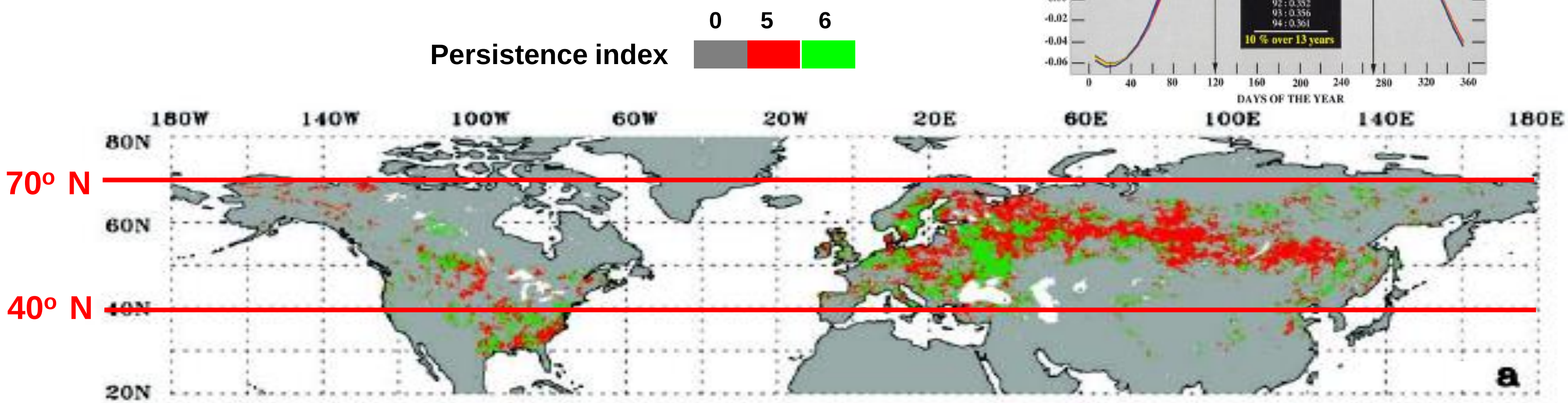
Greening trend of Northern high latitudes– Myneni & Co (1997, 2001)







- AVHRR GIMMS NDVI 8-km, 15-day composites, 1981-2001, 40º-70º N
- Excluded from analysis sparse vegetation (NDVI<0.1). North America and Eurasia exhibit trends- maximum seasonal and duration of the growing season. The NDVI trend correlates with the temperature trend.

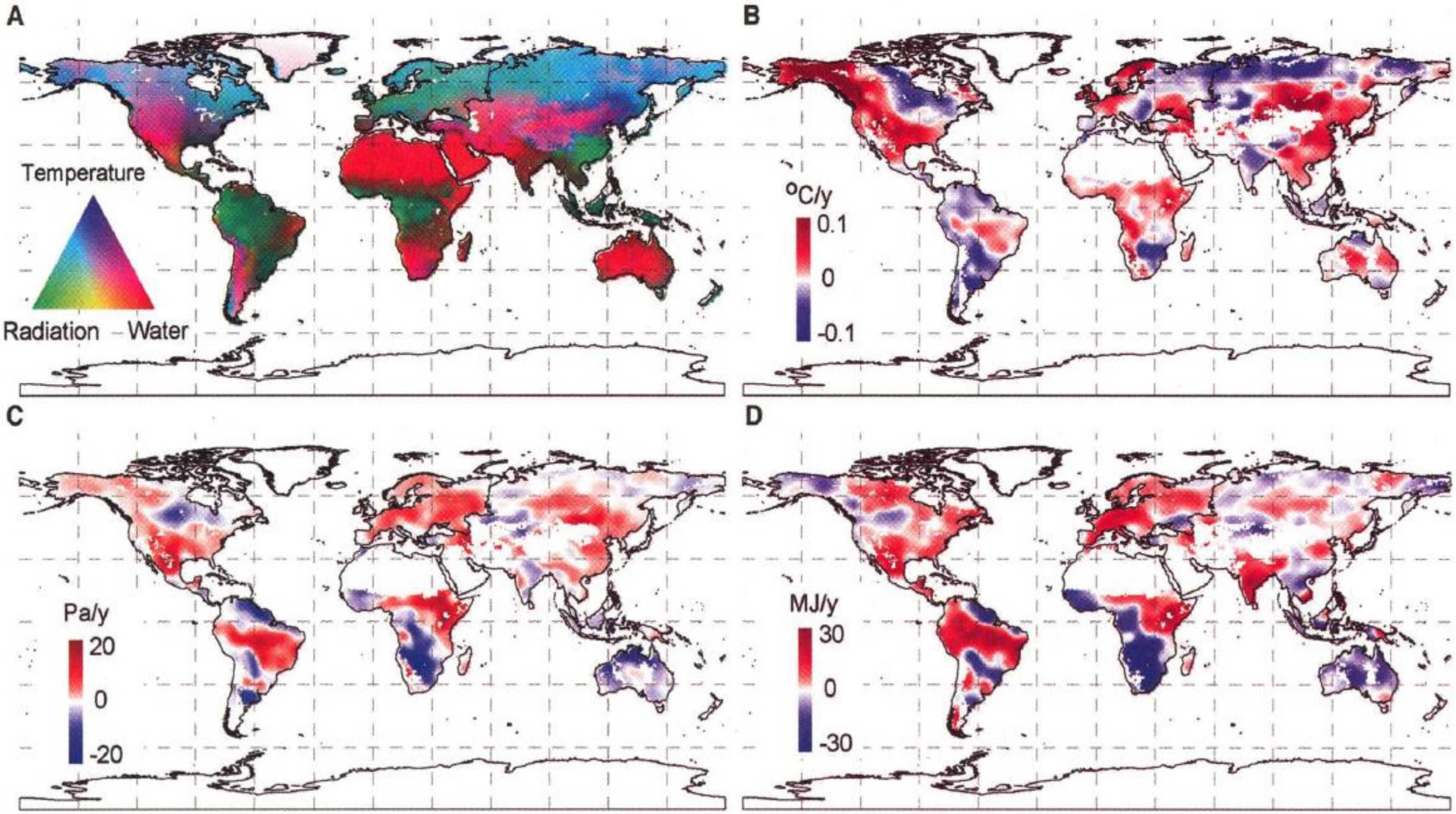
Myneni et al, (1991) Increased plant growth in the northern high latitudes from 1981 to 1991. Nature, 386, 698-702.

Zhou et al., (2001) Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999, JGR, 106(D17), 2069-2083.

Greening trend and climatic constraints – Nemani et al (2003)

Climatic constraints on vegetation growth

Temperature trends during 1982-1999



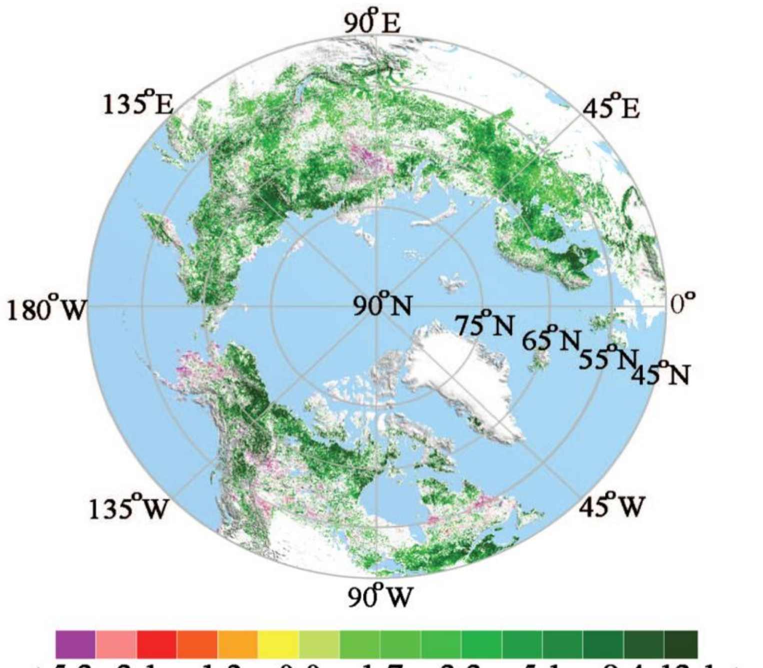
Water vapor pressure deficit trends during 1982-1999

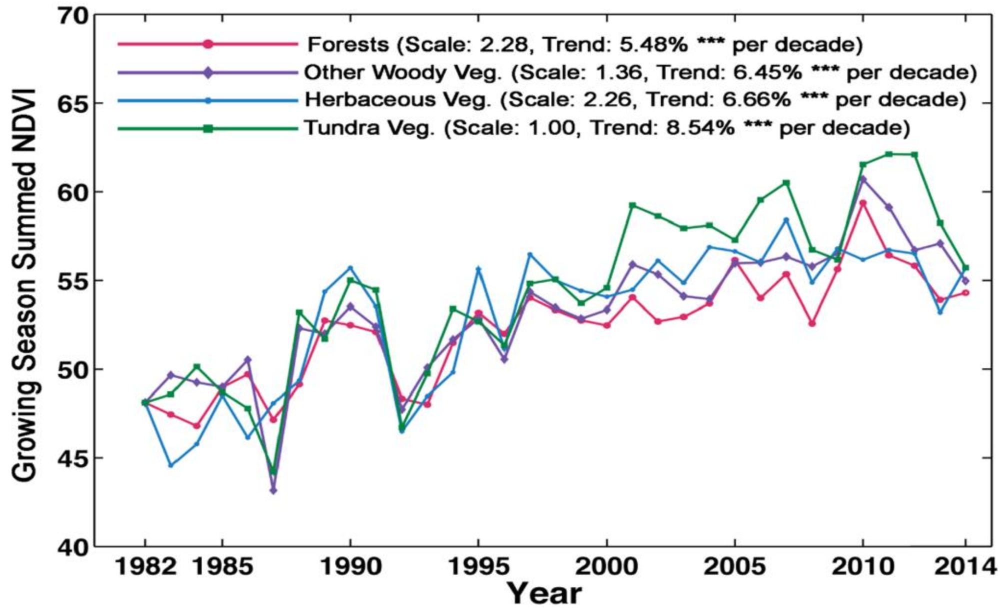
Solar radiation trends during 1982-1999 г.

Observed changes in climate were mostly in the direction of loosening constaints on vegetation growth. The observed NDVI trends indicate that vegetation growth followed those changes of climate.

Nemani et al, (2003) Climate-driven increase in the global terrestrial net primary production from 1982 to 1999, SCIENCE, 300, 1560-1563

Greening trend in 2000s – Myneni & Co (2016)

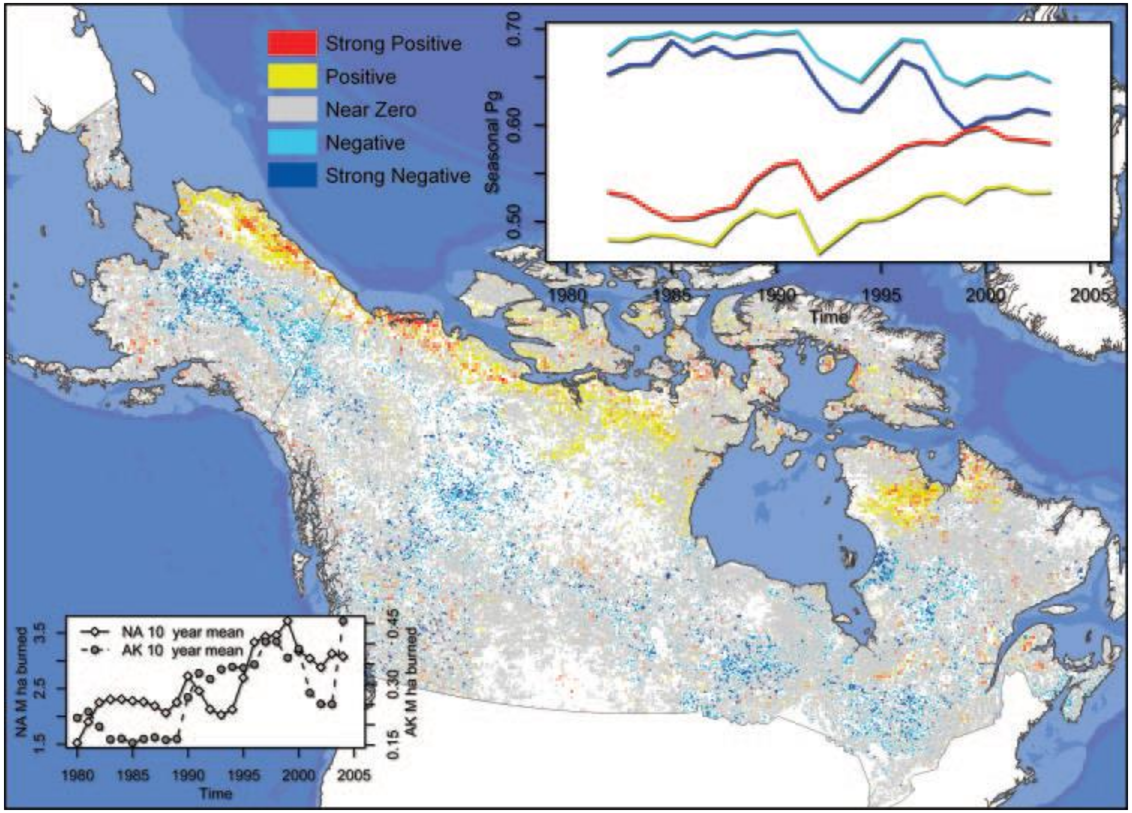




- Expanded interval of time series to 2000s
- Instead of growing season average (JJA), integral over seasonal profile was used- it captures modifications of whole seasonal profile, not just peak seasonal values
- Overall, in 2000s trend has weakened compared to 1980-th and 1990-th of former century.

Park, T.,et al. (2016) Changes in growing season duration and productivity of northern vegetation inferred from long-term remote sensing data. *Environ. Res. Lett.* 11, 084001, doi:10.1088

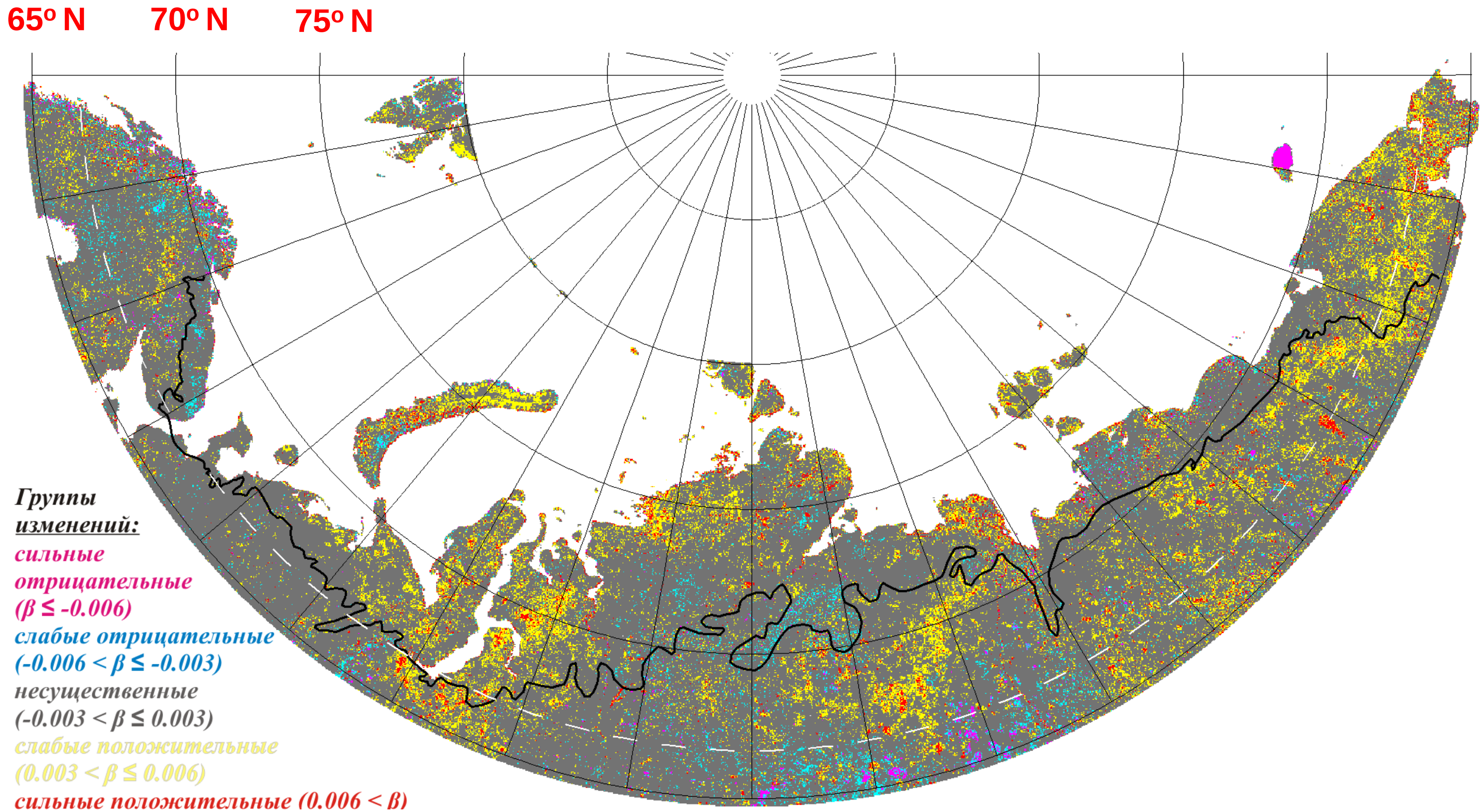
Trends over Northern Canada – Goetz et al. (2005)



- AVHRR GIMMS NDVI converted to Gross Photosynthesis (Pg), 8-km, 15-day compositing, 1982-2003, over Canada
- 15% of the region indicated significant trends, of which nearly half involved temperature-related increases in growing season length and photosynthesis strength, mostly in tundra. In contrast, forest areas decline in photosynthesis and show no systematic change in the growing season length. Stochastic changes are mostly related to frequent and increasing fires

Goetz et al (2005) Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance. PNAS, vol. 102, 38, 13521-13525

Trends over Russian tundra – Elsakov et al (2017)



- MODIS 250m, 16-day composited NDVI, 2000-2016, 65°-80° N
- Focus on Tundra, not forests
- Trends are significantly different for two periods 2000-2009 and 2009-2016

Elsakov (2017) Spatial and interannual heterogeneity of changes in the vegetation cover of Eurasian Tundra: Analysis of 2000-2016 MODIS data, SPDZ, 2017, 14(6) 56-72.

Limitations of the formers studies

a) Radiometric data accuracy: many studies are based on AVHRR data with known issues of stability of the orbit, geolocation accuracy, and low resolution.

b) Data pre-processing algorithms: availability of atmospheric correction, accuracy of cloud screening, and availability of temporal interpolation of seasonal profiles.

c) Choice of variables: typically radiometric quantities (vegetation index) are used and biophysical parameters (LAI, FPAR) are retrieved using linear regression which is in essence rescaling of units. Few physically-based algorithms are implemented. Existing NASA MODIS LAI/FPAR product only available 500m, and data are noisy (older RT simulations, lack of cloud screening and temporal interpolation).

d) Level of exploring phenology: potential is not fully explored, mostly average over growing season, or maximum was used

Very few studies over Russia are available- country with the largest territory and impact on climate is underrepresented at the international level !

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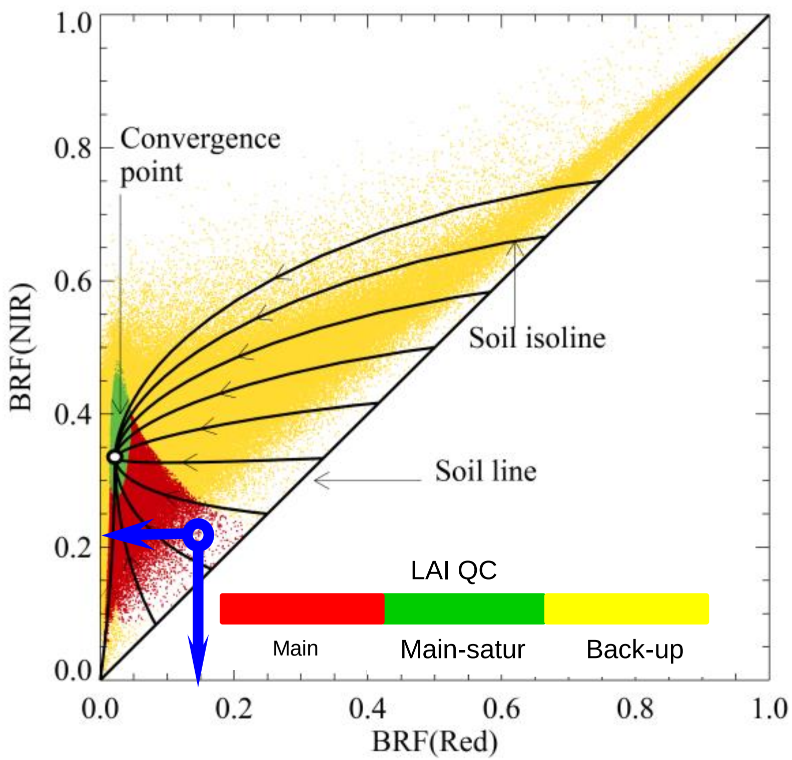
2) **Algorithms and data sets**

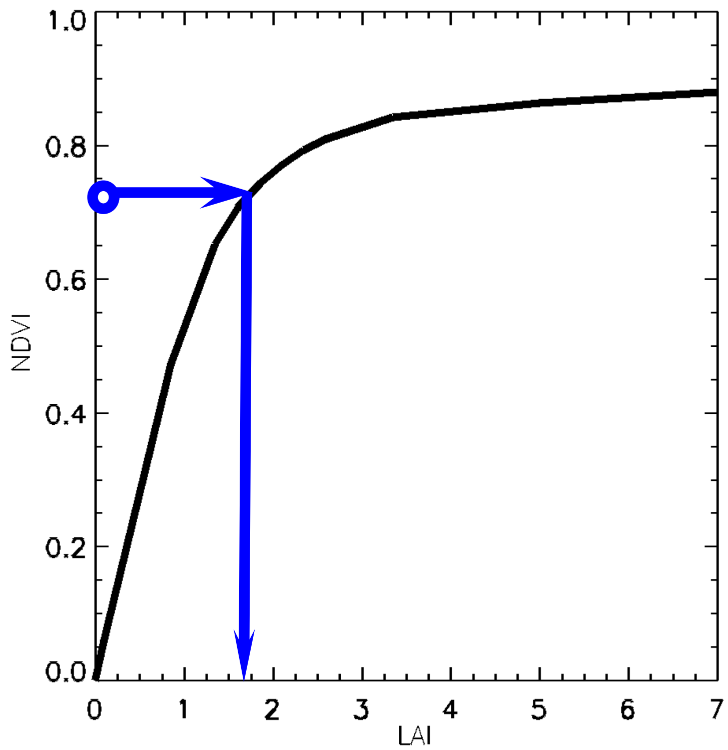
3) LAI trend analysis

Physical basis of IKI MODIS LAI algorithm

Main algorithm



Back-up algorithm



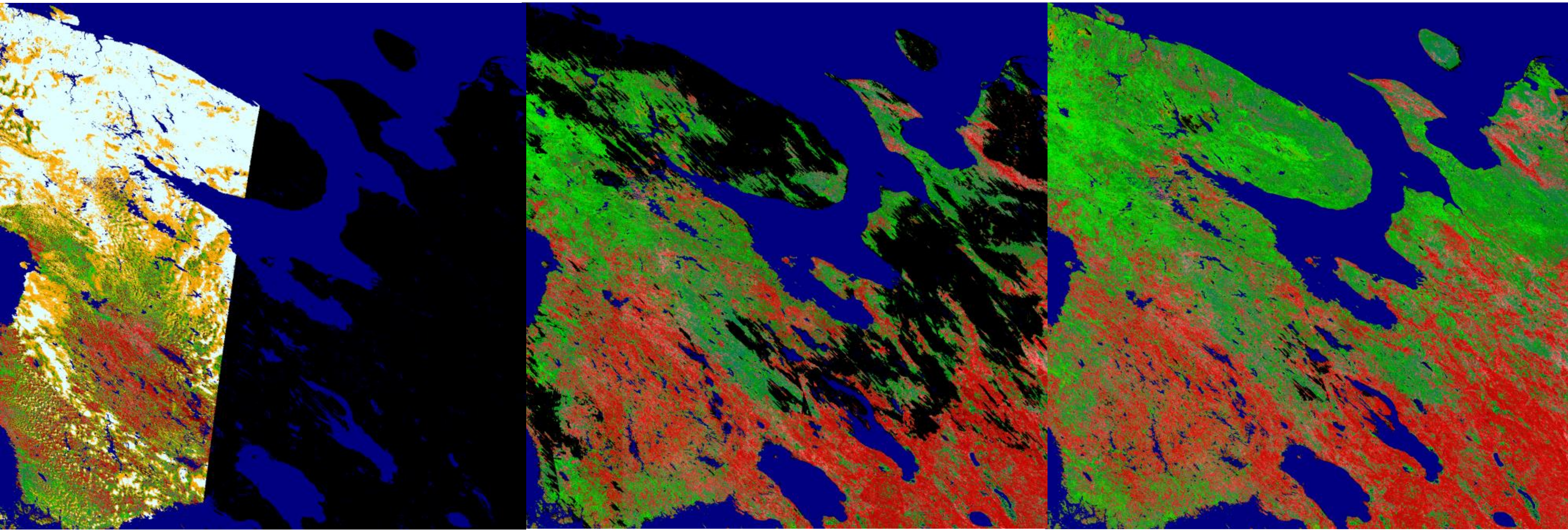
- The operational NASA MODIS LAI was adopted for retrievals of daily LAI
- Main LAI algorithm: Modeling data, BRF as function of LAI are generated using stochastic Radiative Transfer model (and stored in form of Look-up Tables, LUTs). Modeled and MODIS BRF in Red and NIR channels are comapred, and when match is found the corresponding LAI is retrieved.
- Back-up LAI algoruthm: When main algorithm fails, the back-up algorithm calculates LAI using empirical LAI_NDVI relationship (low accuracy retrievals)

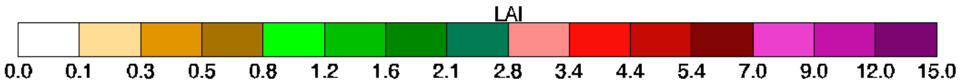
Processing IKI MODIS LAI product

(1) Daily retrievals (up to 14 observations at the North)

(2) weekly compositing

(3) Interpolation





MODIS tile h19v02

1) Daily data are generated using NASA algorithm (previous slide), regardless of atmospheric conditions (including cloudy pixels)
2) Weekly composites are calculated as nearest to median LAI value, calculated after masking out clouds
3) Interpolation using polynomial fitting is used to fill gaps and smooth seasonal profiles.

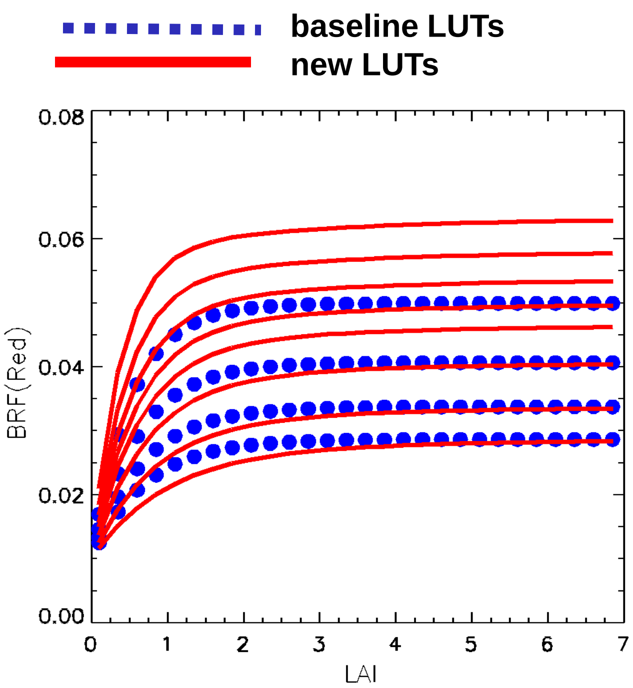
Product is available over extent of Russia, at 7 days temporal resolution, 230 m spatial, March 2000- present. Data are available through IKI web-portal vega-pro.ru

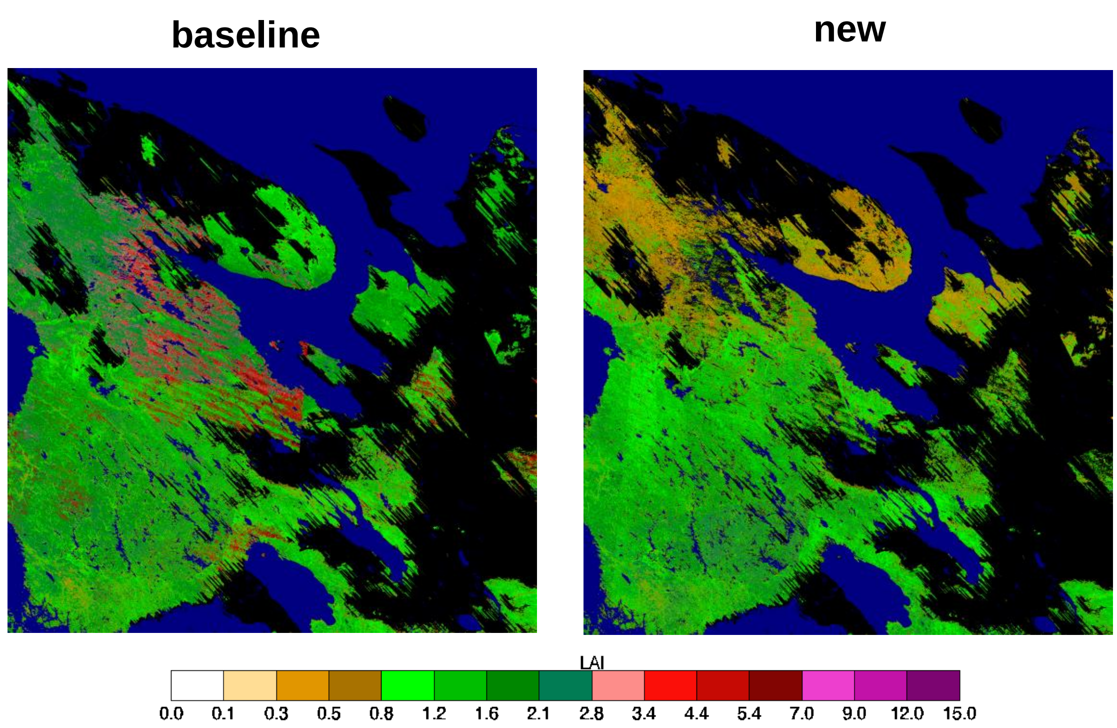
Shabanov, et al (2018). Development of capabilities for remote sensing estimate of Leaf Area Index from MODIS data. *Contemporary Problems of Remote Sensing*. 15(3) , DOI: 10.21046/2070-7401-2018-1

Improvements to IKI MODIS LAI algorithm

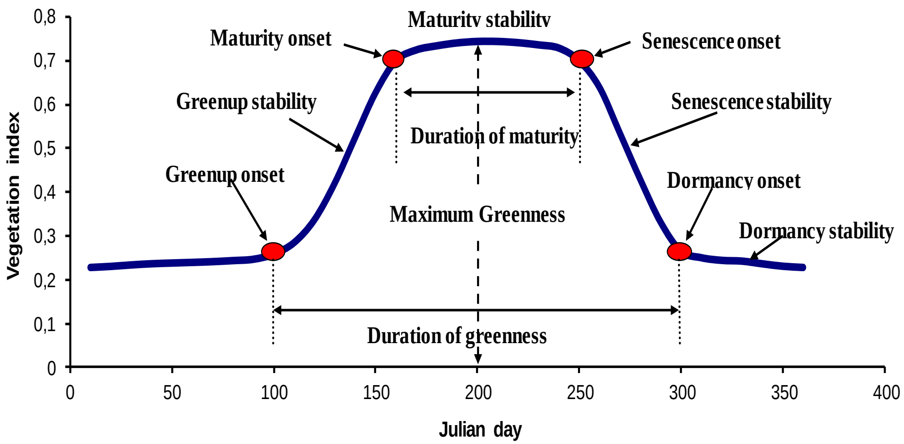
- Original MODIS NASA LAI algorithm LUTs were developed using 1D (turbid medium) version of the Stochastic RT (SRT) model. Only recently theoretical basis was completed with development of pair-correlation and gap fraction models for canopy structure (Huang et al., 2008, Shabanov et al., 2018). New LUTs use whole power of SRT model. Simulations were expanded to include higher Solar Zenith Angles [15º,30º,45º,60º] --> [15º ,30º ,45º ,55º, 60º, 65º, 70º, 75º].
- Red channel of MODIS data exhibits striping (drop of surface reflectances predominantly at high SZA). Compositing scheme was modified to include filter for those artefacts.

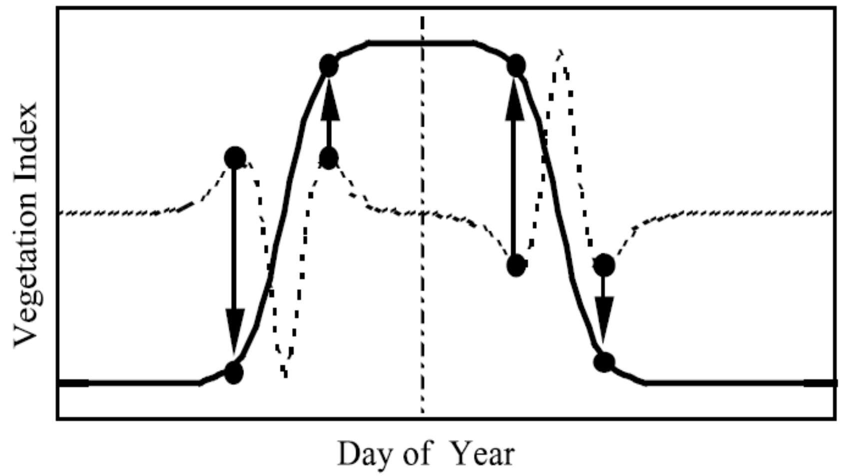
Huang, et al. (2008). Stochastic Transport Theory for Investigating the Three-Dimensional Canopy Structure from Space Measurements. *Remote Sensing of Environment*, 112(1), 35-50.
Shabanov, N.V., and Gastellu-Etchegorry, J.-P. (2018). The Stochastic Beer-Lambert-Bouguer Law for Discontinuous Vegetation Canopies. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 214, 18-32.





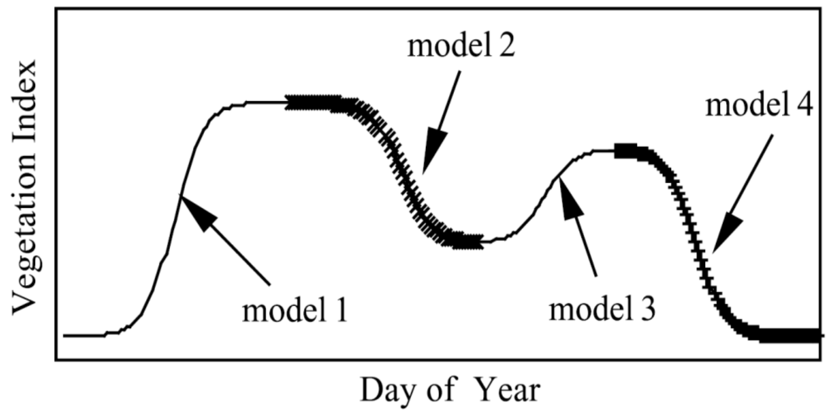
Physical basis of NASA MODIS/VIIRS phenology algorithm





Phenology – is an annual product, providing estimates of timing of four key phenological phases (green up onset, maturity onset, senescence onset, dormancy onset) + integral seasonal profile.

Max/min of the derivative of VI specifies start/end of phenological phases



Calculations are based on EVI derived from normalized surface reflectances (MODIS NBAR product)

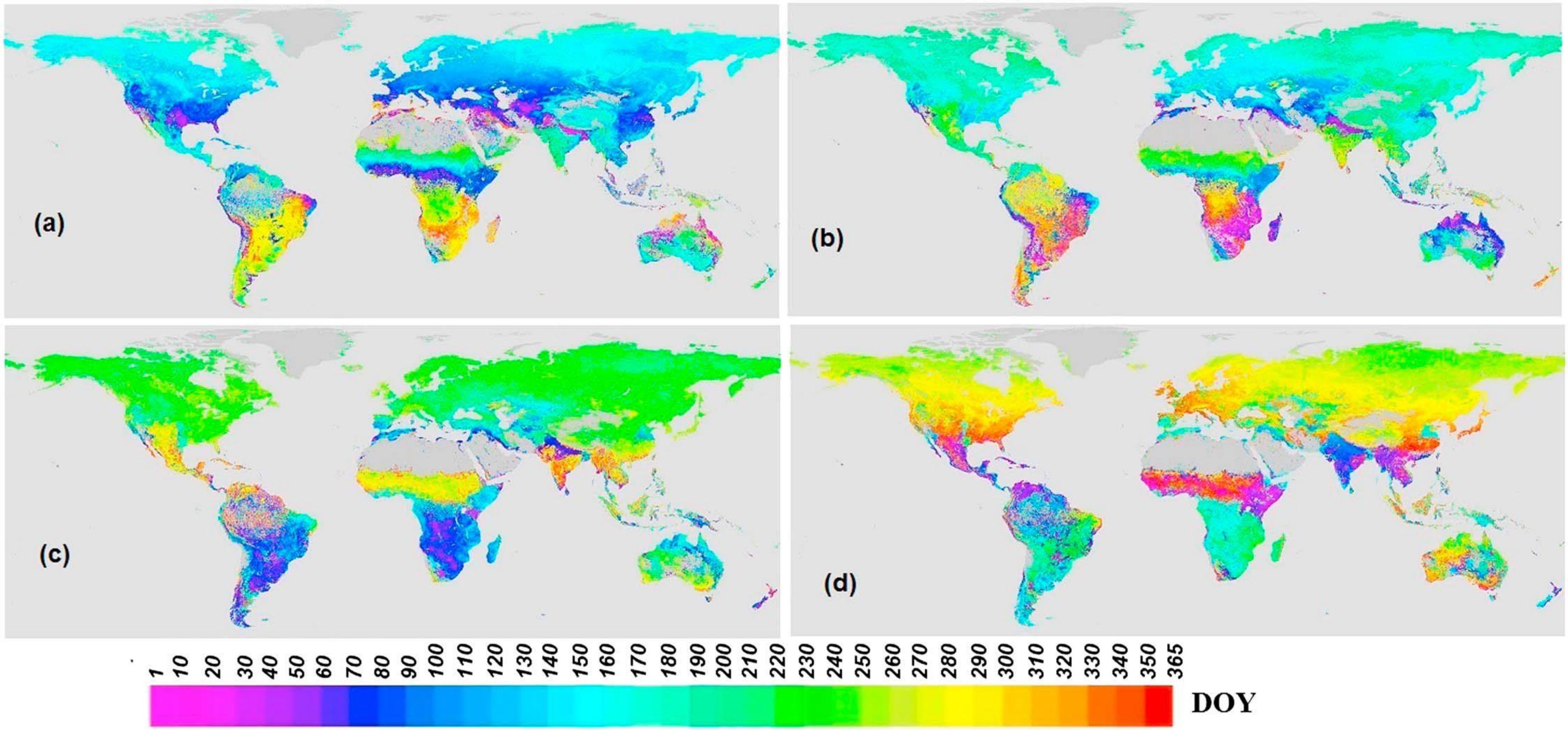
Each phase of VI change is approximated by the logistic curve (sigmoid),

$$EVI(t) = \frac{c}{1 + \exp(a + b \cdot t)} + d$$

If multiple periods of growth exist- multiple sigmoid curves are used.

Ganguly et al. (2010) Land surface phenology from MODIS: characterization of the Collection 5 Global Land Cover Dynamics Product *Remote Sensing of Environment* 114(8):1805-1816

VIIRS global phenology product



(a) Greenup onset

(b) Maturity onset

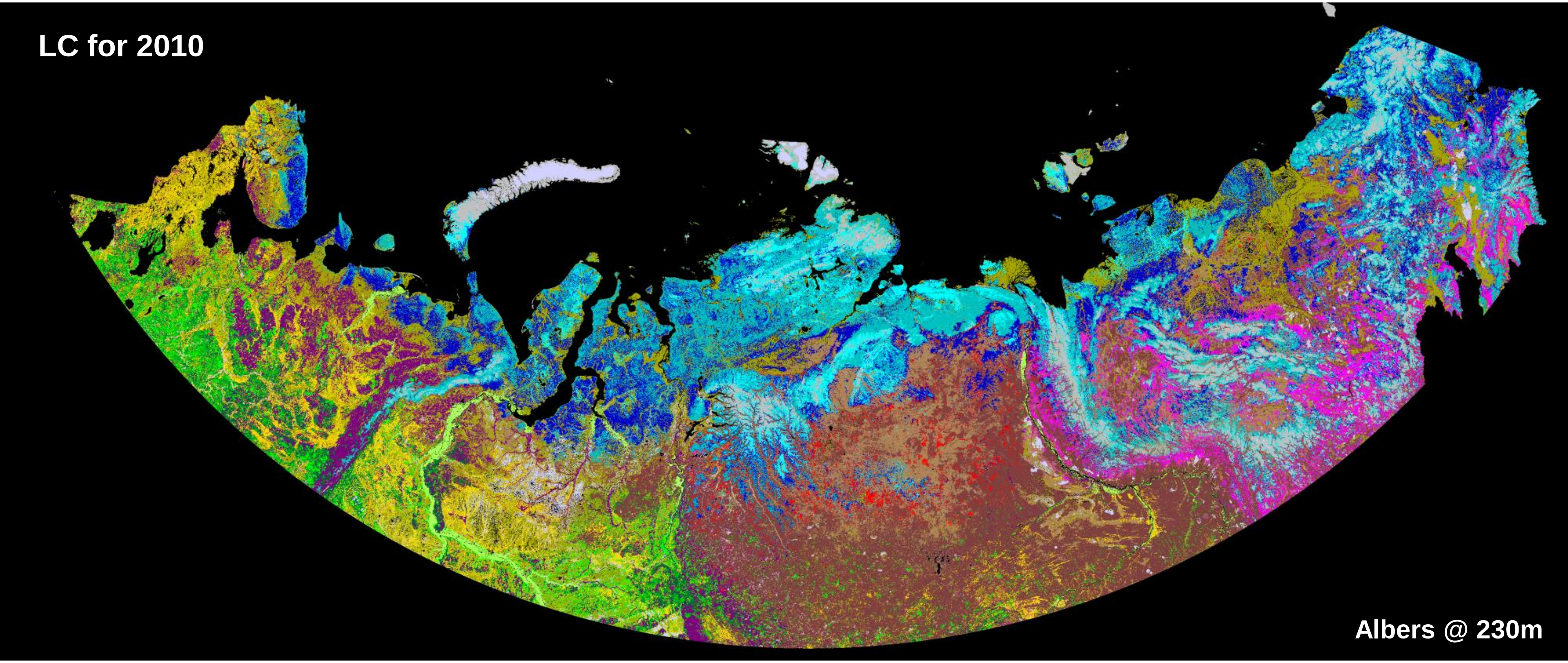
(c) Senescence onset

(d) Dormancy onset

→ Derivative products, i.e., duration of the growing season, etc

Zhang et al. (2017) Comparison of global land surface seasonality and phenology derived from AVHRR, MODIS and VIIRS data. JGR-Biogeosciences, DOI 10.1002/2017JG003811

IKI Landcover



- Annual product over Russia (2000-2018)
- Derived from Red, NIR, SWIR channels
- Maximum likelihood classifier, applied to seasonal composites
- Total of 21 class

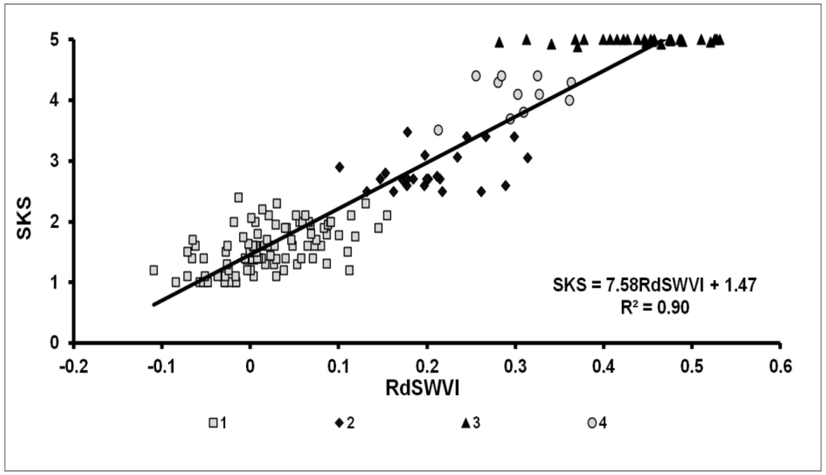
Evergreen dark needleaf forests (1)
Evergreen light needleaf forests (2)
Broadleaf forests (3)
Decidious needleaf forests (4)
Evergreen needleaf shrubs (5)
Peatlands (6,7)
Tundra-small shrubs (17)
Tundra-large shrubs (18)
Sparce Decidious needleaf forests (23)
Burns (24)

Physical basis of burn severity algorithm

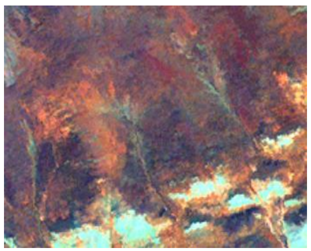
RdSWVI (relative difference short wave vegetation index) was found to be correlated with burn severity,

$$RdSWVI = \frac{SWVI_{pre} - SWVI_{post}}{\sqrt{SWVI_{pre} + 1}} \qquad SWVI = \frac{R_{nir} - R_{swir}}{R_{nir} + R_{swir}}$$

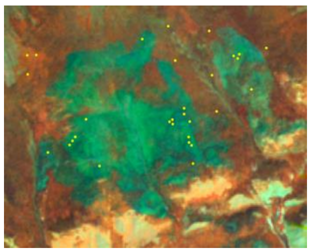
where R_{nir} and R_{swir} are near- and short-wave-infrared spectral channels



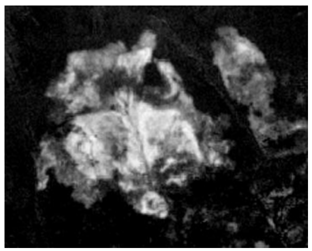
Relationship between trees mortality (SKS) parameter and RdSWVI



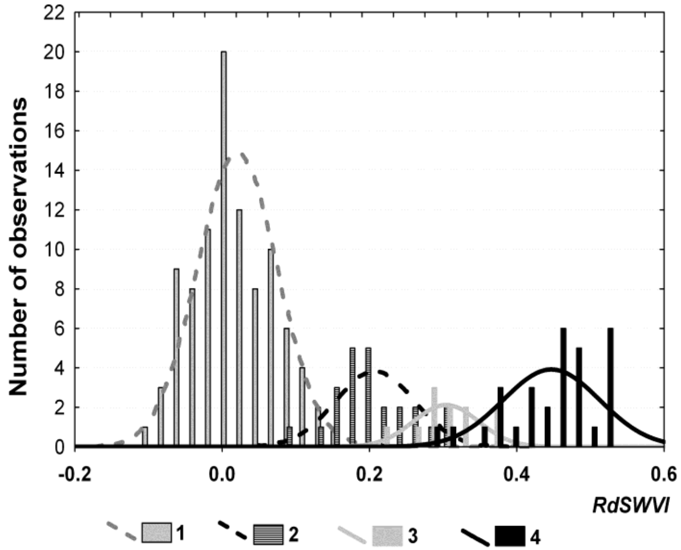
Pre-fire satellite imagery



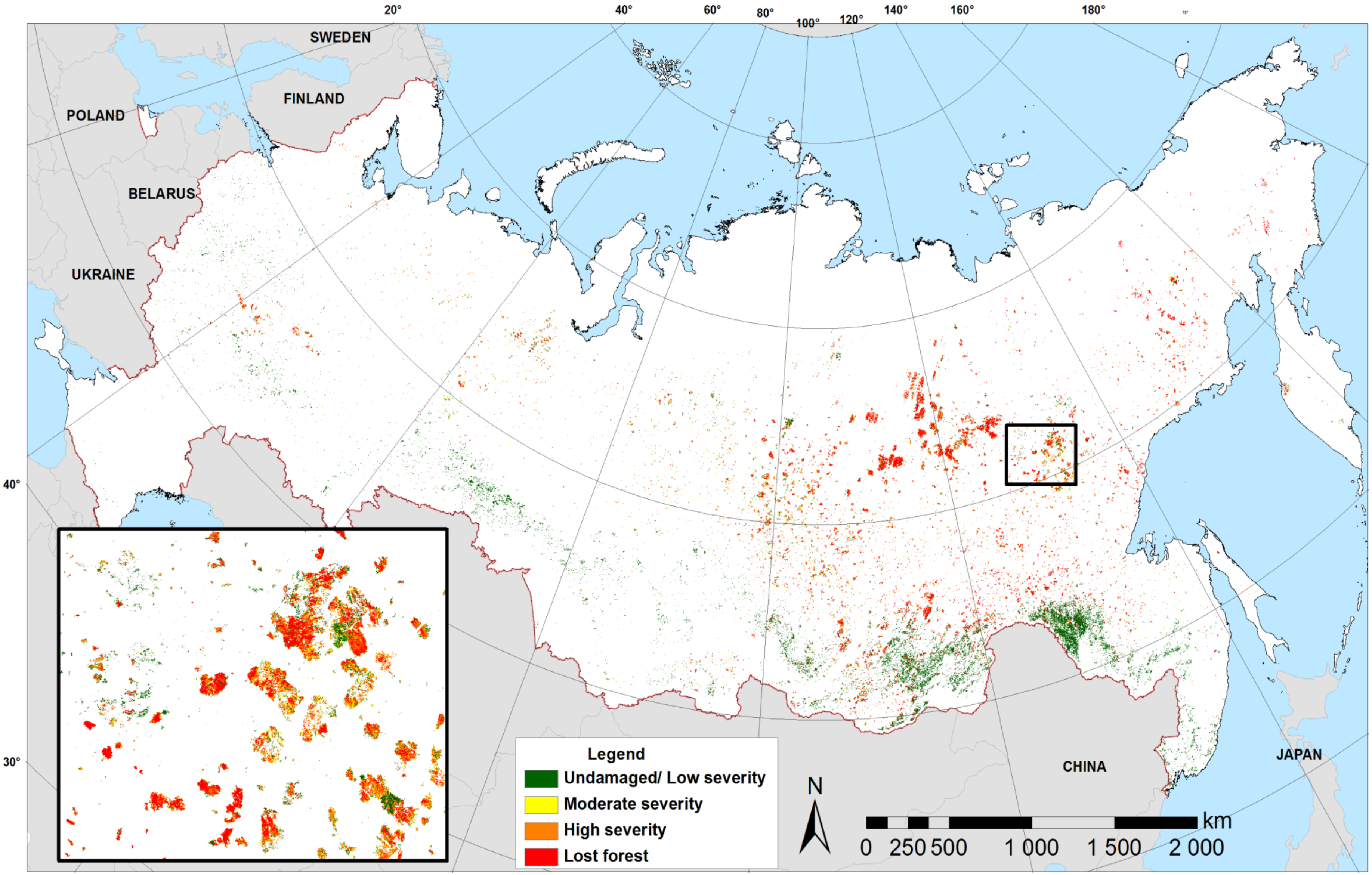
Post-fire satellite imagery with field test sites



RdSWVI index imagery



Russian forests burn severity map for 2005-2018



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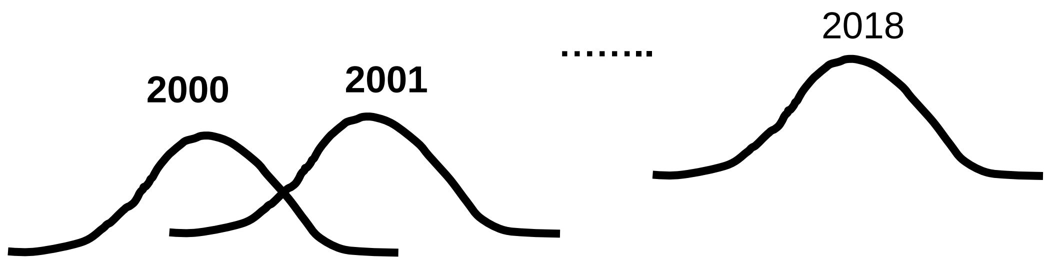
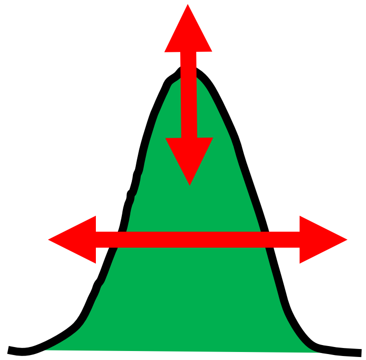
Methodology for trend analysis- which metrics to use?

In the natural vegetation the annual cycle of green biomass repeats itself. Weather/climate/disturbances modify whole seasonal profile.



Which metrics are the best to capture variations and overall trends? We considered the following four:

a) Seasonal maximum LAI
b) Average over peak growing season months (JJA)
c) Integral over the growing season
d) Seasonal profile LAI



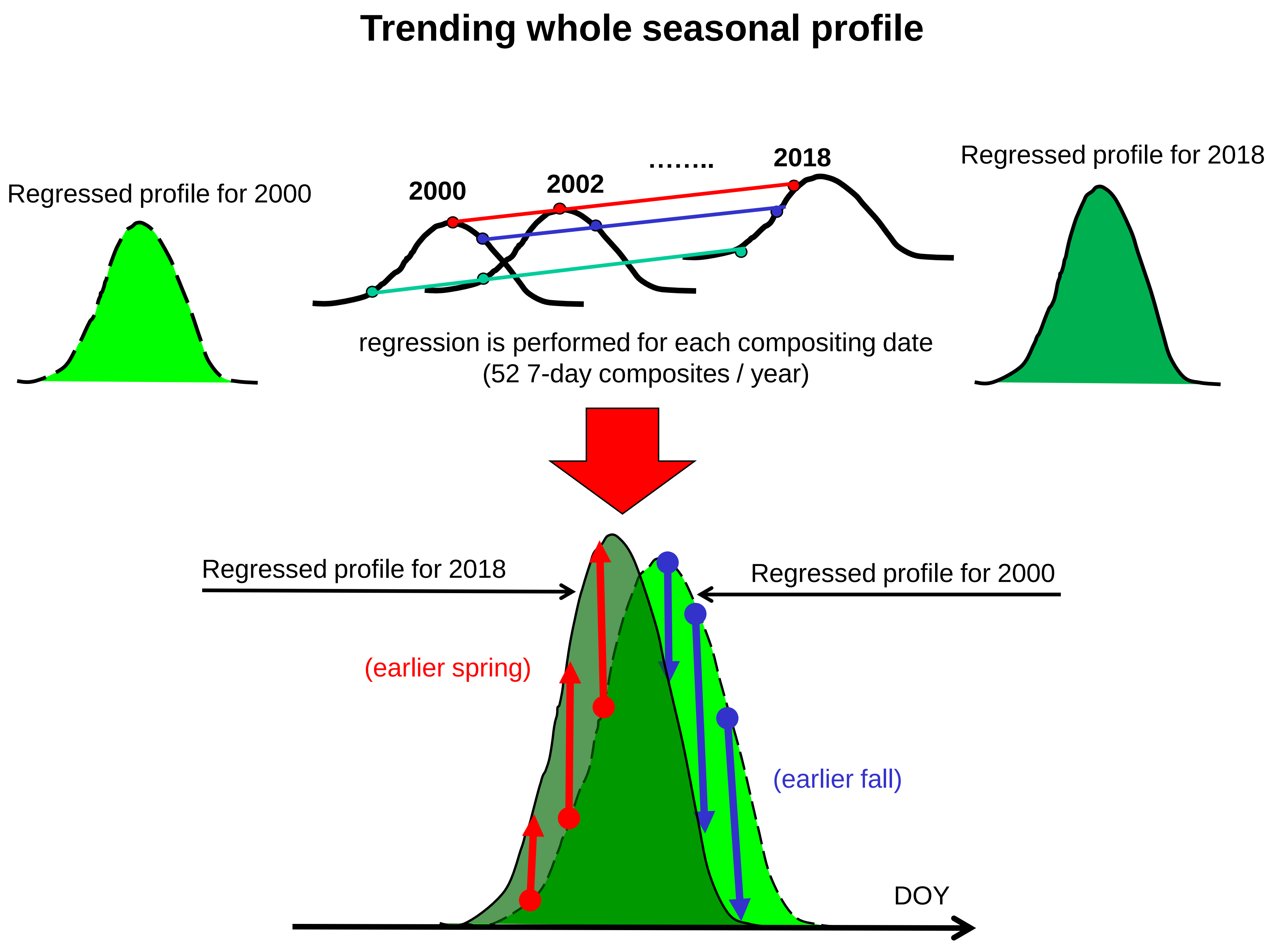
Using the above metrics we performed linear regression

Metrics: $\text{max LAI} = \text{MAX}\{\text{LAI}(t)\}$ $\quad$ $\text{integral LAI} = \int_{t1}^{t2} \text{LAI}(t)dt$ $\quad$ mean_JJA_LAI $\quad$ $\text{LAI}(t)$

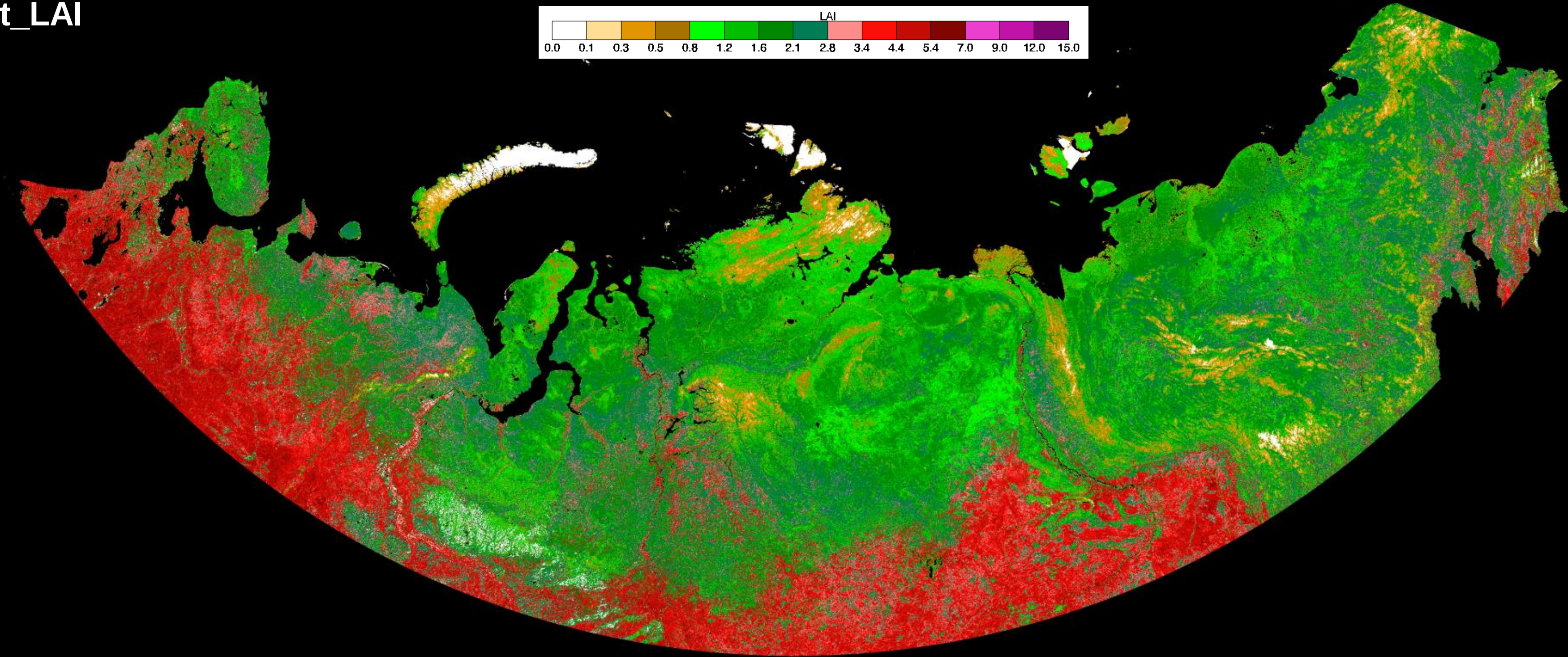
Regression: $\text{mean} = \text{Metrics}^{\text{reg}}(9)$ $\quad$ $\text{delta} = \dfrac{\text{Metrics}^{\text{reg}}(18) - \text{Metrics}^{\text{reg}}(1)}{\text{Metrics}^{\text{reg}}(9)}$ $\quad$ $\text{variance} = \text{Var}\{\text{Metrics}\}$

$\text{r}^\wedge 2 = \text{r}^\wedge 2\{\text{Metrics}\}$

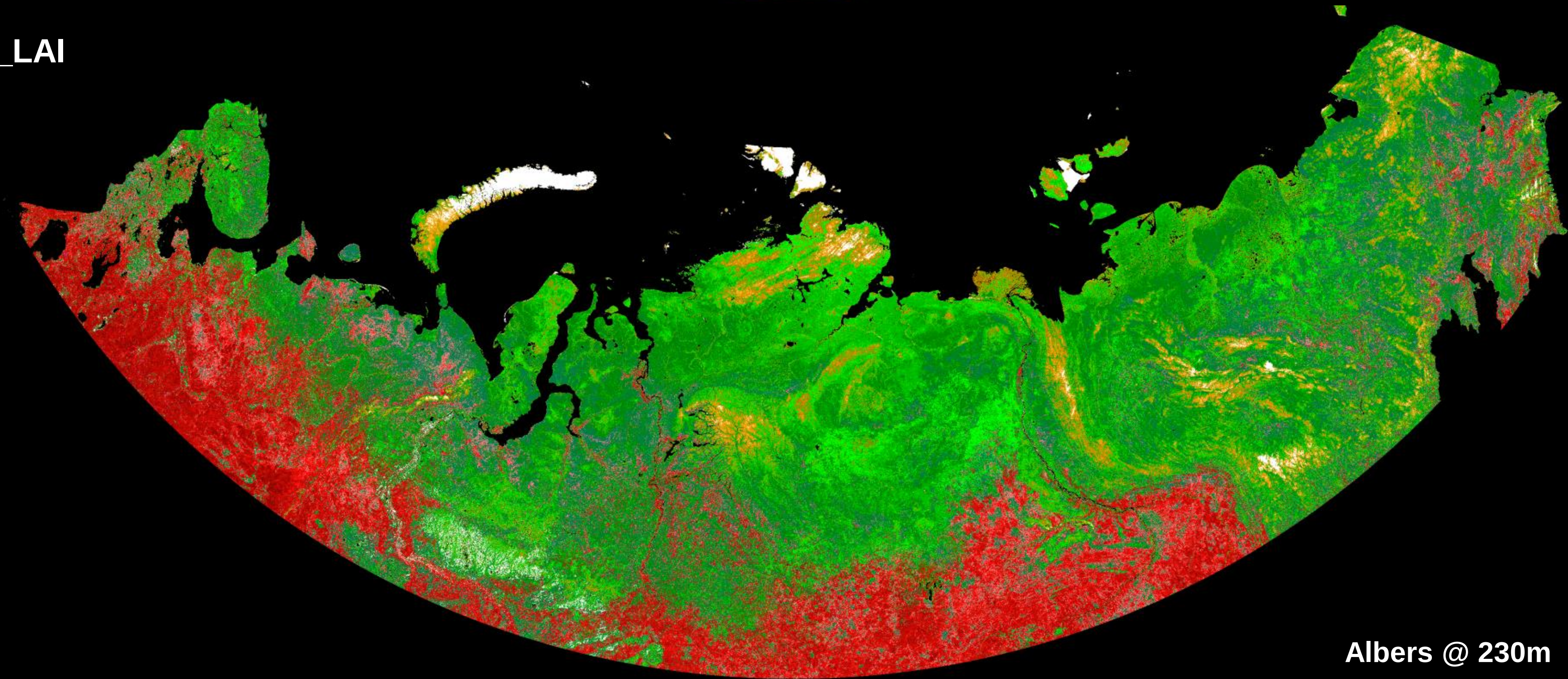
metrics	max_LAI	mean_JJA_LAI	Integral_LAI	Seasonal_profile
Implemented	Yes	No	No	Yes


Trending whole seasonal profile
Regressed profile for 2000
2000
2002
....
2018
Regressed profile for 2018
regression is performed for each compositing date
(52 7-day composites / year)
Regressed profile for 2018
Regressed profile for 2000
(earlier spring)
(earlier fall)
DOY

start_LAI

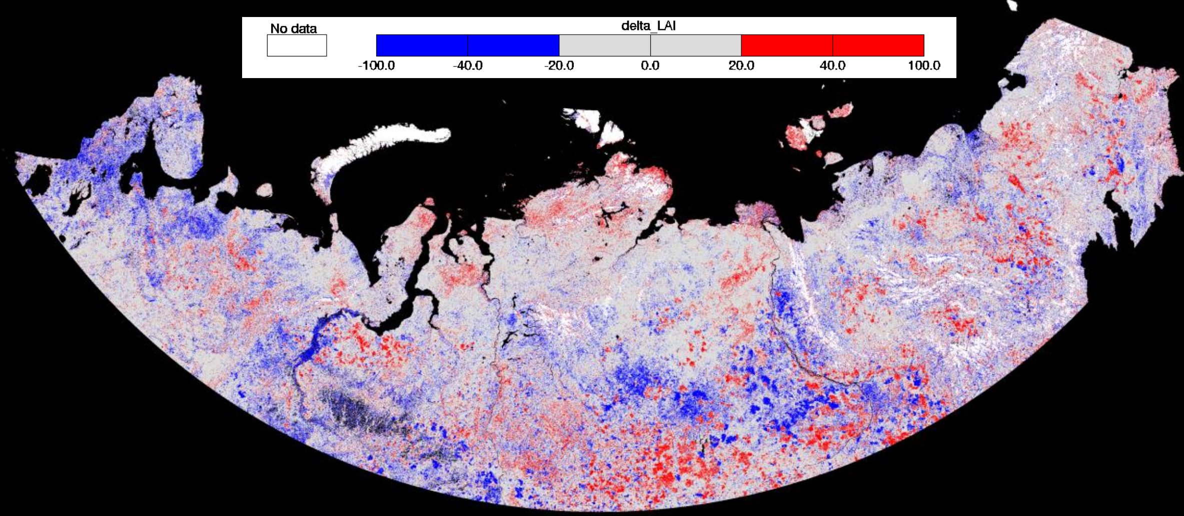


end_LAI

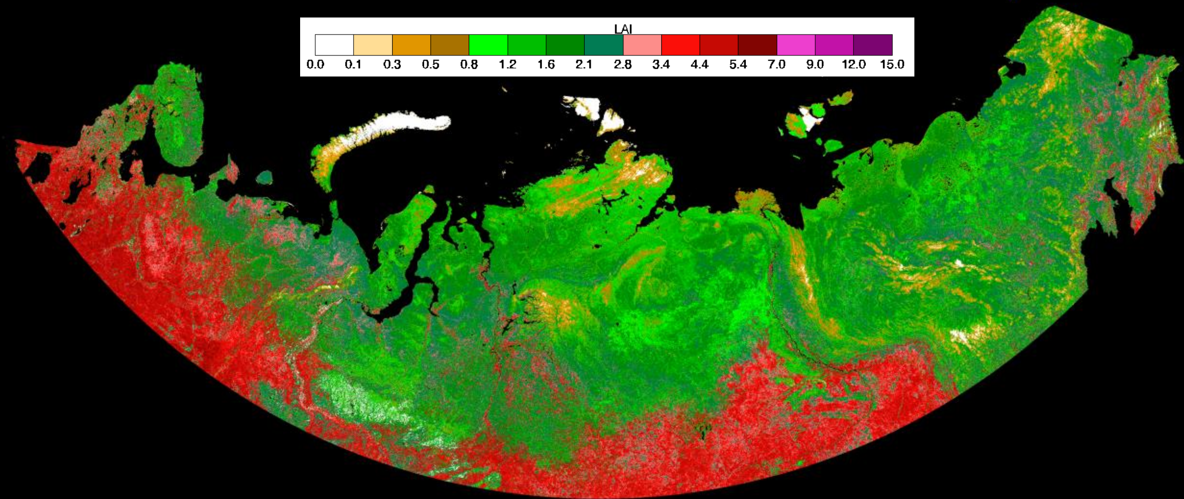


Albers @ 230m

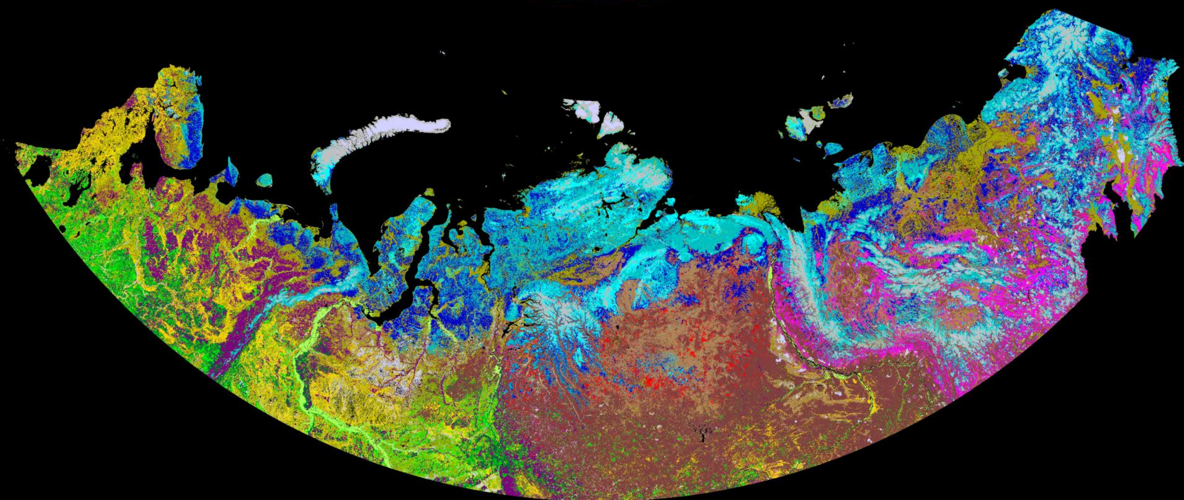
delta_LAI



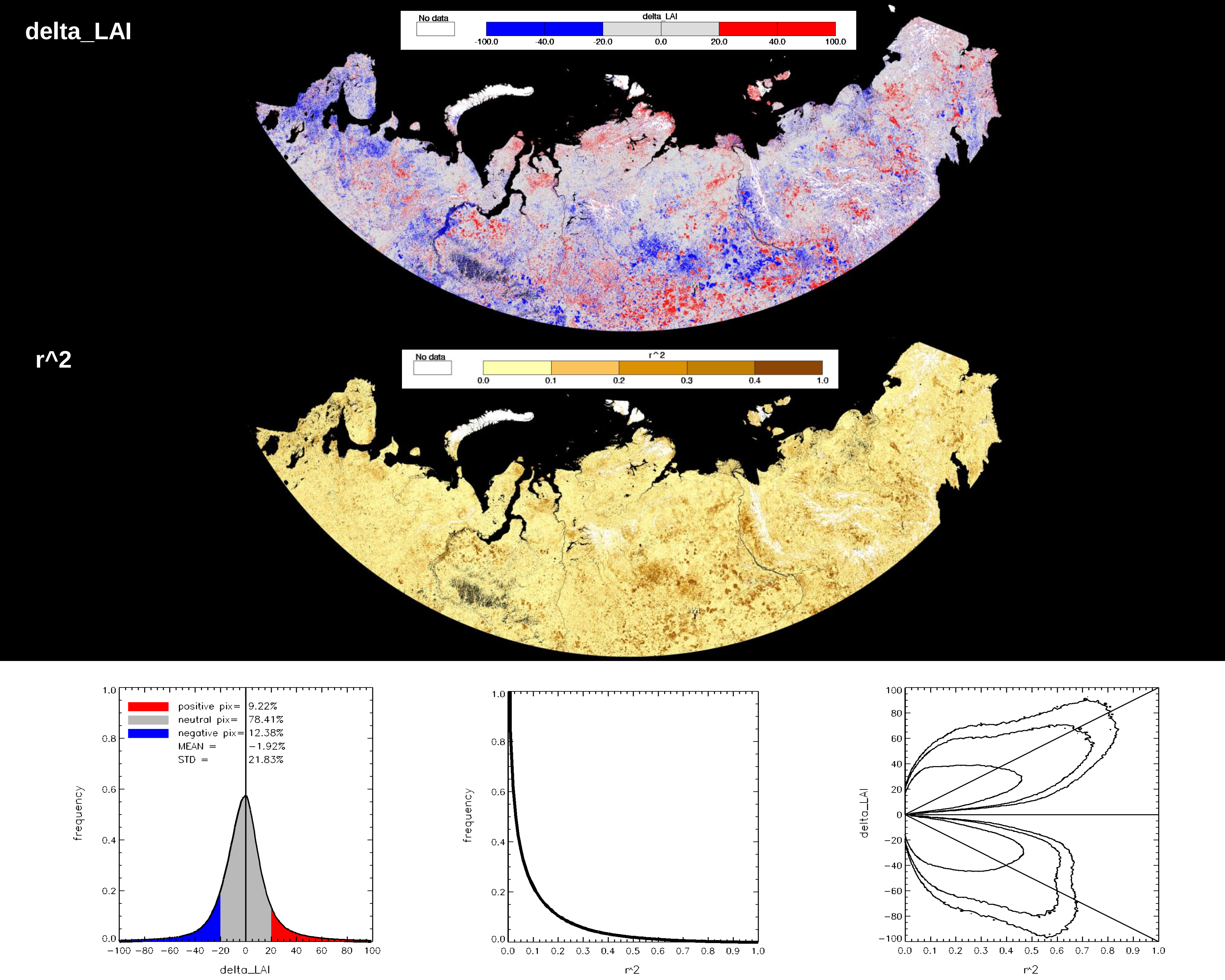
mean_LAI



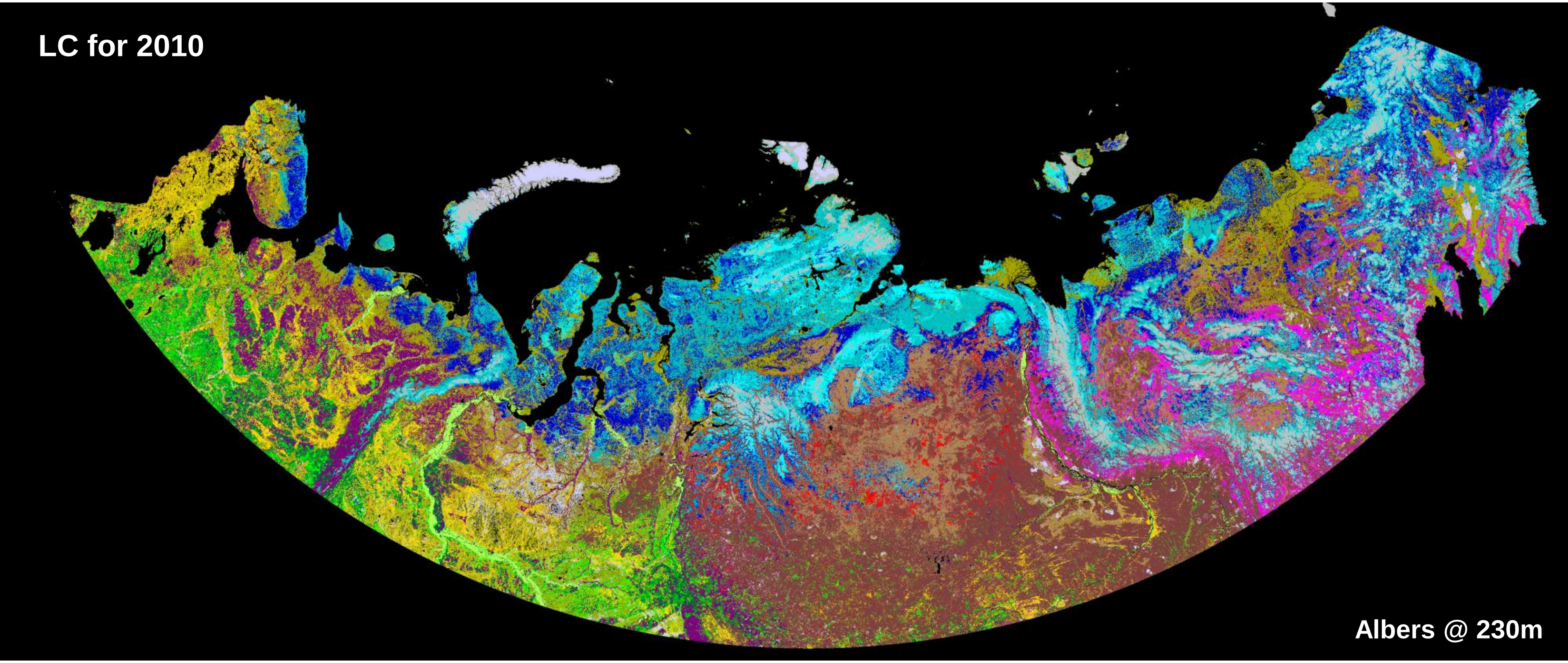
LC for 2010

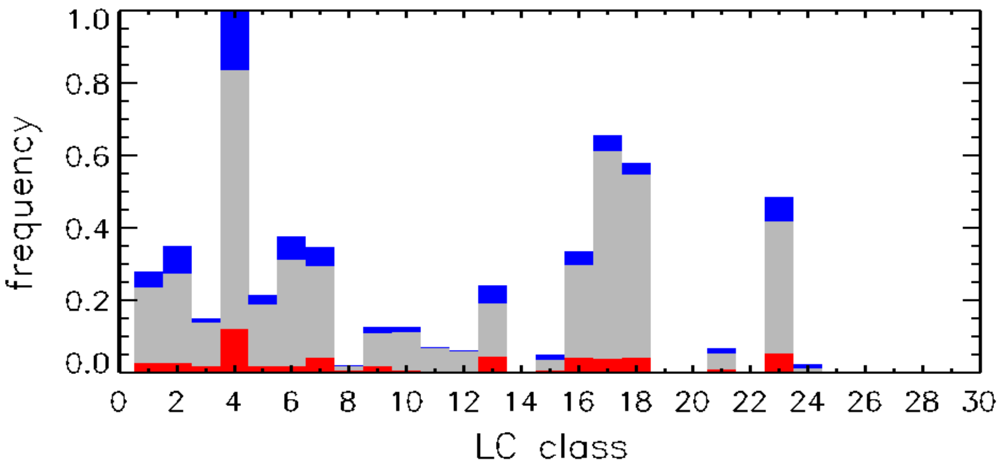


Albers @ 230m


delta_LAI
No data
delta_LAI
-100.0 -40.0 -20.0 0.0 20.0 40.0 100.0
r^2
No data
r^2
0.0 0.1 0.2 0.3 0.4 1.0
positive pix= 9.22%
neutral pix= 78.41%
negative pix= 12.38%
MEAN = −1.92%
STD = 21.83%
frequency
delta_LAI
frequency
r^2
delta_LAI
r^2

delta_LAI as function of LC





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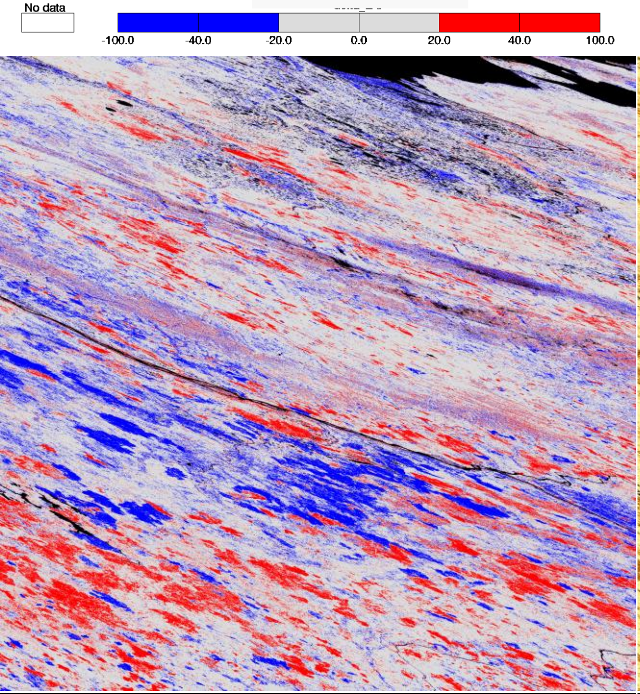
- Sparce Decidious needleaf forests (23)
- Burns (24)

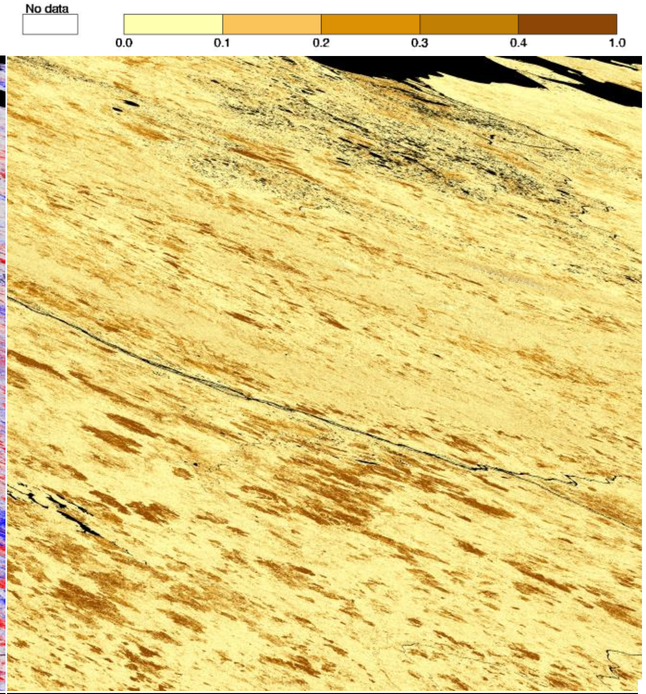
Evaluation of delta_LAI with SKS

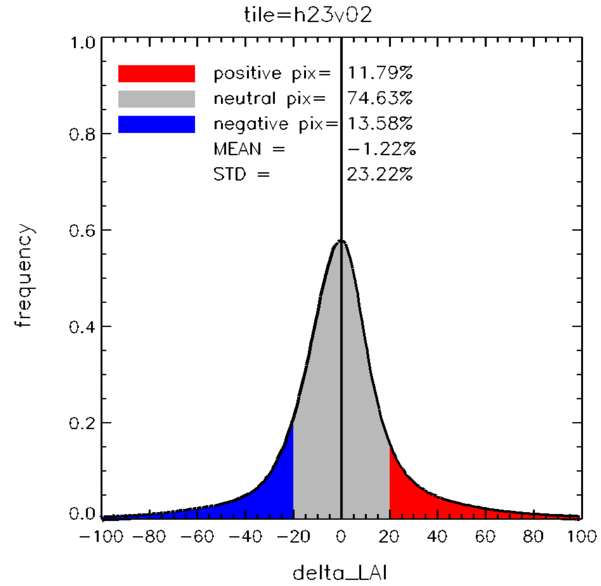
MODIS tile h23v02

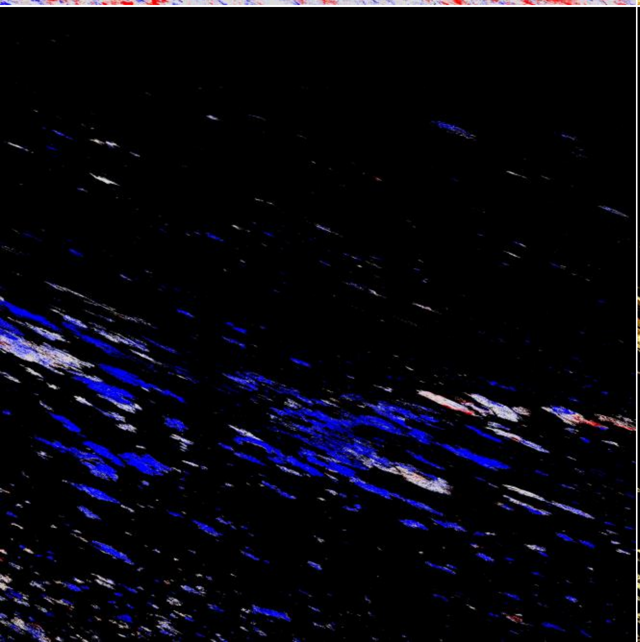
delta_LAI

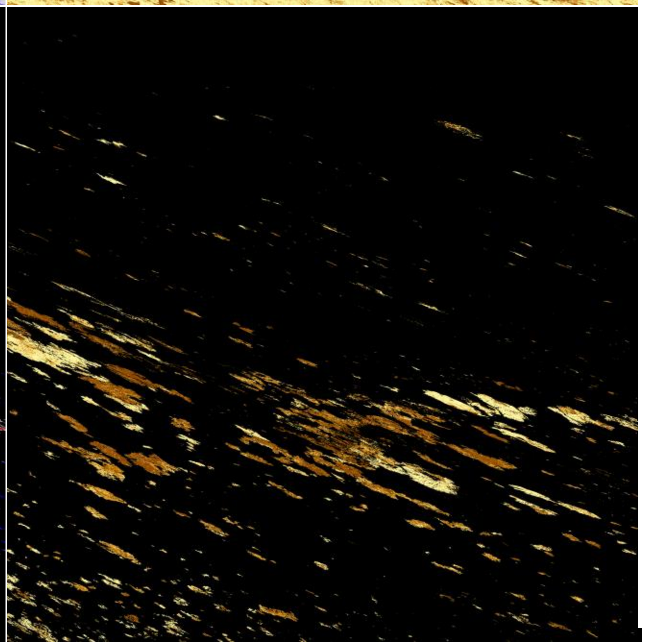


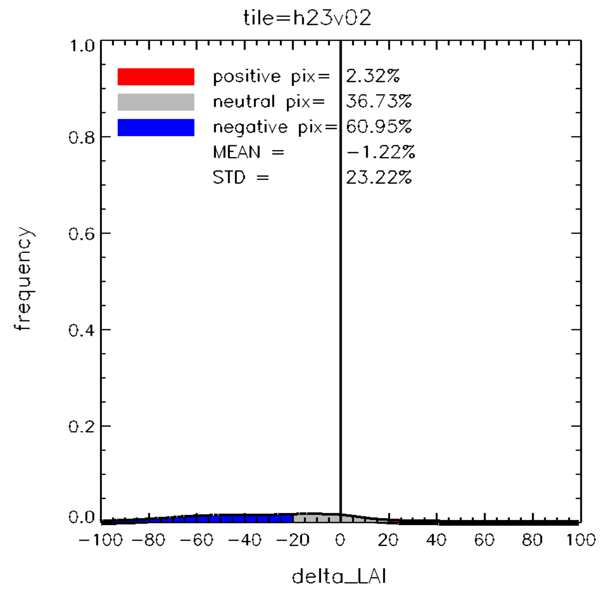
r^2





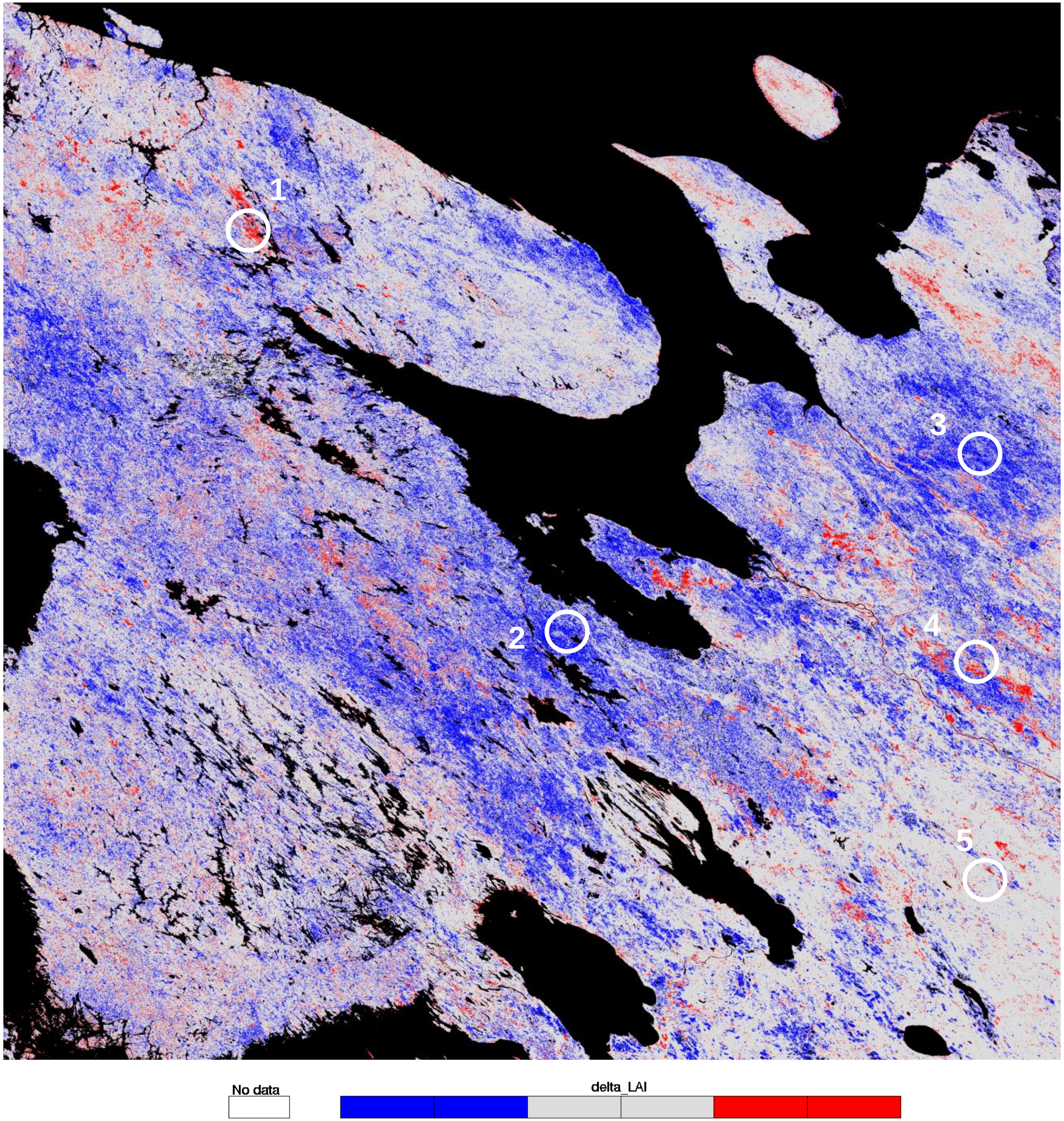




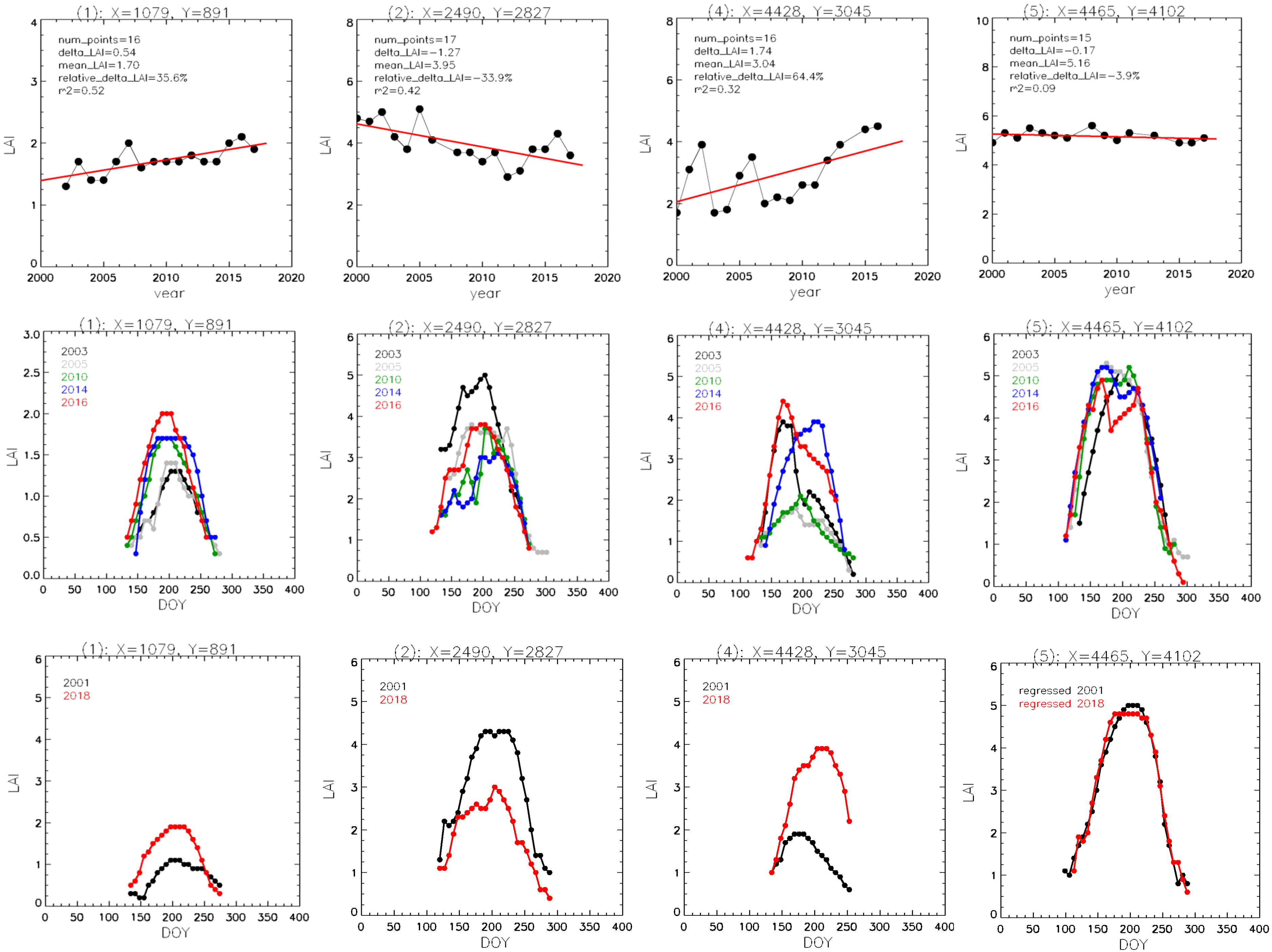


MODIS tile h19v02

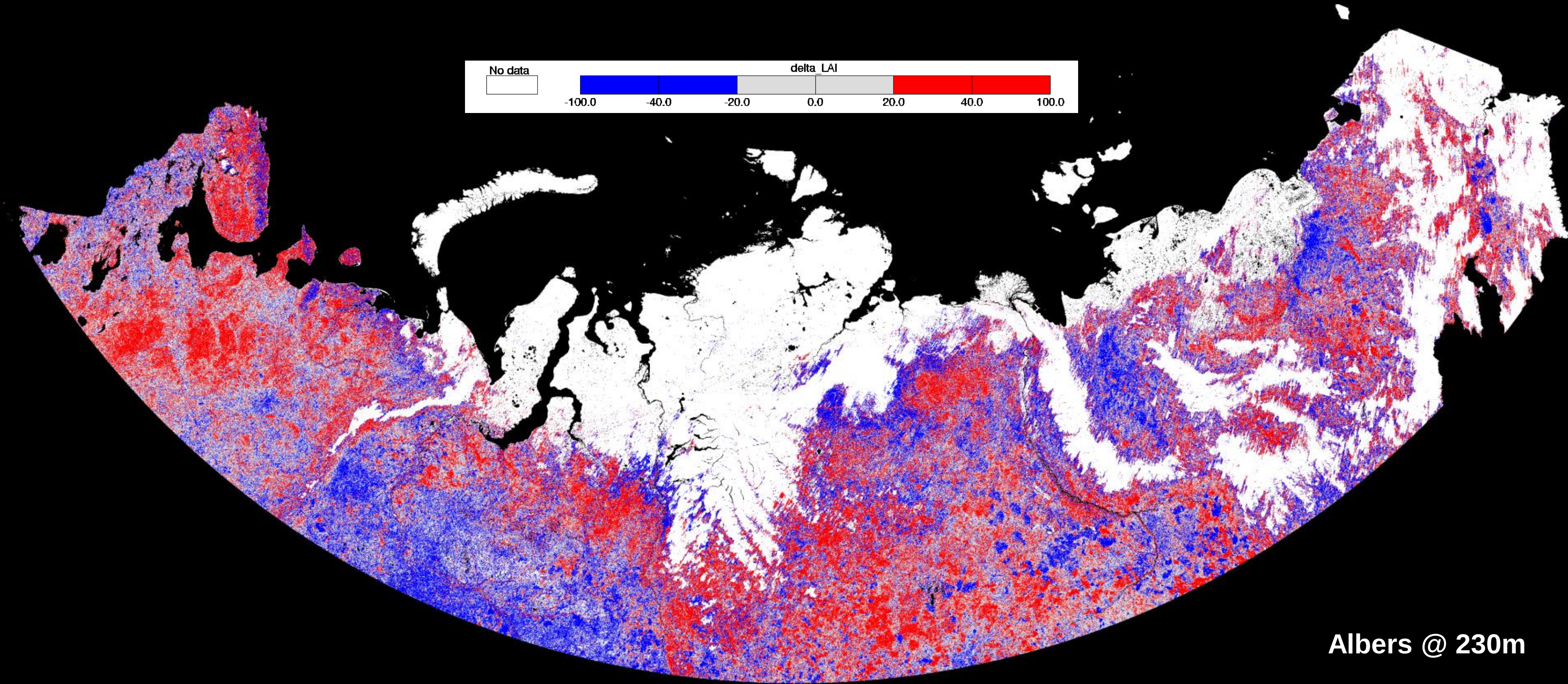
Sampling trends at the pixel level

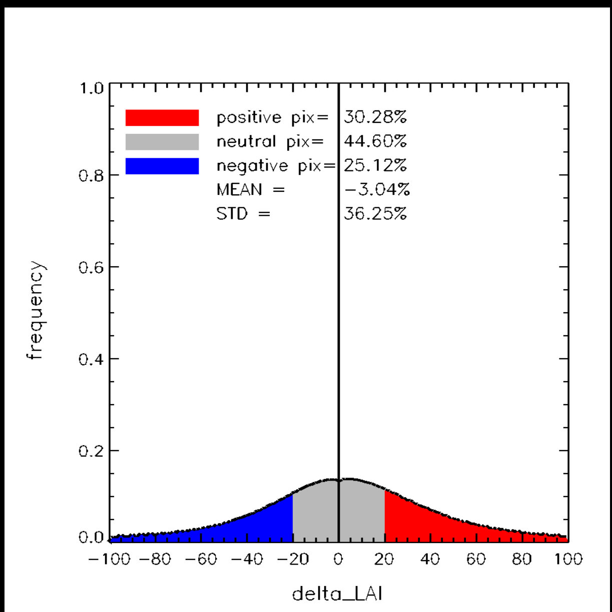


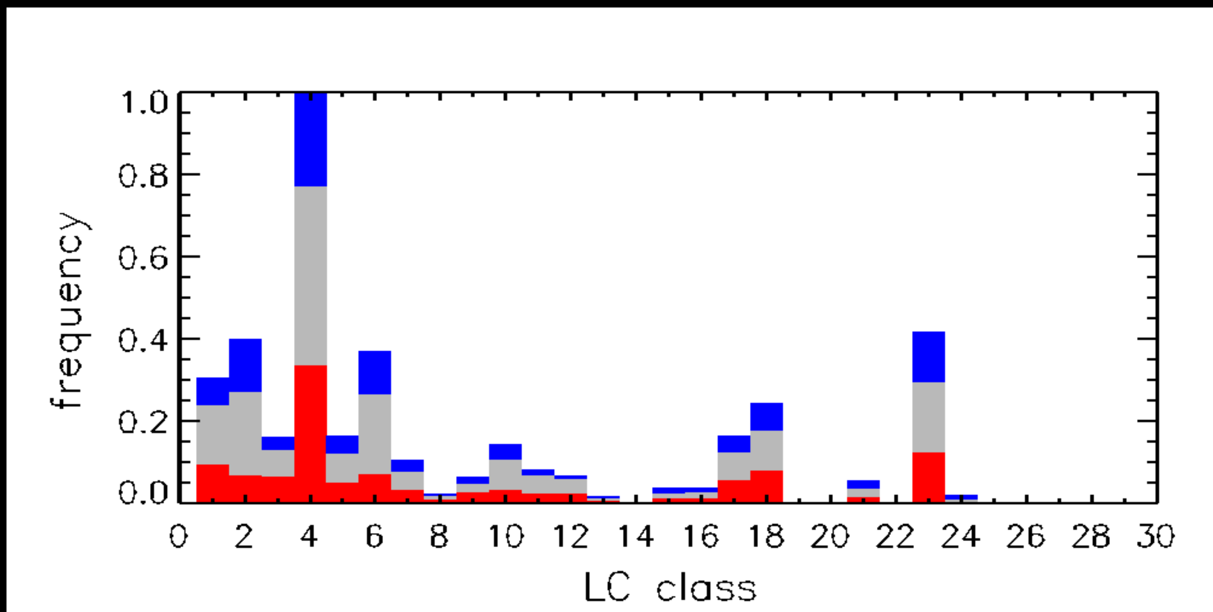
Sampling trends at the pixel level (cont.)



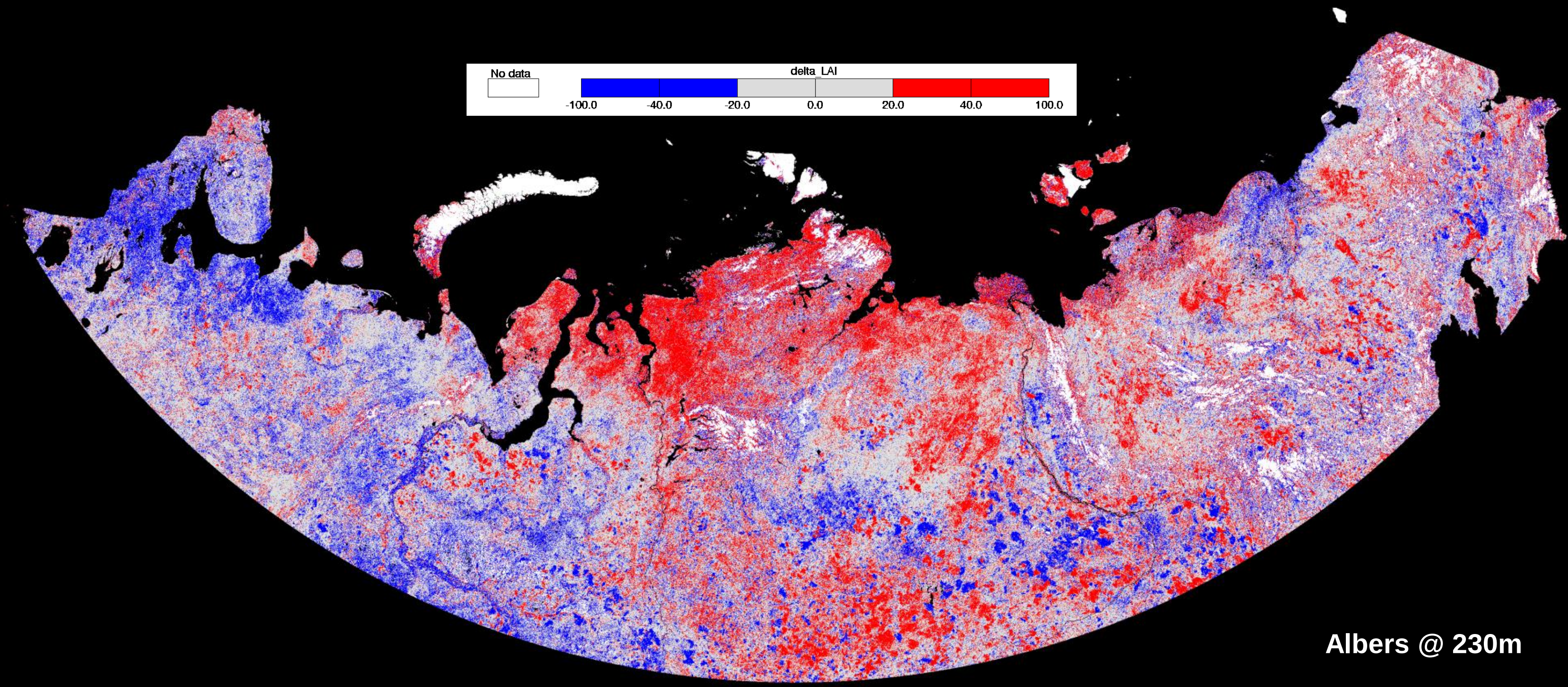
Spring: day 148 (~May 27)

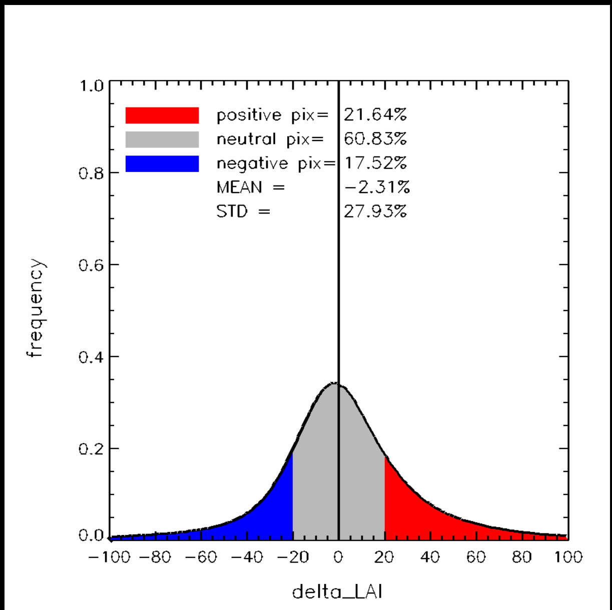


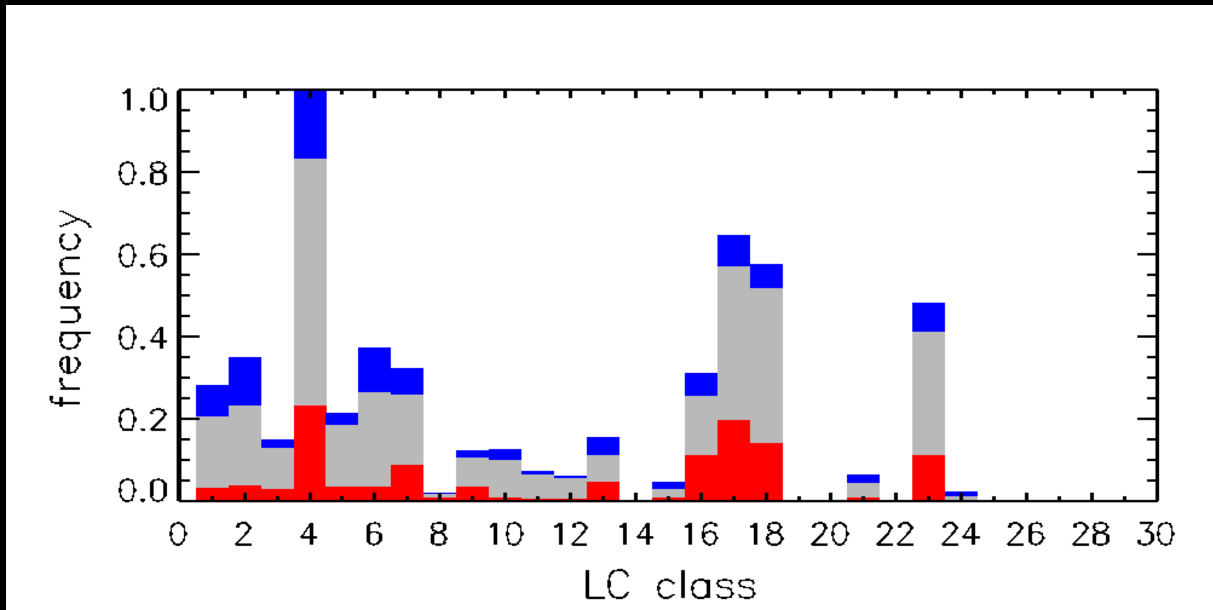




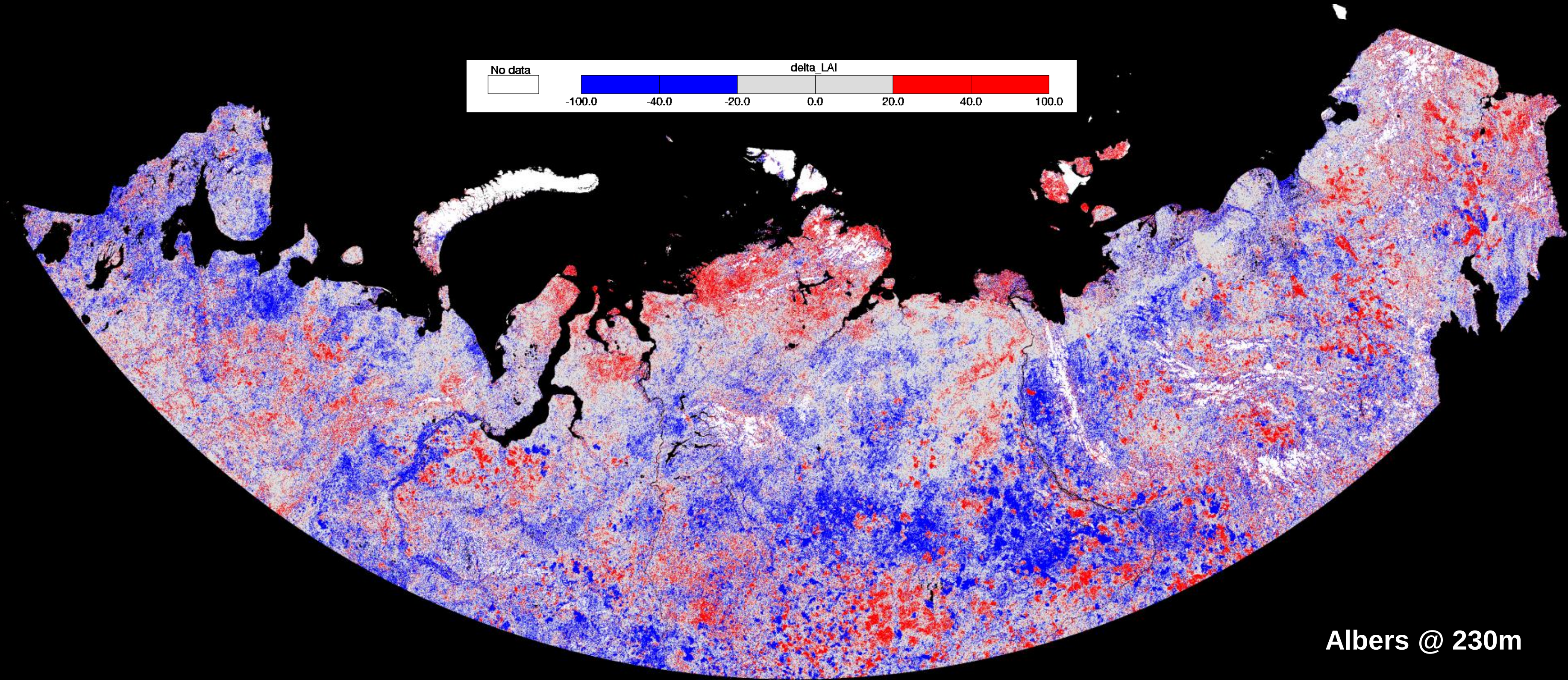
Summer: day 183 (~July 01)

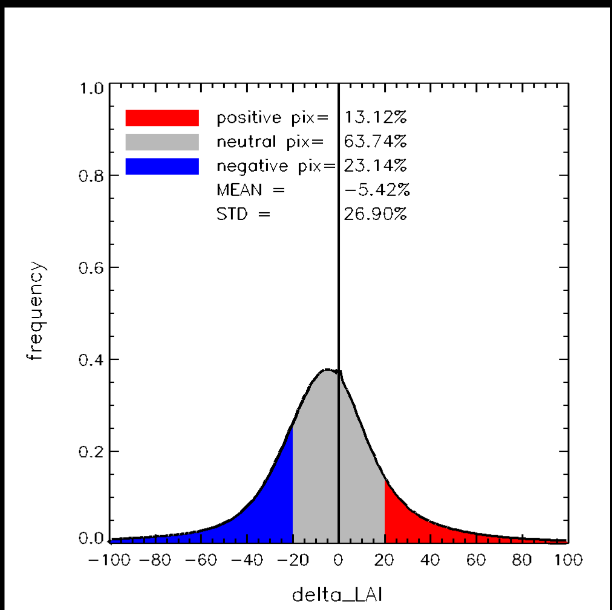


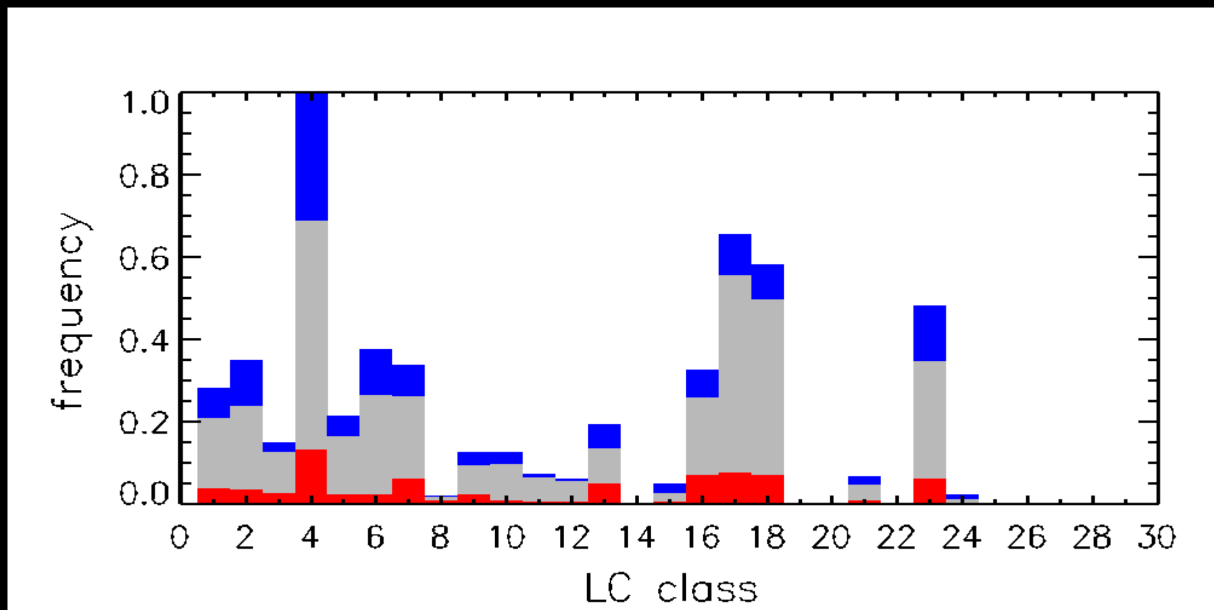




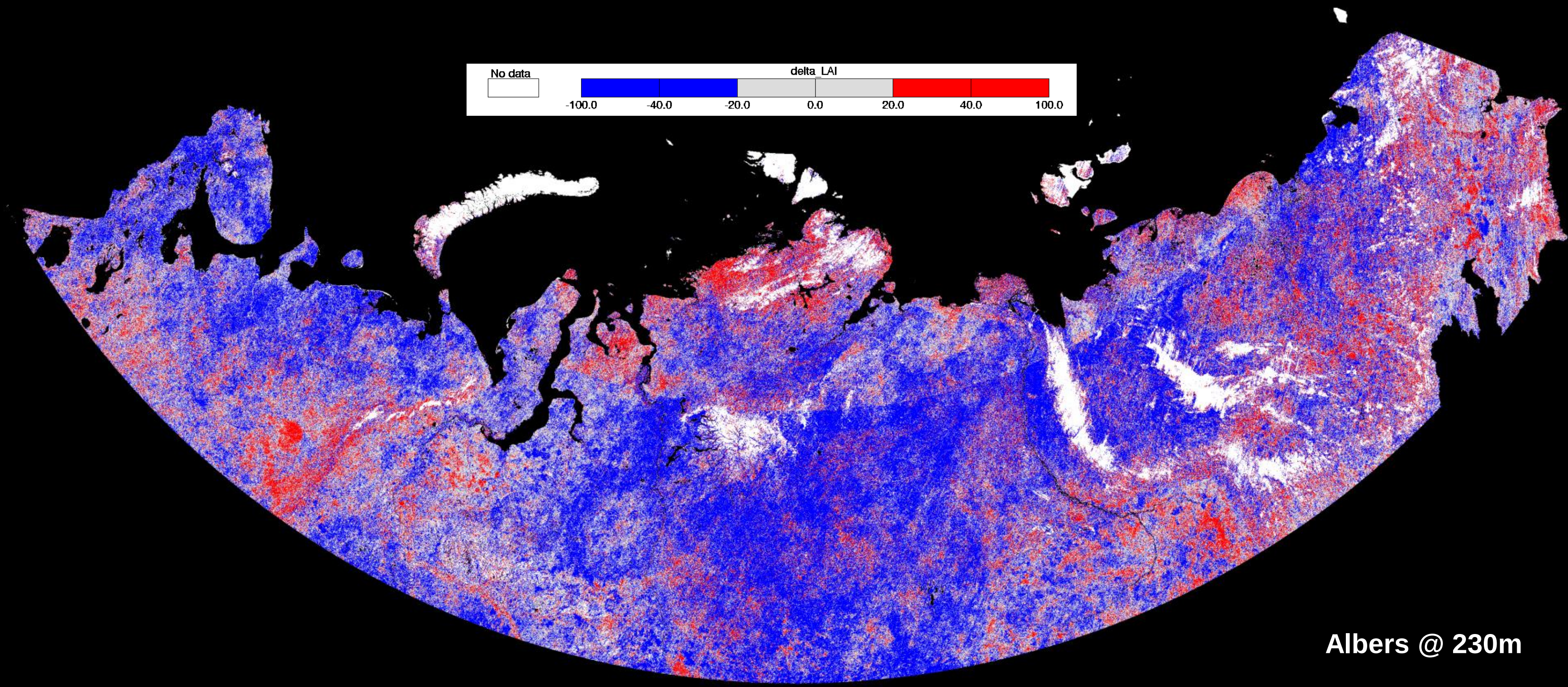
Summer: day 211 (~July 29)

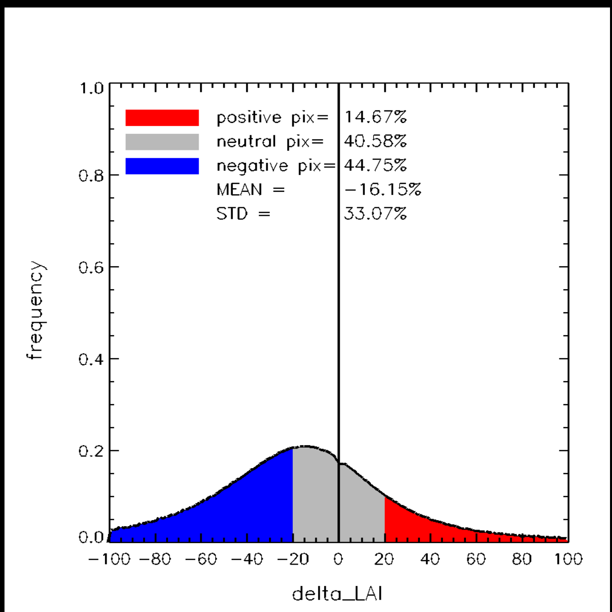


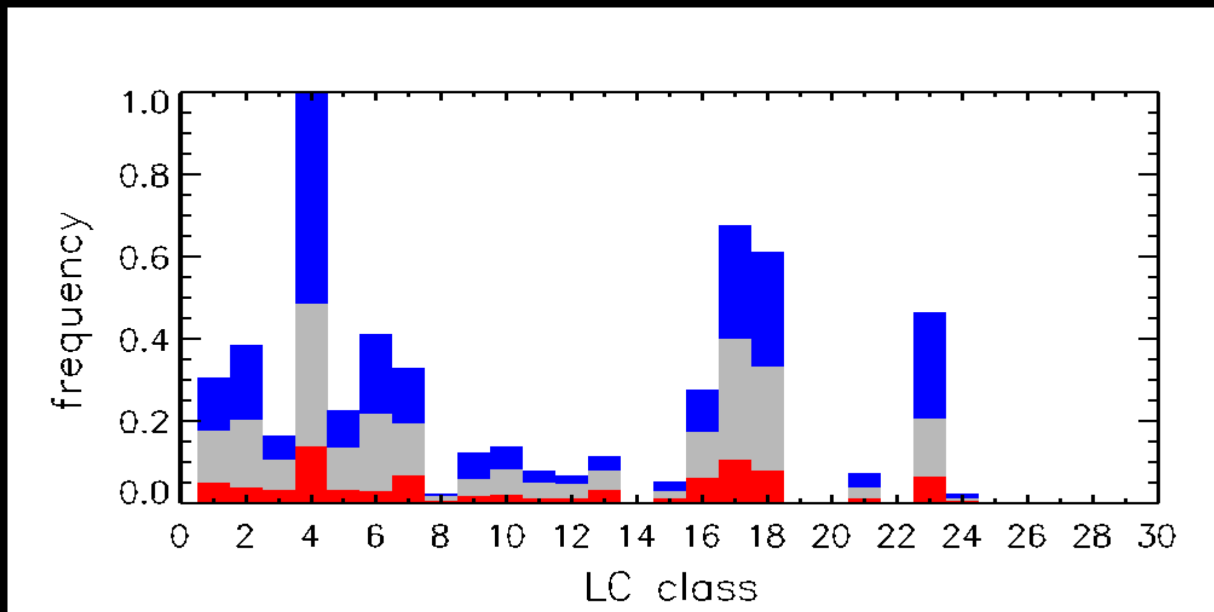




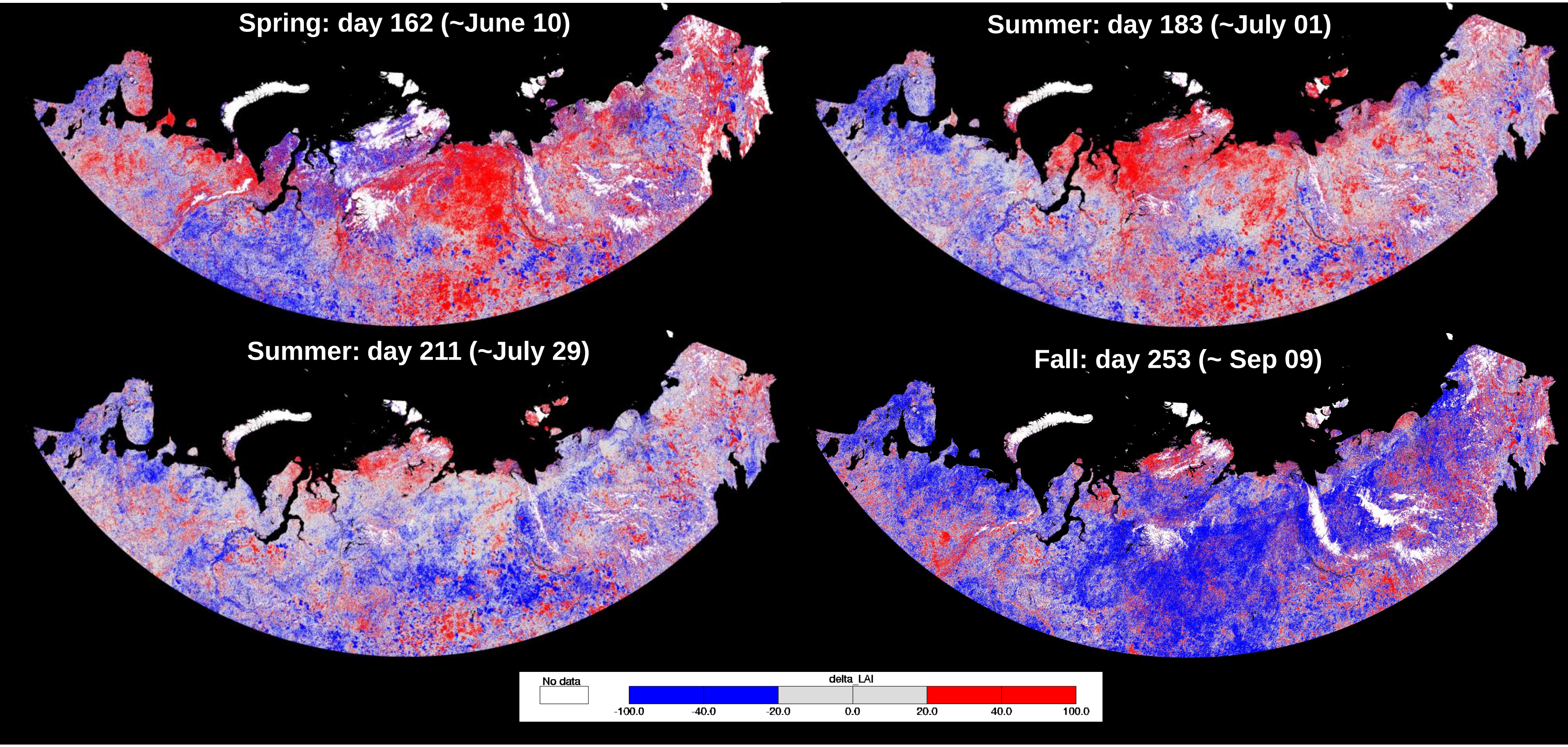
Fall: day 253 (~ Sep 09)







Overall….


Spring: day 162 (~June 10)
Summer: day 183 (~July 01)
Summer: day 211 (~July 29)
Fall: day 253 (~ Sep 09)
No data
delta_LAI
-100.0
-40.0
-20.0
0.0
20.0
40.0
100.0

Results summary

- Summer peak values of LAI do not exhibit significant trends except positive trends at Far North, positive/negative trends over Central Siberian Plateau/Yakutia (fires and vegetation regrowth) and some scattered regions with positive/negative trends (fires and logging and corresponding regrowth). Overall, changes have slight negative bias (-2%), thus northern vegetation of Russia is in balance at its peak over last 20 years. The observed changes are due to disturbances (fires/logging).
- Most significant (large-scale) changes are observed during period of vegetation growth/decline during spring/fall. Earlier spring and earlier fall is observed over European Plain and North Siberian Lowland. Delayed spring is observed over West Siberian Plain. Central Siberian Plateau exhibits earlier fall. Thus, during spring/fall system is not in balance, and in view of large-scale pattern of changes, those could be due to climate change (temperature and snow fall changes).

Future work

Main direction: attribution of the observed trends by studying correlation between temperature/snow cover and LAI during spring/fall periods