remote sensing

MDPI

Supplementary Materials

Performance of smoothing methods for reconstructing NDVI time-series and estimating vegetation phenology from MODIS data

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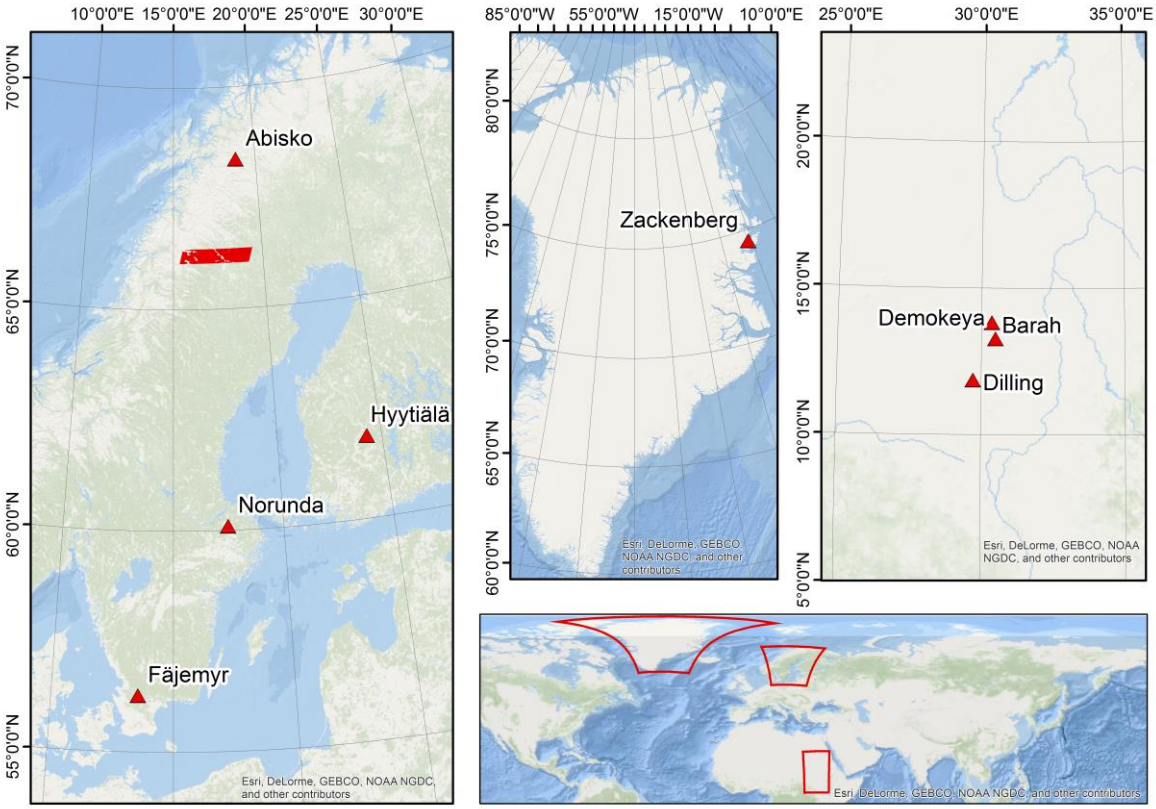
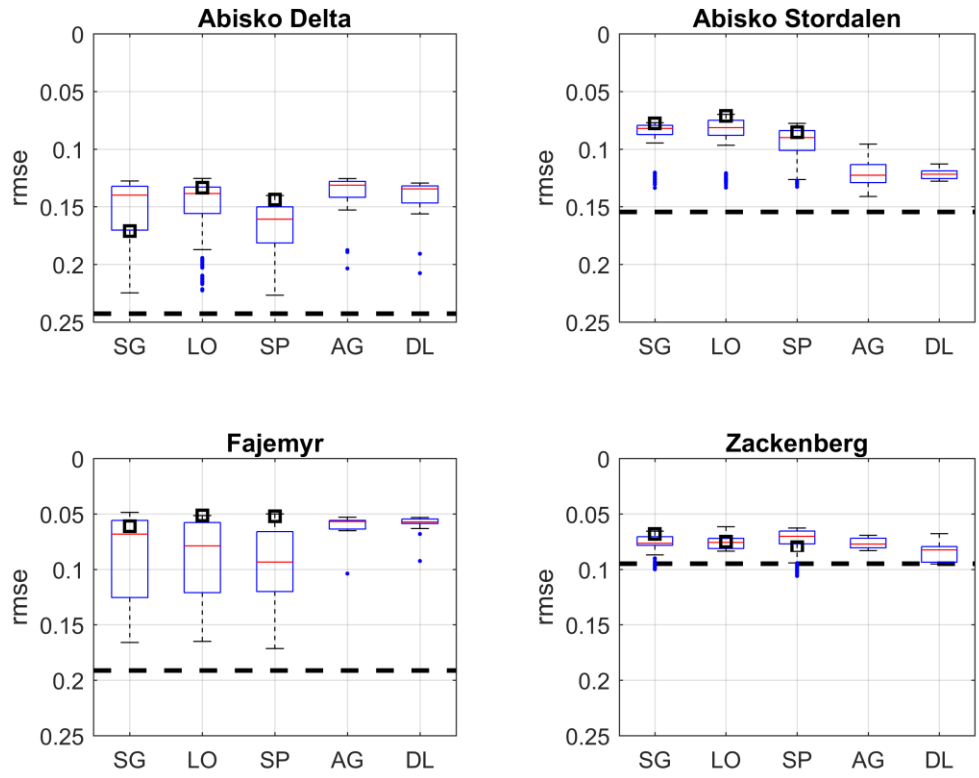


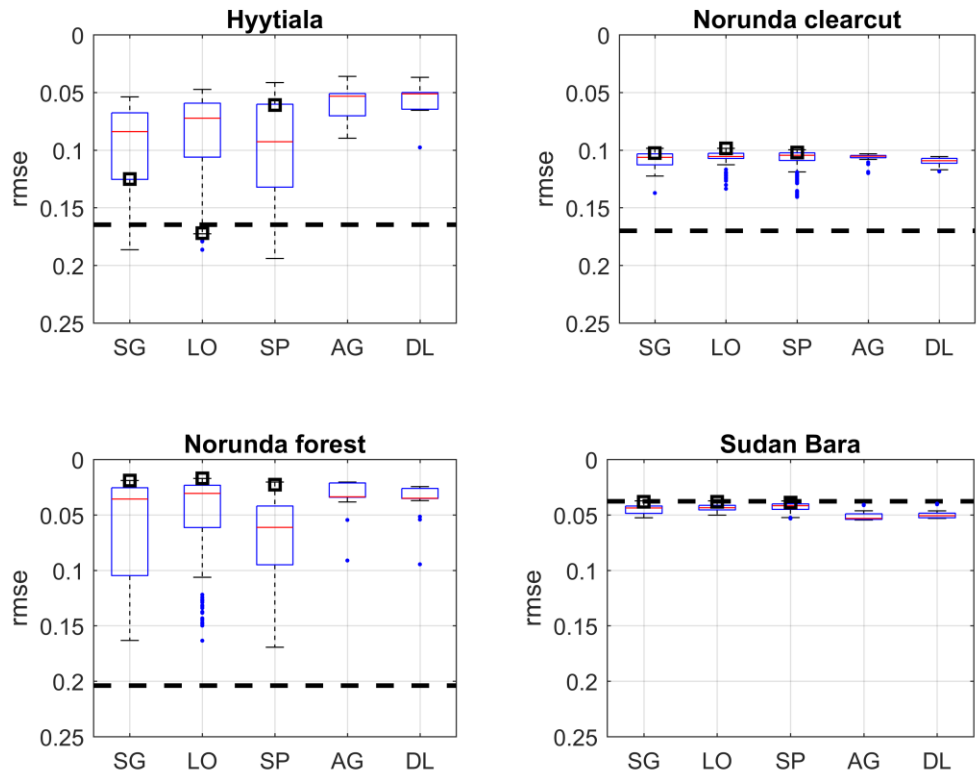
Figure S1. Geographic distributions of ground-based spectral observation sites (marked as red triangles) and Ammar region (marked as red rectangle). Background map sources: Esri, GeLorme, GEBCO, NOAA NGDC, and other contributors.

Table S1: Additional information of ground-based spectral observation sites and flux tower sites.

Site	Temperature (°C)*	Precipitation (mm)*	Species
Abisko Delta	-1.3	60	Birch *(Betula pubescens*)
Abisko Stordalen	-1.3	60	Sedge *(Carex rotundata)*, and Cottongrass *(Eriophorum vaginatum/Eriophorum angustifolium)*
Fäjemyr*	6.3	100	Dwarf shrubs *(Calluna vulgaris L. Hull/Erica tetralix L. S.)*, Sphagnum-mosses *(magellanicum Brid. and S. rubellum Wils.)* and Sedges *(Eriophorum vaginatum L.)*
Zackenberg*	-10.1	20	Moss campion *(Silene acaulis)*, Arctic cottongrass *(Eriophorum scheuchzeri)* and Dark cottongrass *(Eriophorum triste)*
Hyytiälä*	3.1	60	Scots pine *(Pinus sylvestris/)*
Norunda Clear-cut	4.8	50	Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies*)
Norunda Forest*	4.8	50	Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies*)
Sudan Barah	27.9	20	Grassland
Sudan Dilling	28.0	50	Grassland
Sudan Demokeya	27.3	20	Millet

*Mean temperature and precipitation of 1981-2010 [1].


Abisko Delta
Abisko Stordalen
Fajemyr
Zackenberg
rmse
0
0.05
0.1
0.15
0.2
0.25
SG
LO
SP
AG
DL


Hyytiala
Norunda clearcut
Norunda forest
Sudan Bara
rmse
0
0.05
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SG
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AG
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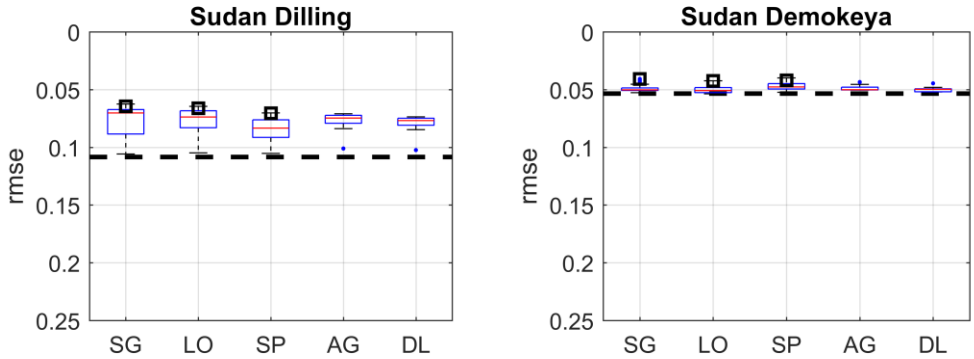
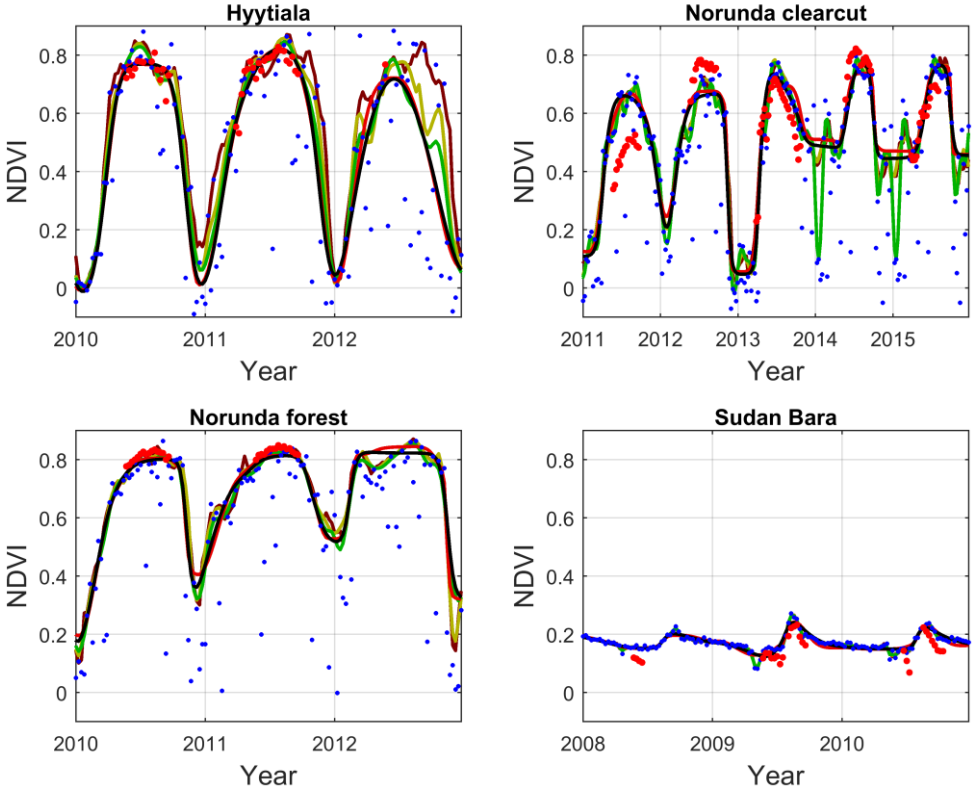
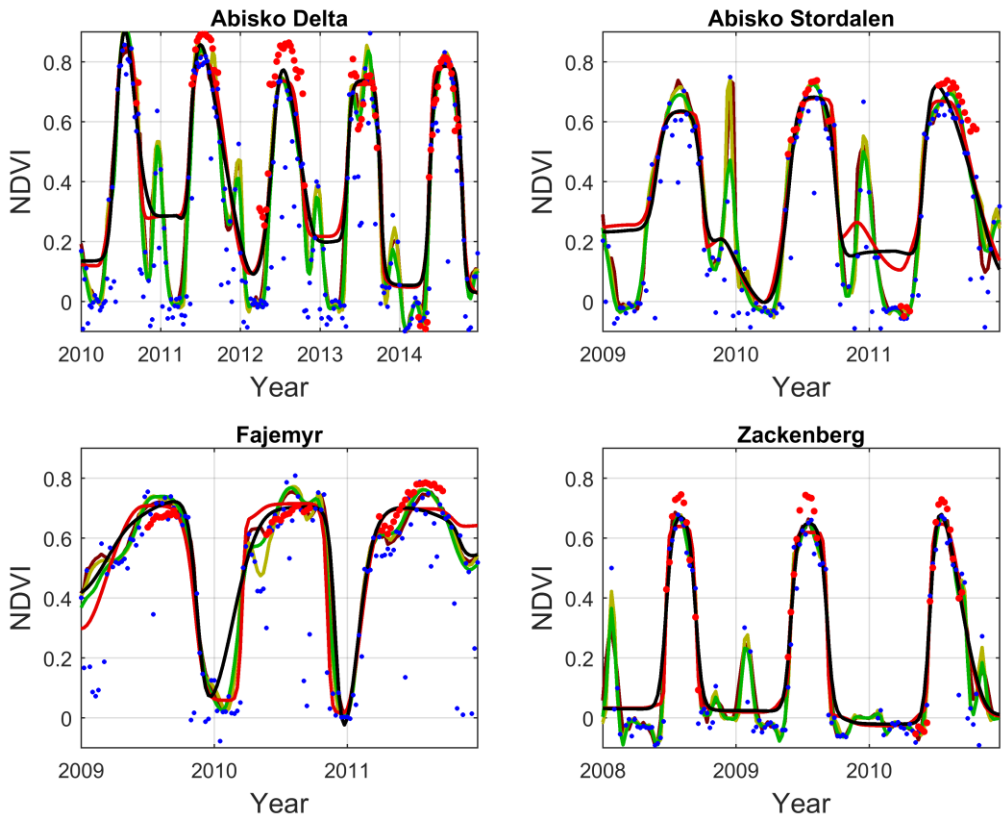


Figure S2. Boxplots of RMSEs between ground-based measured NDVI and smoothed satellite NDVI. Each box contains all settings of each smoothing algorithm at the testing sites. Dashed line = RMSE of raw data and ground based measured NDVI. Note: inverted y-scale; lowest RMSE at the high end of the y-axis. Note: dashed line indicates raw data RMSE.


Hyytiala
Norunda clearcut
Norunda forest
Sudan Bara
NDVI
Year
0
0.2
0.4
0.6
0.8
2010
2011
2012
2013
2014
2015
2008
2009

10


Abisko Delta
Abisko Stordalen
Fajemyr
Zackenberg
NDVI
Year
0
0.2
0.4
0.6
0.8
2008
2009
2010
2011
2012
2013
2014

11

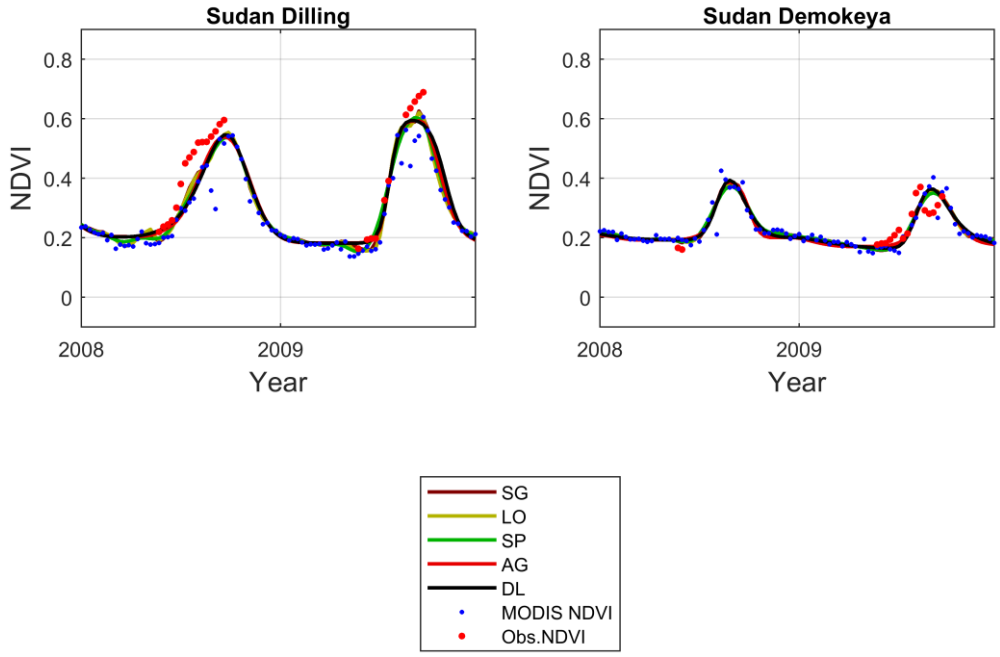


Figure S3. Plots of smoothed curves of each method at all testing sites based on the settings that provide the minimum RMSE values.

Table S2. The minimum, median and range of RMSE between smoothed MODIS NDVI from all settings of each smoothing algorithm and ground measured NDVI from all spectral sensor tower sites.

		SG	LO	SP	AG	DL	Raw
Abisko Delta	Minimum	0.128	0.125	0.140	0.126	0.129	
	Median	0.140	0.139	0.161	0.131	0.135	
	CV	0.171	0.133	0.150	-	-	0.240
	Range	0.097	0.097	0.086	0.078	0.078	
	Improving	100%	100%	100%	100%	100%	
Abisko Stordalen	Minimum	0.077	0.070	0.078	0.096	0.113	
	Median	0.082	0.081	0.090	0.123	0.122	
	CV	0.078	0.071	0.091	-	-	0.150
	Range	0.057	0.064	0.055	0.045	0.015	
	Improving	100%	100%	100%	100%	100%	
Fäjemyr	Minimum	0.049	0.052	0.050	0.053	0.053	
	Median	0.068	0.079	0.093	0.057	0.057	
	CV	0.061	0.052	0.062	-	-	0.190
	Range	0.117	0.113	0.121	0.051	0.039	
	Improving	100%	100%	100%	100%	100%	
Zackenberg	Minimum	0.066	0.062	0.063	0.069	0.068	
	Median	0.077	0.076	0.070	0.077	0.082	
	CV	0.068	0.075	0.079	-	-	0.090
	Range	0.034	0.022	0.043	0.014	0.027	
	Improving	94%	100%	95%	100%	86%	
Hyytiälä	Minimum	0.054	0.047	0.041	0.036	0.037	
	Median	0.084	0.072	0.093	0.053	0.051	
	CV	0.125	0.172	0.058	-	-	0.160
	Range	0.133	0.139	0.153	0.054	0.061	
	Improving	95%	85%	92%	100%	100%	
Norunda Clear-cut	Minimum	0.099	0.099	0.100	0.103	0.106	
	Median	0.106	0.106	0.105	0.105	0.109	
	CV	0.103	0.099	0.104	-	-	0.170
	Range	0.039	0.035	0.041	0.017	0.013	
	Improving	100%	100%	100%	100%	100%	
Norunda Forest	Minimum	0.019	0.017	0.020	0.020	0.025	
	Median	0.036	0.031	0.061	0.034	0.035	
	CV	0.019	0.017	0.044	-	-	0.200
	Range	0.144	0.146	0.149	0.071	0.070	
	Improving	100%	100%	100%	100%	100%	
Sudan Barah	Minimum	0.037	0.037	0.037	0.041	0.040	
	Median	0.044	0.044	0.042	0.053	0.051	
	CV	0.038	0.038	0.047	-	-	0.040
	Range	0.015	0.013	0.016	0.014	0.013	
	Improving	6%	5%	7%	0%	0%	
Sudan Dilling	Minimum	0.063	0.065	0.070	0.071	0.074	
	Median	0.070	0.074	0.083	0.075	0.077	

	CV	0.064	0.066	0.077	-	-	0.110
	Range	0.043	0.040	0.035	0.030	0.029	
	Improving	100%	100%	100%	100%	100%	
Sudan Demokeys	Minimum	0.041	0.042	0.040	0.043	0.045	
	Median	0.050	0.051	0.048	0.050	0.050	
	CV	0.041	0.042	0.045	-	-	0.050
	Range	0.012	0.011	0.012	0.007	0.007	
	Improving	100%	95%	100%	100%	100%	
Average improving rate:		90%	89%	89%	90%	89%	

Table S3. Maximum, median and range of ρ between smoothed MODIS NDVI from all settings of each smoothing algorithm and ground measured GPP.

		SG	LO	SP	AG	DL	Raw
Fäjemyr	Max	0.340	0.320	0.400	0.690	0.360	
	Median	0.190	0.190	0.170	0.530	0.280	
	CV	0.220	0.294	0.328	-	-	0.070
	Range	0.300	0.300	0.340	0.290	0.110	
	Improving	96%	94%	96%	100%	100%	
Zackenberg	Max	0.790	0.790	0.780	0.760	0.760	
	Median	0.770	0.760	0.770	0.720	0.740	
	CV	0.767	0.773	0.754	-	-	0.560
	Range	0.190	0.070	0.030	0.140	0.090	
	Improving	100%	100%	100%	100%	100%	
Hyytiala	Max	0.780	0.780	0.820	0.740	0.720	
	Median	0.620	0.650	0.650	0.580	0.590	
	CV	0.464	0.604	0.687	-	-	0.430
	Range	0.320	0.250	0.290	0.180	0.170	
	Improving	100%	100%	100%	100%	100%	
Norunda forest	Max	0.630	0.650	0.630	0.500	0.570	
	Median	0.370	0.390	0.430	0.390	0.400	
	CV	0.360	0.441	0.454	-	-	0.290
	Range	0.440	0.360	0.310	0.250	0.290	
	Improving	85%	99%	100%	95%	95%	
Average improving rate:		95%	98%	99%	99%	99%	

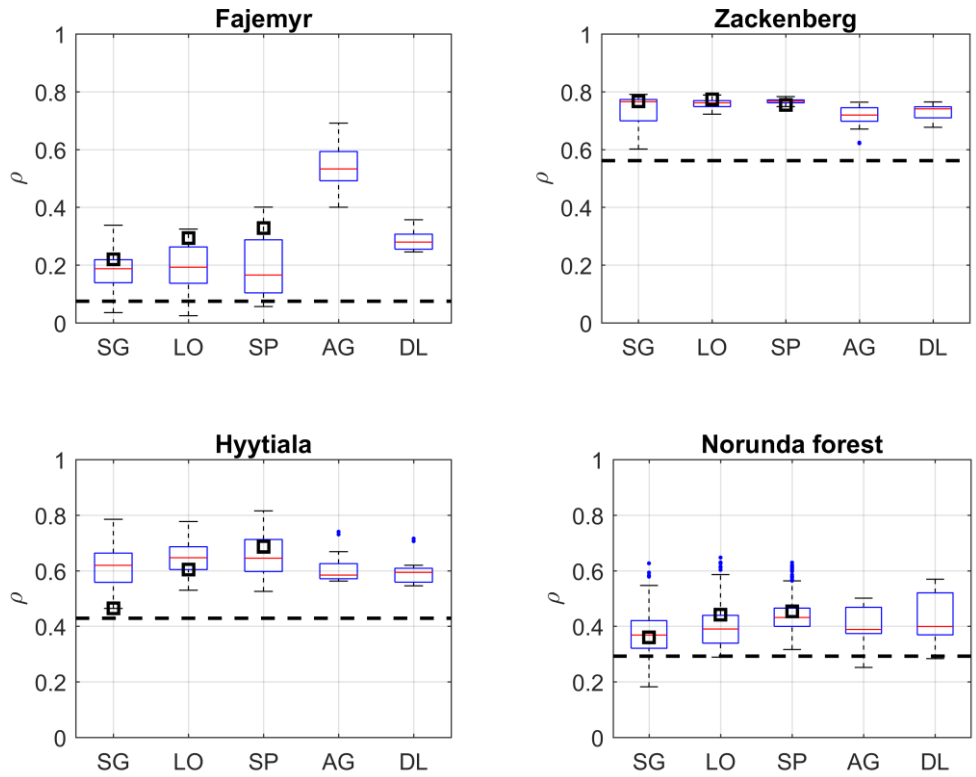


Figure S4. Boxplots of Spearman's rank correlation coefficient of tower GPP and smoothed MODIS NDVI for each method, showing the distribution with different settings at test sites. Note: dashed line indicates ρ of raw MODIS NDVI and ground measured GPP.

Table S4. The maximum, median and range of ρ between elevations and land surface phenology parameters extracted by each smoothing algorithm of all settings on MODIS NDVI.

		SG	LO	SP	AG	DL
SOS	Max	0.877	0.856	0.886	0.904	0.904
	Median	0.682	0.715	0.693	0.887	0.891
	Range	0.670	0.606	0.645	0.103	0.077
EOS	Min	-0.779	-0.753	-0.785	-0.807	-0.831
	Median	-0.585	-0.637	-0.668	-0.767	-0.785
	Range	0.541	0.441	0.483	0.065	0.075
LOS	Min	-0.866	-0.842	-0.868	-0.882	-0.886
	Median	-0.732	-0.765	-0.776	-0.873	-0.874
	Range	0.424	0.346	0.379	0.024	0.020
SI	Min	-0.631	-0.622	-0.636	-0.638	-0.665
	Median	-0.518	-0.566	-0.558	-0.630	-0.655
	Range	0.347	0.303	0.323	0.041	0.044

References

1. Willmott, C. J. and K. Matsuura (2001) Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950 - 1999), http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts2.html.