remote sensing

MDPI

Supplementary material

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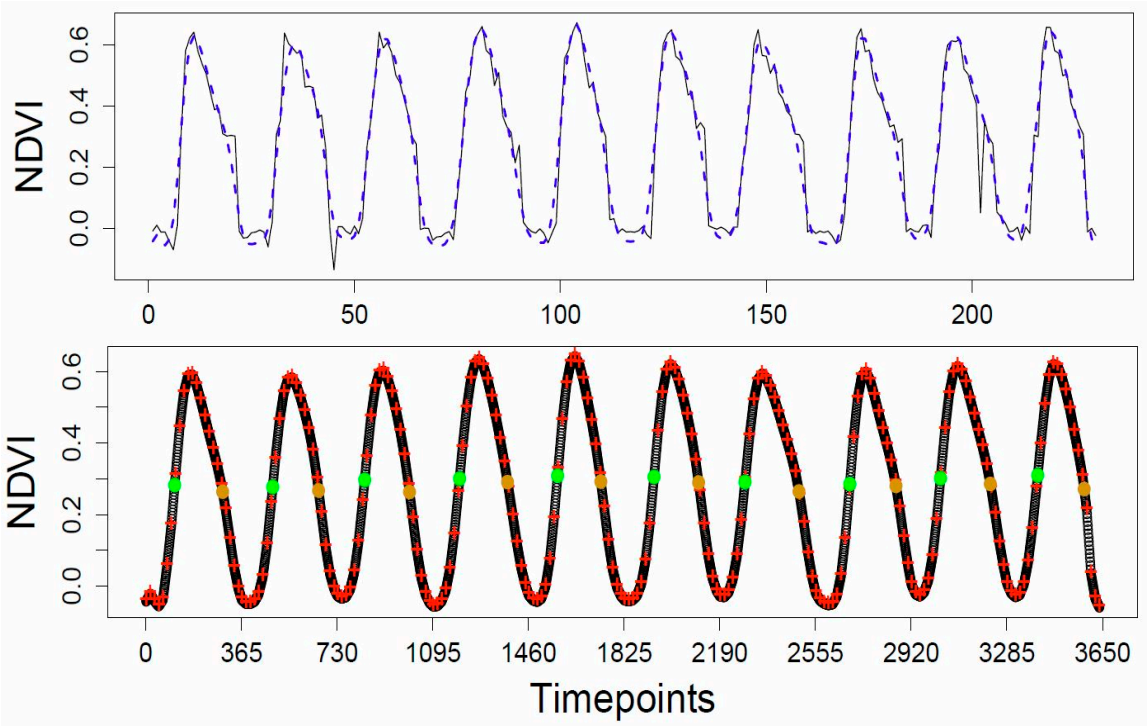

Figure S1. Figure showing preprocessing and phenology extraction from NDVI time series. Raw (black) and corrected and smoothed (dotted blue) time series of bi–weekly NDVI (upper panel) are interpolated to daily values for phenology extraction (lower panel). Red crosses represent the corrected bi–weekly NDVI values and the black points are interpolated ones. Start (SOS) and end (EOS) of the growing season (green and brown dots) are determined as time points when 50% of the annual amplitude are reached.

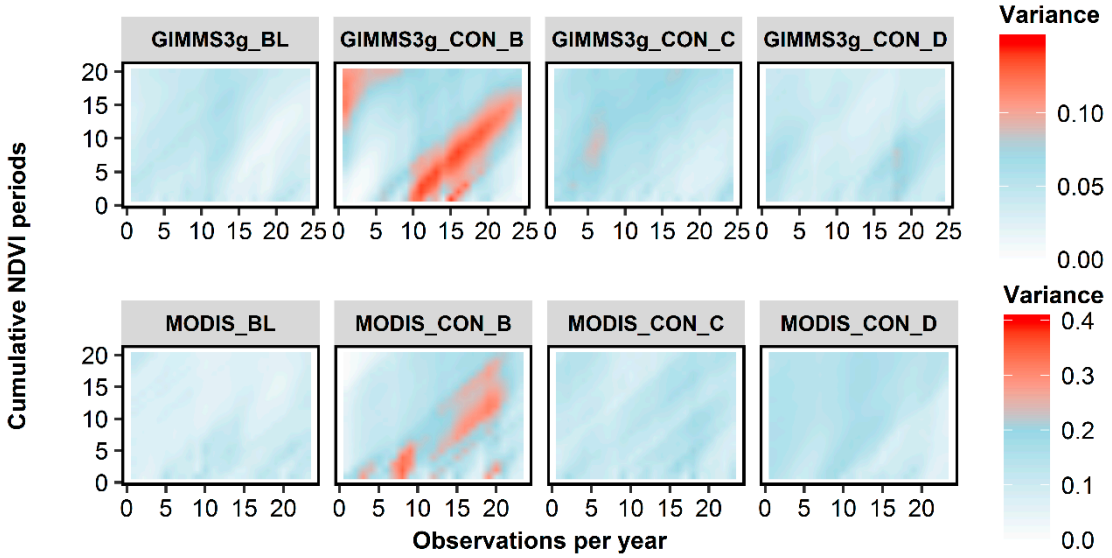

Figure S2 Variance of Pearson correlation coefficients between time series of RWI and cumulative NDVI at different temporal scales (1–20, y−axis) for 69 tree−ring sites. Cumulative NDVI is either based on GIMMS3g (8 km resolution) or MODIS (250 m resolution). BL indicates 16 sites with broadleaf species, CON_B, CON_C, and CON_D refers to 4, 21, and 28 sites with coniferous tree species in climate zones B, C, and D, respectively. Zone B indicates arid/semiarid climate, C and D represent temperate and continental climates, respectively, as per the Köppen–Geiger climate classification [1].

Section S3: Validation Statistics to Assess Performance of RF Model

In order to access the performance of the Climate−NDVI MODIS RF model, we list some validation statistics. Observed refers to observed RWI and predicted to the corresponding predictions of the Climate−MODIS NDVI Random Forest Model. In the formulae of the validation metric ratios, model refers to the training and validation to the test data.

- The mean relative error (RE) is given by mean of {(predicted – observed) / observed} = 0.03
- The mean absolute error (MAE) error ratio is given by mean ((abs (predicted – observed))), The MAE ratio is calculated as Model MAE/Validation MAE = 0.66.
- The root mean square error (RMSE) is given by sqrt(mean((predicted − observed)^2)), The RMSE ratio is calculated as Model RMSE/Validation RMSE = 0.53.

From the above we see that the mean Relative Error, the MAE ratio and RMSE ratio were calculated to be 0.03, 0.66 and 0.53, respectively. The results show that the model is not very robust for prediction. However, with this study we aim to only make a comparison of the different spatial−resolution NDVI datasets and propose which phenological metrics have the potential to best explain RWI. RWI reconstruction or prediction is not intended or suggested.

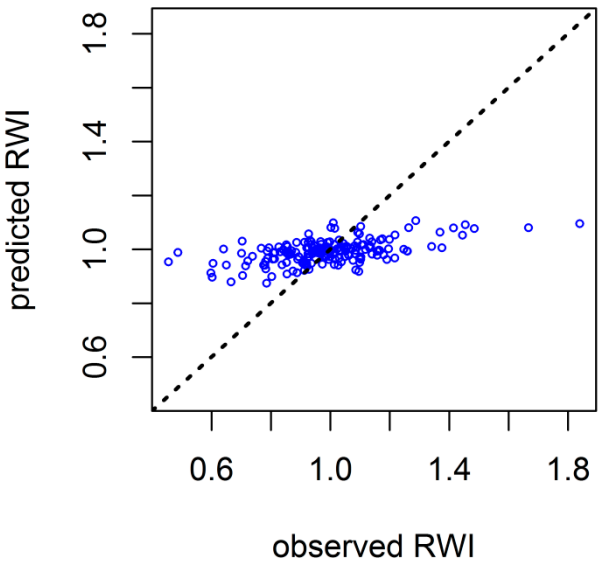

Figure S4. Scatter plot of observed and predicted RWI. The predicted values are from the Climate–MODIS NDVI Random Forest Model and observed values are from the test dataset. The black dashed line represents the line when intercept and slope is fixed at 0 and 1 respectively.

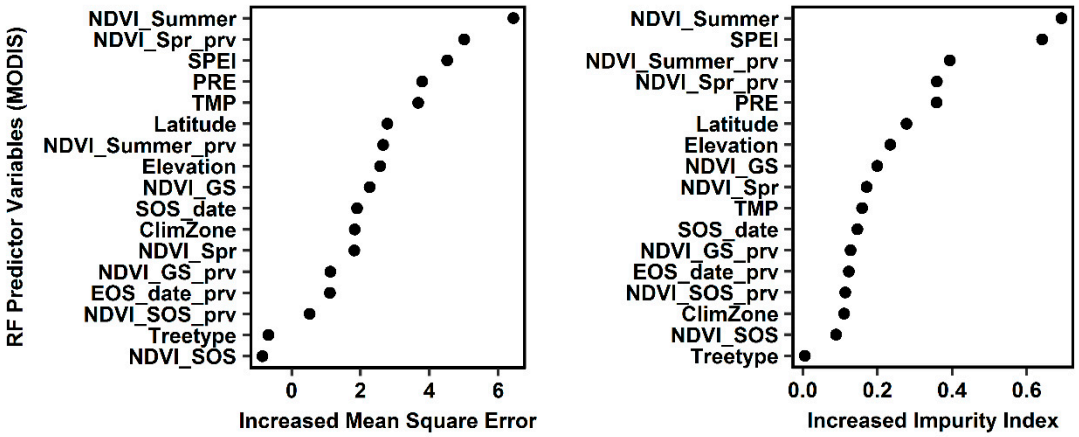

Figure S5. Random−forest variable−importance plot for RF (MODIS) climate−NDVI model performed with drought index SPEI. Variables are ranked in terms of importance on the y−axis (with variables of highest importance for predicting RWI at the top). PRE, TMP, SPEI, Latitude, Elevation, Tree type and ClimZone represent precipitation, temperature, Standardized Precipitation Evapotranspiration Index , latitude of the forest site, elevation of the forest site, tree type (coniferous or broadleaf) and climate zone (B, C or D) as per the Köppen–Geiger climate classification [1], respectively. For definitions of NDVI phenological metrics: NDVI_GS, NDVI_GS_prv, NDVI_Sum, NDVI_Sum_prv, NDVI_Spr, NDVI_Spr_prv, NDVI_SOS, NDVI_SOS_prv, SOS_date and EOS_date_prv, see Table 1. The variance of RWI of all forests explained by the RF model was 22.1%.

Table S1. Information on sites analyzed: Co−ordinates, species, climate zone (see climate data important tree−ring metrics and chronology coverage. Latitude (Lat) and Longitude (Lon) are the geographic coordinates (WGS84 datum) of each site. Country names are coded according to ISO3. For Type, "CON" and "BL" denotes conifers and broadleaves respectively. Zone B, C and D denote arid/semiarid, temperate and continental climates, respectively as per Köppen−Geiger climate classification [1]. Elevation is given in m a.s.l. The tree ring metrics shown are the mean inter−series correlation (RBAR) and mean sensitivity (MS). RBAR is the average correlation coefficient between tree−ring series and MS is a within−series statistic that measures the relative change in ring width from one year to the next.

ID	Country	Lat (°)	Lon (°)	Species	Type	Zone	Elevation	RBAR	MS	Start	End
UT531	USA	41.23	−111.26	*Juniperus scopulorum* Sarg.	CON	D	1980	0.62	0.24	1173	2010
UT538	USA	41.91	−111.65	*Pseudotsuga menziesii* (Mirb.) Franco	CON	D	2730	0.55	0.17	1274	2010
CA680	USA	37.46	−119.49	*Calocedrus decurrens* (Torr.) Florin	CON	C	1843	0.57	0.19	1581	2011
UT534	USA	40.15	−111.25	*Pinus edulis* Engelm.	CON	D	2130	0.65	0.28	1428	2011
UT533	USA	40.08	−111.2	*Pinus edulis* Engelm.	CON	D	1960	0.71	0.27	1313	2011
swit280	CHE	46.35	7.58	*Pinus cembra* L.	CON	D	1900	0.51	0.21	1546	2011
swit279	CHE	46.35	7.59	*Picea abies (L.)* Karst.	CON	D	1850	0.65	0.17	1670	2011
swit281	CHE	46.32	8.5	*Pinus cembra* L.	CON	D	1850	0.52	0.19	1707	2012
swit282	CHE	46.32	8.5	*Pinus mugo* Turra	CON	D	1920	0.5	0.18	1761	2012
swit274	ITA	46.26	9.47	*Larix decidua* Mill.	BL	D	1850	0.71	0.27	1691	2011
RUSS240	RUS	52.29	98.58	*Larix decidua* Mill.	BL	D	2170	0.65	0.3	1603	2013
VA036	USA	37.16	−80.26	*Quercus alba* L.	BL	C	800	0.53	0.24	1918	2010
UT532	USA	41.3	−111.23	*Juniperus scopulorum* Sarg.	CON	D	2100	0.58	0.2	1227	2010
UT536	USA	41.21	−111.58	*Pseudotsuga menziesii* (Mirb.) Franco	CON	D	2133	0.66	0.24	1370	2012
UT537	USA	41.22	−111.57	*Pseudotsuga menziesii* (Mirb.) Franco	CON	D	2750	0.54	0.21	1133	2011

ME036	USA	46.24	−69	*Picea rubens* Sarg.	CON	D	310	0.6	0.21	1879	2013
CANA458	CAN	53.52	−72.25	*Picea mariana* (Mill.) Britt.	CON	D	481	0.49	0.17	642	2011
CANA460	CAN	54.06	−71.38	*Picea mariana* (Mill.) Britt.	CON	D	451	0.49	0.16	774	2011
CANA461	CAN	54.15	−72.23	*Picea mariana* (Mill.) Britt.	CON	D	436	0.52	0.16	596	2011
NM588	USA	36.17	−106.38	*Pinus ponderosa* Dougl. ex Laws.	CON	D	2525	0.75	0.41	620	2011
NM589	USA	36.05	−108.52	*Pinus ponderosa* Dougl. ex Laws.	CON	B	2650	0.66	0.31	842	2010
MONG039	MNG	48.1	99.52	*Pinus sibirica* Du Tour	CON	D	2077	0.8	0.39	−106	2010
CA687	USA	37.33	−121.51	*Quercus lobata* Nee	BL	C	89	0.54	0.29	1697	2010
CA686	USA	37.33	−121.51	*Platanus racemosa* Nutt.	BL	C	89	0.54	0.38	1700	2010
BT021	BTN	27.25	90.58	*Picea* spp. A. Dietr.	CON	C	3268	0.42	0.16	1280	2013
CA674	USA	40.06	−120.38	*Pinus ponderosa* Dougl. ex Laws.	CON	C	1385	0.56	0.27	1450	2010
OR093	USA	43.42	−120.28	*Juniperus occidentalis* Hook.	CON	B	1475	0.82	0.42	870	2010
OR094	USA	43.57	−121.03	*Juniperus occidentalis* Hook.	CON	C	1146	0.79	0.46	830	2010
CA677	USA	39.34	−120.17	*Pinus Jeffrey*i Grev. & Balf. in A. Murr.	CON	C	1688	0.61	0.26	1415	2010
OR095	USA	43.09	−119.48	*Juniperus occidentalis* Hook	CON	B	1514	0.78	0.36	1337	2010
CA678	USA	37.57	−119.09	*Pinus Jeffrey*i Grev. & Balf. in A. Murr.	CON	C	2499	0.58	0.24	1304	2010
OR092	USA	43.1	−120.53	*Juniperus occidentalis* Hook	CON	C	1428	0.78	0.49	530	2010
GERM188	BEL	50.36	6.29	*Pinus sylvestris* L.	CON	C	415	0.66	0.24	1854	2011
OR097	USA	44.13	−121.52	*Tsuga mertensiana* (Bong.) Carr.	CON	C	1454	0.57	0.21	1837	2013

OR096	USA	44.26	−121.57	*Pseudotsuga menziesii* (Mirb.) Franco	CON	C	1139	0.5	0.17	1838	2013
WV009	USA	37.58	−80.56	*Pinus rigida* Mill.	CON	C	700	0.53	0.31	1828	2014
WV007	USA	37.59	−82.22	*Tsuga canadensis* (L.) Carr.	CON	C	250	0.55	0.24	1756	2012
WV006	USA	37.31	−80.59	*Tsuga canadensis* (L.) Carr.	CON	C	670	0.66	0.25	1858	2012
CZEC003	AUT	48.4	14.42	*Abies alba* Mill.	CON	C	785	0.51	0.2	1587	2010
CZEC004	AUT	48.4	14.42	*Fagus sylvatica* L.	BL	C	785	0.45	0.26	1603	2010
CZEC005	AUT	48.4	14.42	*Picea abies* (L.) Karst.	CON	C	785	0.49	0.21	1569	2010
CHIN073	CHN	28.36	119.27	*Pinus massoniana* Lamb.	CON	C	435	0.54	0.27	1846	2013
CO652	USA	37.14	−108.25	*Pseudotsuga menziesii* (Mirb.) Franco	CON	D	2226	0.78	0.42	480	2014
CO651	USA	37.16	−108.21	*Pseudotsuga menziesii* (Mirb.) Franco	CON	D	2226	0.82	0.4	722	2011
NY043	USA	44.21	−74.44	*Pinus strobus* L.	CON	D	455	0.58	0.2	1916	2012
AK149	USA	67.29	−162.13	*Picea glauca* (Moench) Voss	CON	D	120	0.57	0.24	1814	2012
AK148	USA	67.29	−162.13	*Picea glauca* (Moench) Voss	CON	D	125	0.5	0.26	1855	2012
RUSS241	RUS	52.24	98.41	*Larix sibirica* Ledeb.	BL	D	2020	0.44	0.29	1523	2013
GA023	USA	34.53	−84.39	*Tsuga canadensis* (L.) Carr.	CON	C	600	0.44	0.2	1947	2011
NC024	USA	35.17	−82.43	*Tsuga canadensis* (L.) Carr.	CON	C	670	0.46	0.22	1910	2010
PA016	USA	40	−77.48	*Tsuga canadensis* (L.) Carr.	CON	C	500	0.49	0.19	1896	2010
VA032	USA	37.11	−80.29	*Tsuga canadensis* (L.) Carr.	CON	C	570	0.57	0.25	1869	2010
WV008	USA	38.37	−79.47	*Tsuga canadensis* (L.) Carr.	CON	C	900	0.55	0.21	1770	2010

MN029	USA	46.17	−96.36	*Quercus macrocarpa* Michx.	BL	D	293	0.56	0.26	1877	2010
ND009	USA	47.54	−97.01	*Quercus macrocarpa* Michx.	BL	D	254	0.65	0.28	1854	2010
ND012	USA	46.51	−96.47	*Quercus macrocarpa* Michx.	BL	D	268	0.66	0.27	1870	2010
ND010	USA	46.53	−96.46	*Quercus macrocarpa* Michx.	BL	D	268	0.65	0.28	1878	2010
ND007	USA	48.58	−97.14	*Quercus macrocarpa* Michx.	BL	D	236	0.68	0.28	1856	2010
ND011	USA	46.52	−96.47	*Quercus macrocarpa* Michx.	BL	D	275	0.57	0.26	1886	2010
ND008	USA	47.56	−97.02	*Quercus macrocarpa* Michx.	BL	D	254	0.73	0.27	1865	2010
MN028	USA	48.58	−97.14	*Quercus macrocarpa* Michx.	BL	D	236	0.76	0.27	1890	2010
MN030	USA	46.17	−96.36	*Quercus macrocarpa* Michx.	BL	D	290	0.6	0.24	1868	2010
ak131	NA	58.23	−134.26	*Tsuga mertensiana* (Bong.) Carr.	CON	D	220	0.5	0.24	1454	2010
id015	USA	43.45	−116.06	*Pinus ponderosa* Dougl. ex Laws	CON	B	1825	0.62	0.25	1488	2011
ak134	USA	65	−147.39	*Picea mariana* (Mill.) Britt.	CON	D	431	0.41	0.23	1875	2010
ak133	USA	65	−147.39	*Picea mariana* (Mill.) Britt.	CON	D	465	0.54	0.23	1908	2010
ak135	USA	65	−147.4	*Picea mariana* (Mill.) Britt.	CON	D	317	0.5	0.23	1895	2010
ak136	USA	65	−147.4	*Picea mariana* (Mill.) Britt.	CON	D	300	0.43	0.21	1857	2012
UT541	USA	40.55	−111.13	*Juniperus osteosperma* (Torr.) Little	CON	D	2130	0.79	0.37	736	2013

References:

1. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World map of the Köppen−Geiger climate classification updated. *Meteorol. Z.* **2006**, *15*, 259–263.