1.Spatiotemporal distribution map

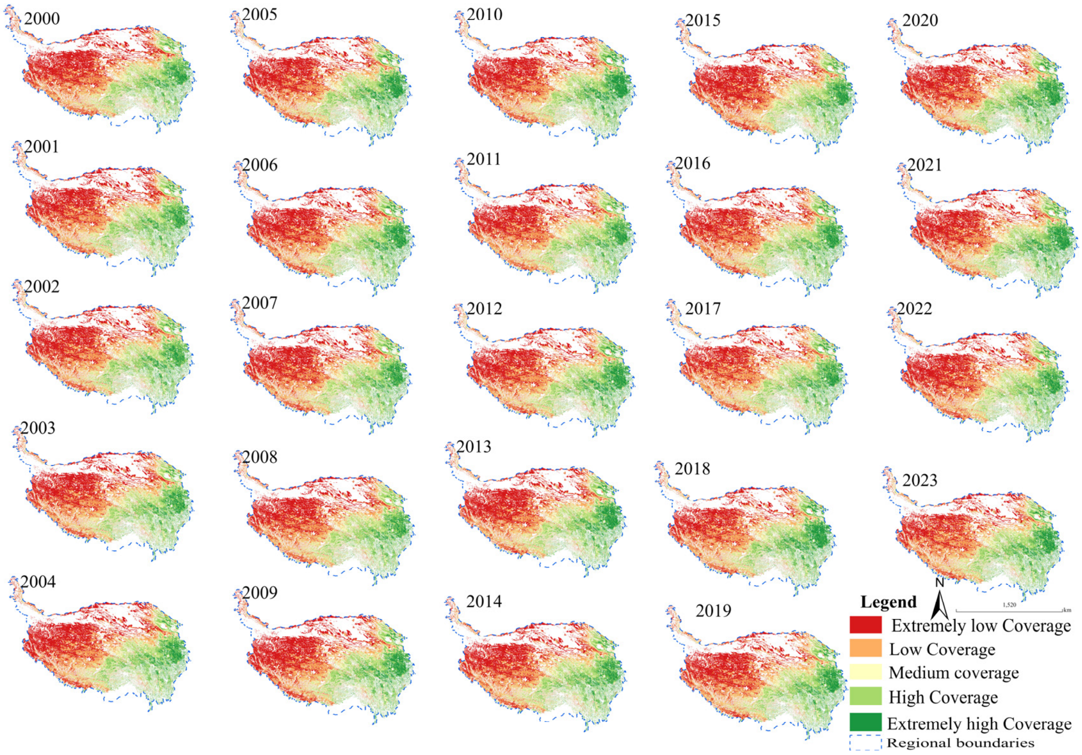

Figure S1. Annual spatial distribution of FVC in QTP grassland from 2000 to 2023

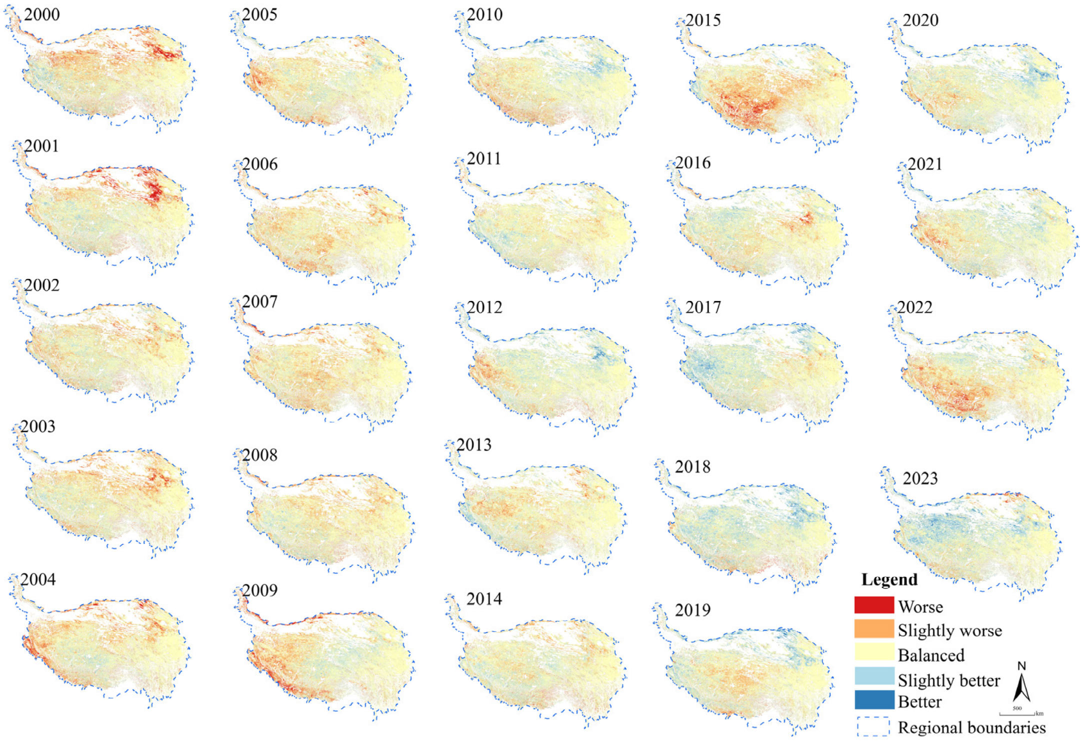

Figure S2. Annual spatial distribution of growth index

2. Spatial distribution map of driving factors

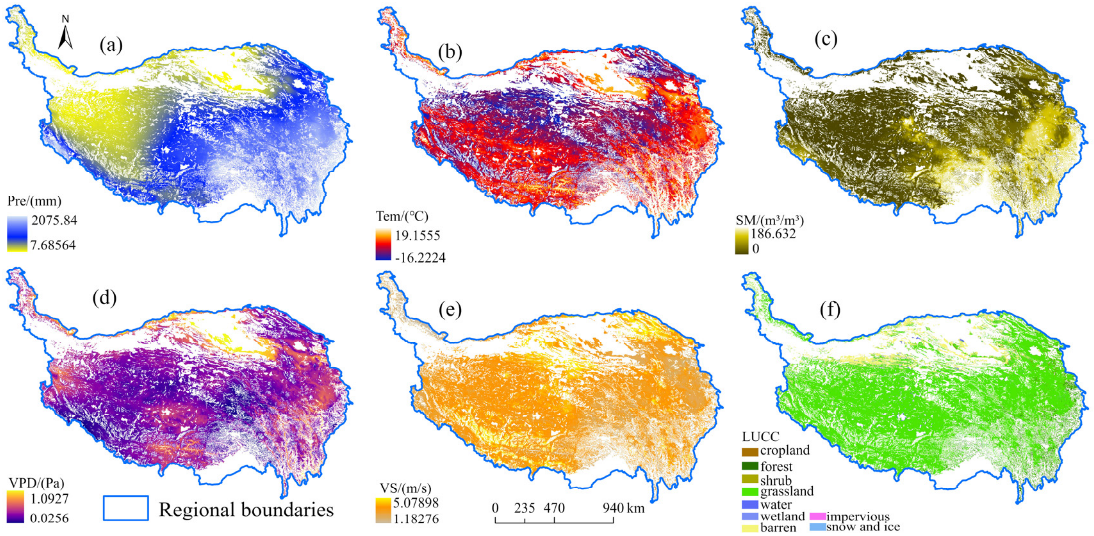

Figure S3. Spatial distribution of independent variable factors. (a: average annual precipitation; b: average annual temperature; c: average annual soil moisture; d: average annual saturated va-por pressure deficit (VPD); e: average annual wind speed (VS); f: land cover)

3.Research Methods Calculation Formula

(1)Pixel dichotomy model

$$FVC = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \tag{S1}$$

Where FVC is the vegetation coverage, and the range is [0-100] in percentage; $NDVI_i$is the NDVI value of a pixel in the period;$NDVI_{max}$ and $NDVI_{min}$ are the maximum NDVI value and the minimum NDVI value of all pixels in the study area, respectively.

(2) Grassland Growth Index

$$GI = \frac{FVC_m - FVC_n}{FVC_m + FVC_n} \tag{S2}$$

Where $GI$is the grassland vegetation growth index,FVC_nrepresents the FVC value of grassland in different periods, and FVC_m represents the benchmark value, that is, the average FVC of grassland in the Qinghai-Tibet Plateau over 24 years. The grassland growth index is divided into five ranges.

(3)Trend analysis

① The spatial variation trend of FVC in QTP grassland was analyzed using the Mann-Kendall and Sen slope estimation trend estimation method. This is a non-parametric statistical method that is suitable for analyzing trends in long series and has been widely recognized, The principle is as follows:

$$\beta = \text{median}\frac{\text{FVC}_j - \text{FVC}_i}{j - i} \tag{S3}$$

Where 1<i<j<n,β represents the Sen slope of FVC.When β>0,the FVC change trend increases; otherwise, it decreases.i represents the year, and n represents the duration of the study.

Mann-Kendall test statistic:

For a set of time series{$FVC_1, FVC_2, \dots, FVC_n$},The statistic S for the Mann-Kendall test is calculated as follows:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sgn}\left(FVC_j - FVC_i\right) \tag{S4}$$

Where $\text{sgn}\left(FVC_j - FVC_i\right)$ is the sign function, defined as:

$$\operatorname{sgn}(FVC_j - FVC_i) = \begin{cases} 1, (FVC_j - FVC_i) > 0 \\ 0, (FVC_j - FVC_i) = 0 \\ -1, (FVC_j - FVC_i) < 0 \end{cases} \tag{S5}$$

Where 1<i<j<n，Sis the test statistic,When n>10，After standardization of the test statistic S, the standard normal test statistic Z is obtained, which is used to express the significance level. The principle formula is as follows：

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \tag{S6}$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0 \quad , S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \tag{S7}$$

② The Hurst index is a method to measure the long-range dependence of time series data. It is based on the ratio of the cumulative deviation of the time series to the standard deviation and is obtained by least squares fitting. Hurst index calculations are obtained using the R/S calculation, which is calculated using the following equation：

$$R(n) = \max(FVC_1, FVC_2, \ldots, FVC_n) - \min(FVC_1, FVC_2, \ldots, FVC_n) \tag{S8}$$

$$S(n) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(FVC_i - \overline{FVC})^2} \tag{S9}$$

$$H = \frac{\log\left(\frac{R(n)}{S(n)}\right)}{\log(n)} \tag{S10}$$

Where，$R(n)$ is the difference between the maximum and minimum FVC of the first n QTP grasslands, and $S(n)$ is the standard deviation of the FVC of the first n QTP grasslands.

(4)Coefficient of variation

$$CV = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(FVC_i - avg(FVC)\right)^2}{n-1}}}{avg(FVC)} \tag{S11}$$

Where CV refers to the coefficient of variation of FVC of QTP grassland, n represents the number of years studied,$FVC_i$is the FVC of the ith year，avg(FVC)represents the average FVC. The larger the CV value, the lower the stability; the smaller the CV value, the higher the stability. We divide CV into five levels: extremely low volatility (<0.05), lower volatility (0.05⩽CV<0.1), low volatility (0.1⩽CV<0.15), medium-low volatility (0.15⩽CV<0.2) and high volatility (⩾0.2).

(5)Geographic detector

① Factor Detection

The calculation method includes: (a) spatial superposition analysis of the FVC layer and the natural factor layer; (b) dividing the natural factors into different spatial types or subzones; and (c) significance test for differences in the mean values of the natural factors to detect the relative importance of the natural factors. The model for calculating the explanatory power of each natural factor is as follows:

$$PD = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{S12}$$

Where PD is the explanatory power of natural factors on QTP grassland FVC,$h = 1$，⋯，L is the stratification, classification or segmentation of y or factor x;N_h and Nrepresent the number of units in h and the entire region, respectively; N and σ^2 are the total number of samples and the variance of y values in the entire area respectively;$N_h$is the variance of h units.

The value range of PD is [0,1],The larger the PD value, the more obvious the spatial differentiation of y.

The formula for calculating the variance of the y value in the entire region is:

$$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}\left(Y_i - \overline{Y}\right)^2 \tag{S13}$$

Where Y_i and $\overline{Y}$are the ith sample and mean in the study area respectively.

$$\sigma_h^2 = \frac{1}{N_h-1}\sum_{i=1}^{N_h}\left(Y_{h,i} - \overline{Y}_h\right)^2 \tag{S14}$$

Where $Y_{h,i}$ and $\overline{Y}_h$ are the ith sample and mean in region h, respectively.

② Interaction Detection

Factor interaction detection was used to identify interactions between natural factors, that is, to assess the magnitude of their combined effects (enhancement or attenuation) and their individual effects on FVC of QTP grassland.

First, the PD values of the two variable factors on QTP grassland FVC (PD(X_1) and PD(X_2) were calculated. Then, the PD value of the interaction between the natural factors (PD($X_1 \cap X_2$)) was calculated and compared with PD(X_1) and PD(X_2).

(6)Partial Correlation Analysis

$$r_{ij\cdot k} = \frac{r_{ij} - r_{ik}r_{jk}}{\sqrt{(1-r_{ik}^2)(1-r_{jk}^2)}} \tag{S15}$$

Where,$r_{ij\cdot k}$ is the partial correlation coefficient between variables X_i and X_j after controlling for other variables X_k.

3.Statistical summary

Table S1. Statistics on the annual average value of FVC in QTP grassland from 2000 to 2023

Year	FVC mean(%)	Year	FVC mean(%)
2000	39.16%	2012	41.46%
2001	39.65%	2013	40.40%
2002	40.00%	2014	40.24%
2003	39.36%	2015	38.41%
2004	39.45%	2016	40.31%
2005	40.40%	2017	41.41%
2006	39.56%	2018	42.27%
2007	39.20%	2019	40.65%
2008	39.45%	2020	41.82%
2009	39.91%	2021	41.65%
2010	41.16%	2022	39.39%
2011	40.24%	2023	42.16%

Table S2. The proportion of different types of QTP grassland FVC in 2000-2023

Year	Extremely low FVC(%)	Low FVC(%)	Medium FVC(%)	Medium-high FVC(%)	High FVC(%)
2000	33.84	24.54	13.47	19.92	8.23
2001	33.33	24.37	13.23	20.46	8.62
2002	32.72	24.69	13.33	20.26	9.00
2003	32.98	25.21	13.58	20.05	8.18
2004	34.18	23.64	13.31	20.21	8.66
2005	33.13	23.55	13.43	19.48	10.41
2006	33.69	24.65	12.98	18.88	9.79
2007	34.05	24.23	13.53	19.92	8.27
2008	32.57	25.09	14.23	20.46	7.65
2009	34.87	22.54	12.67	19.90	10.02
2010	32.07	24.07	13.31	18.67	11.88
2011	30.76	26.11	14.35	20.28	8.51
2012	30.59	24.88	13.68	19.80	11.04
2013	32.61	24.19	13.75	19.14	10.31
2014	31.90	24.78	14.16	20.29	8.86
2015	35.51	24.75	13.01	18.11	8.60
2016	31.07	26.39	13.48	19.66	9.40
2017	27.66	27.95	14.90	20.02	9.47

2018	28.24	26.53	14.29	18.79	12.15
2019	31.16	25.29	14.20	19.72	9.63
2020	31.14	24.02	12.94	20.11	11.78
2021	31.31	24.03	13.42	19.38	11.86
2022	33.45	25.00	13.65	19.17	8.73
2023	27.70	27.16	13.87	20.32	10.96

Table S3. Statistical table of area proportion of different growth index categories from 2000 to 2023

·	Worse(%)	Slightly worse(%)	Balanced(%)	Slightly better(%)	Better(%)
2000	4.86	25.79	58.06	9.31	1.99
2001	5.73	19.47	61.56	11.51	1.73
2002	2.10	19.39	66.17	10.40	1.94
2003	2.65	22.67	64.34	8.89	1.45
2004	3.66	23.77	63.09	8.23	1.25
2005	2.13	17.64	67.90	10.98	1.35
2006	2.07	22.46	67.23	7.01	1.23
2007	2.16	22.88	67.04	6.77	1.14
2008	2.00	19.61	67.80	9.15	1.44
2009	4.40	22.14	62.18	10.10	1.18
2010	1.87	13.40	66.89	15.48	2.36
2011	0.94	11.53	73.63	12.27	1.63
2012	1.38	10.52	66.91	18.69	2.51
2013	1.22	15.82	70.35	10.88	1.73
2014	1.58	15.38	69.03	12.34	1.67
2015	4.22	29.48	57.86	7.33	1.11
2016	1.43	14.26	68.33	13.74	2.24
2017	0.96	8.62	63.21	23.06	4.16
2018	1.50	7.45	59.67	27.30	4.09
2019	1.18	13.51	66.72	15.78	2.81
2020	0.86	9.92	67.45	19.39	2.38
2021	1.09	11.30	66.68	18.37	2.57
2022	2.98	22.18	62.15	10.87	1.82
2023	1.14	7.70	59.92	26.53	4.69