UNIVERSITY OF SOUTH DAKOTA

MICHIGAN STATE UNIVERSITY
Center for Global Change and Earth Observations

LEES
LANDSCAPE ECOLOGY & ECOSYSTEM SCIENCE

Grassland canopy cover and above ground biomass on the Mongolian Plateau: Spatiotemporal estimates and controlling factors

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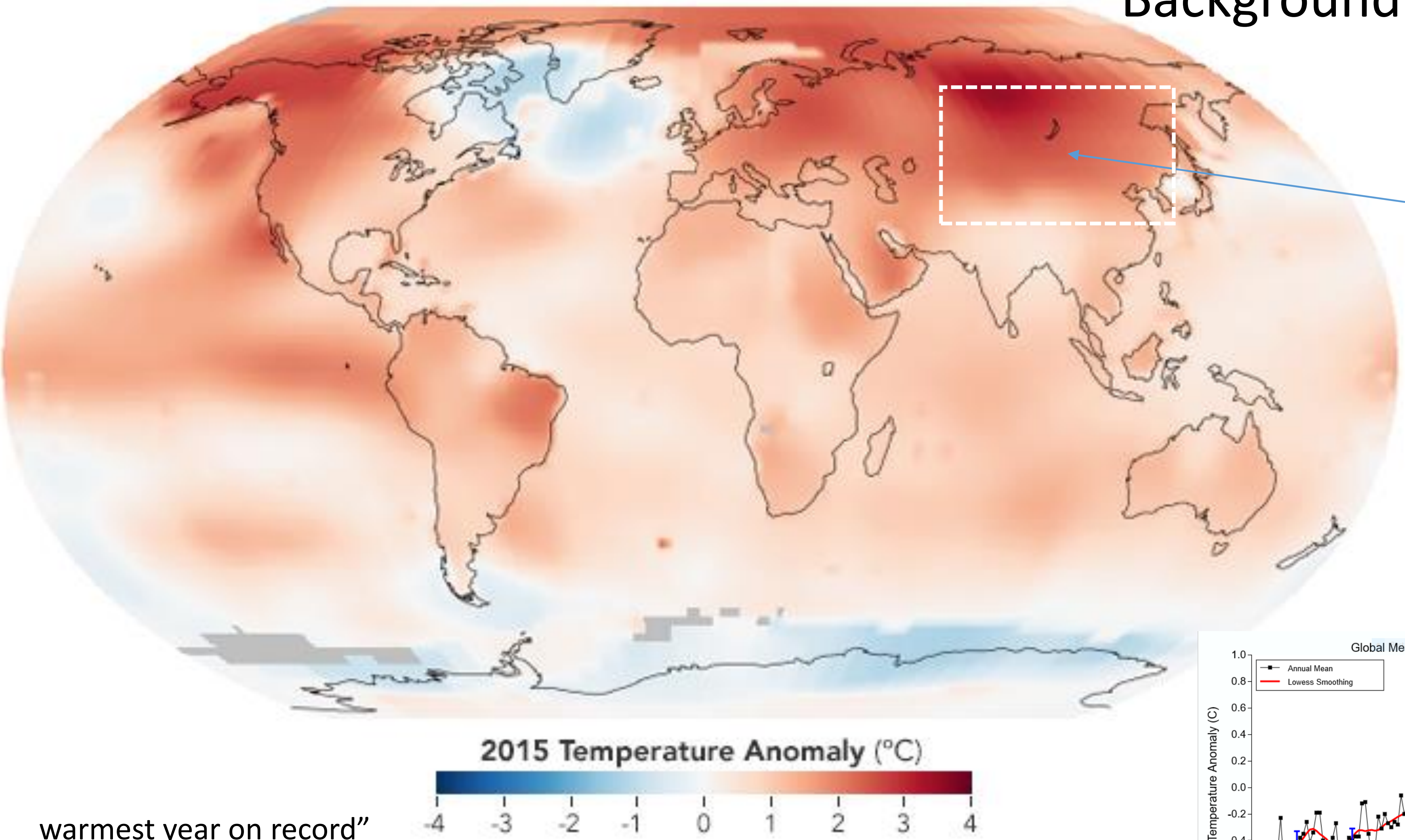
NSF

Background

warming trends

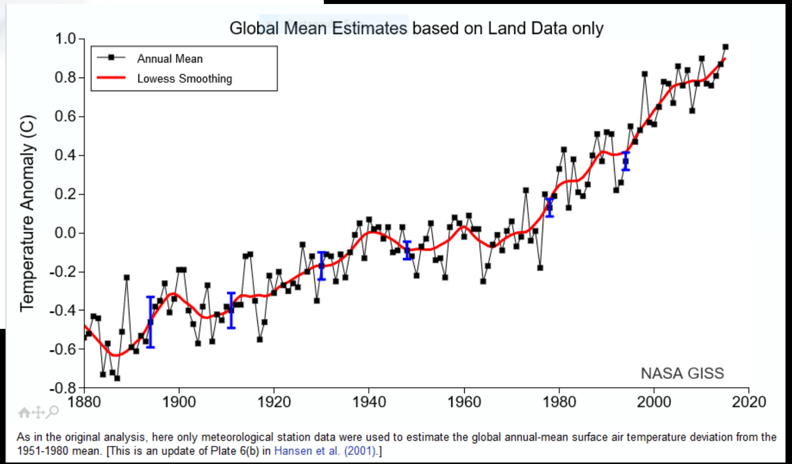
Mongolian Plateau

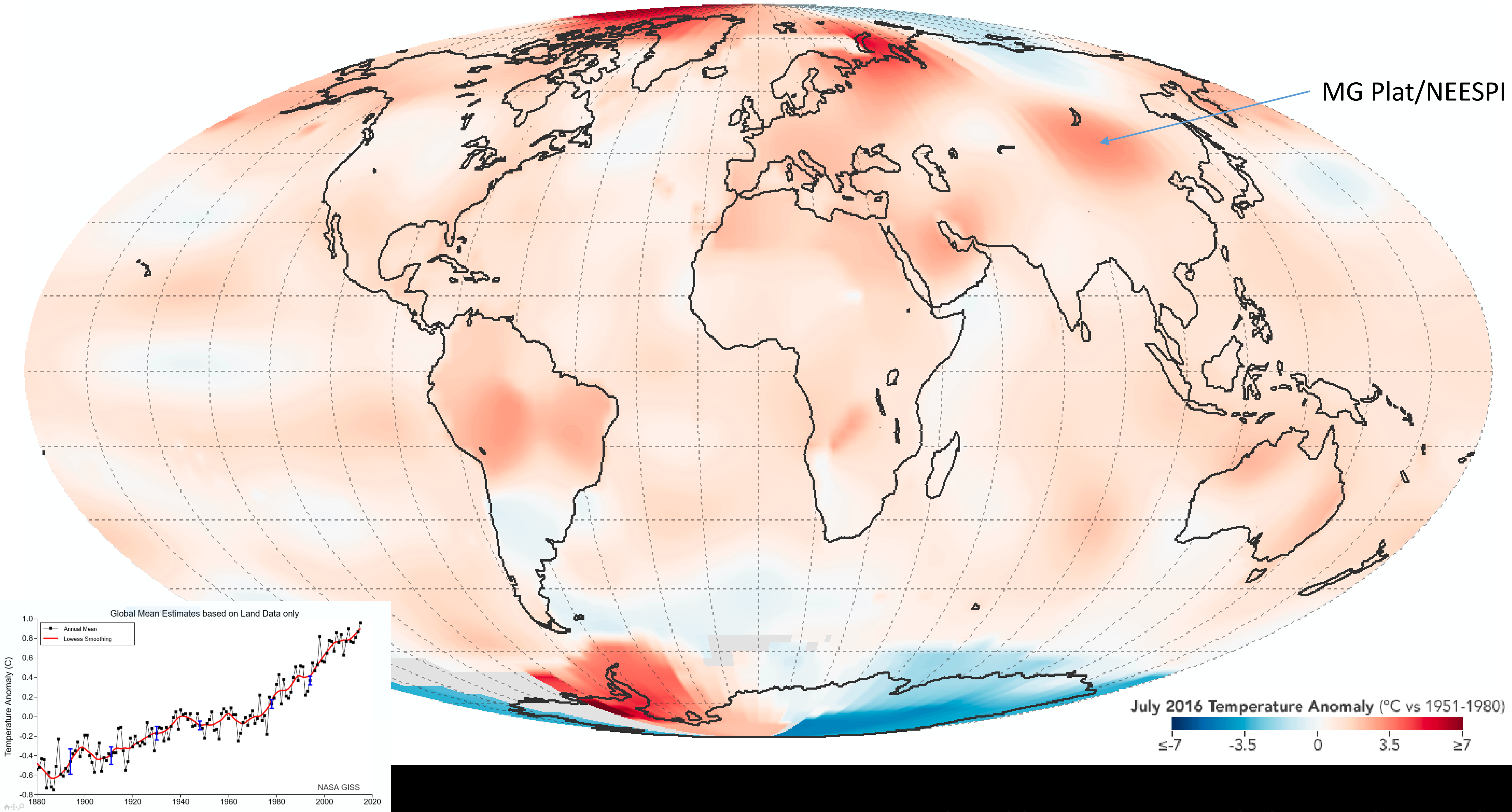


warmest year on record”

http://earthobservatory.nasa.gov/IOTD/view.php?id=87359&eocn=image&eoci=related_image

http://data.giss.nasa.gov/gistemp/graphs/





As in the original analysis, here only meteorological station data were used to estimate the global annual-mean surface air temperature deviation from the 1951-1980 mean. [This is an update of Plate 6(b) in Hansen et al. (2001).]

http://data.giss.nasa.gov/gistemp/graphs/

http://earthobservatory.nasa.gov/IOTD/view.php?id=88607&eocn=home&eoci=iotd_grid

Rationale

- Tropical forest biomes dominate terrestrial carbon sink, but inter-annual variability - semiarid ecosystems
- Need to model ecosystem structure/function vulnerable to degradation in water-limited ecosystems
- vulnerable to coupled effects of rapid LCLUC change-socio-economic drivers after collapse of Soviet Union
- increased frequency-extreme climate events

Research questions

Can we:

- 1) develop accurate non-parametric predictive models to scale-up *in situ* CC and AGB
- 2) model uncertainties and quantify inter-annual variability of peak season CC and AGB
- 3) explain spatiotemporal heterogeneity of CC and AGB by examining anthropogenic drivers and inter-annual climatic variability

Introduction

- World's arid-semiarid biome, 41% - land area, 38% - population, vulnerable to climate change/land degradation
- major portion - Eurasian Steppe-largest, extant-contiguous grassland ecosystem-high species diversity
- few studies-vulnerable-combined effects of climatic change & anthropogenic modification
- two entities (i.e., MG and IM), similar ecosystems, but distinct socio-economic, political regimes, ethnic compositions and divergent land cover/use change trajectories (1979 and 1991)

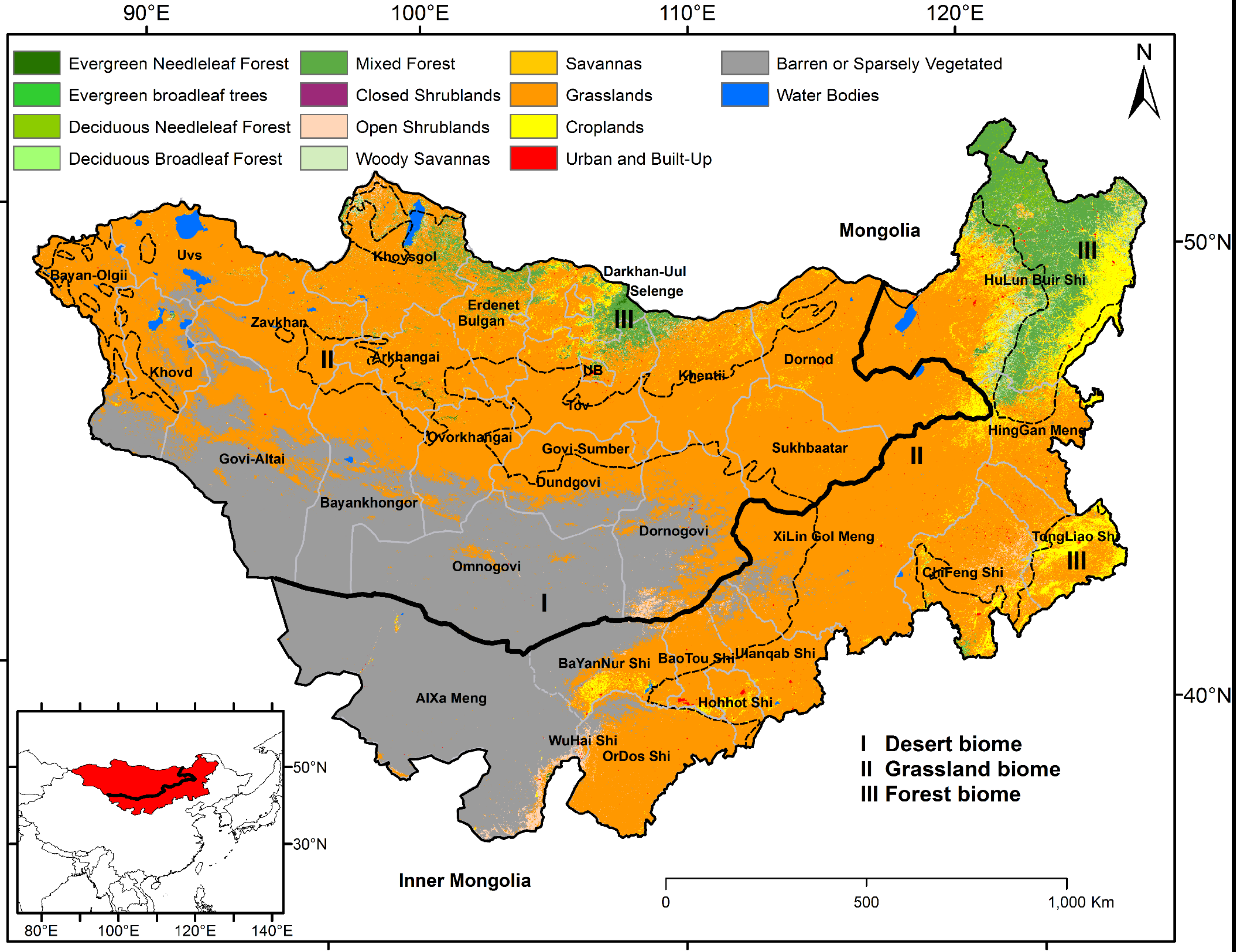
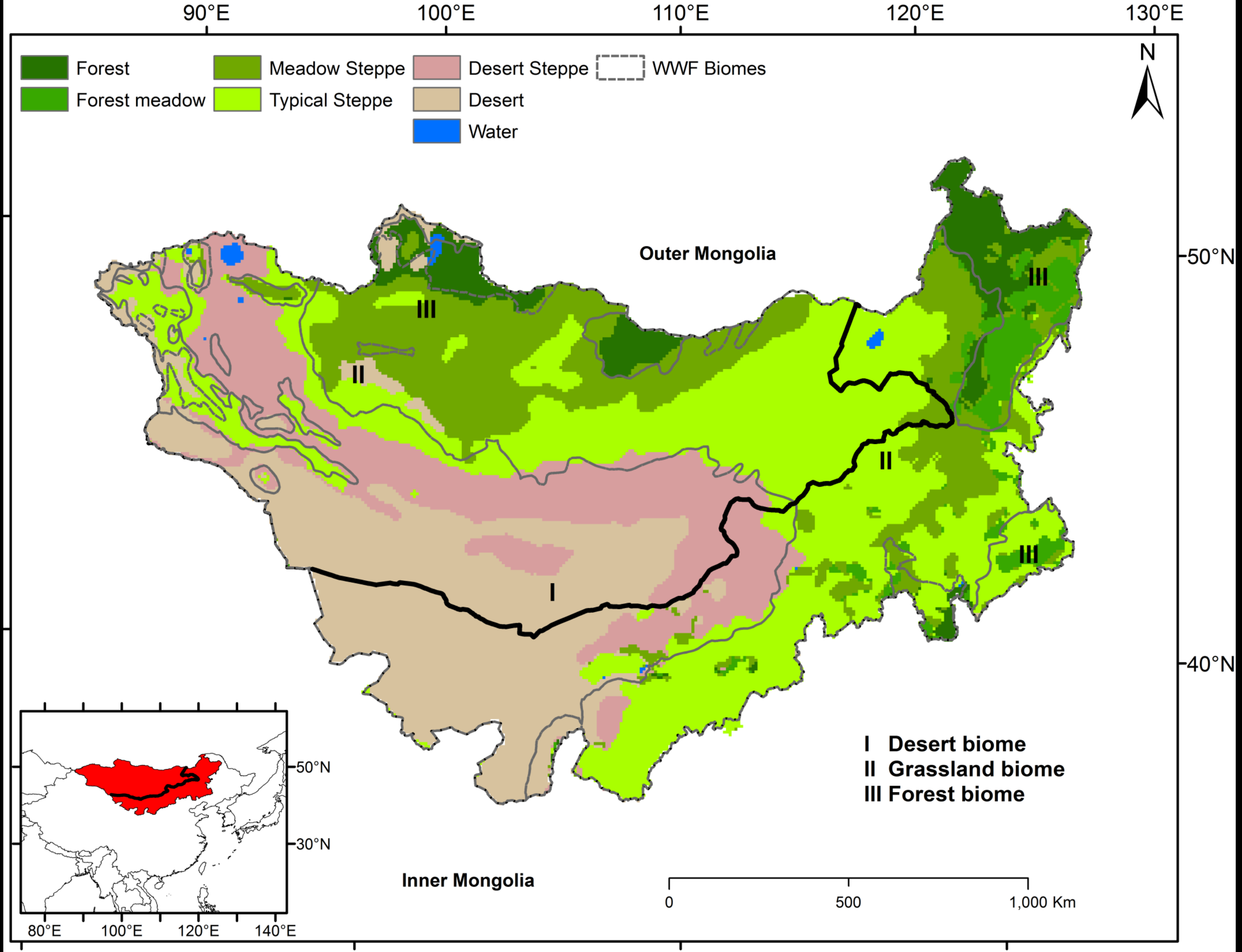


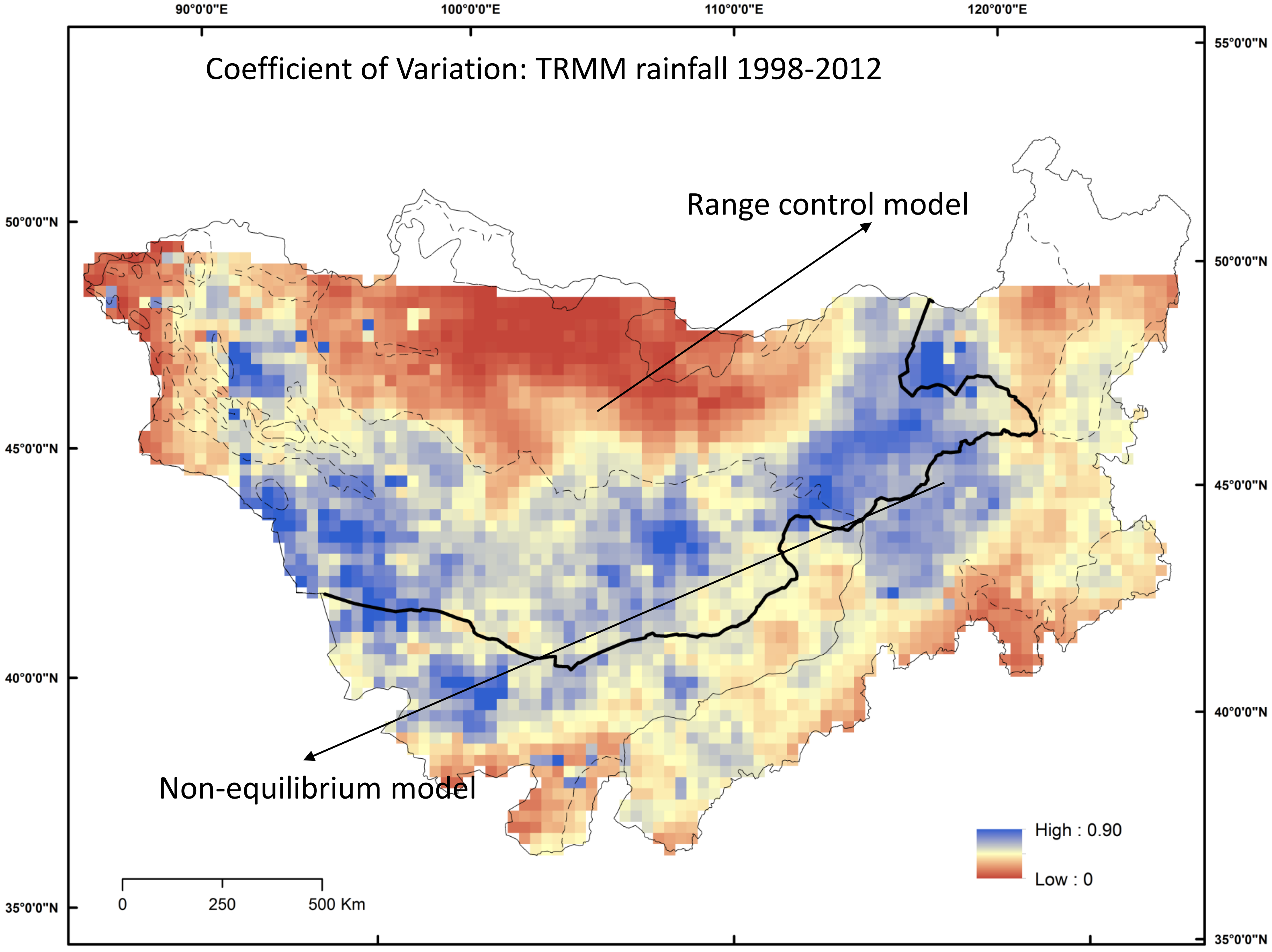
Figure 1: MODIS-derived land cover/use (MCD12Q1) overlaid by terrestrial ecoregions (WWF) biome boundaries: desert (I), grassland (II), and forest (III) and by political boundaries (Mongolia and the province of Inner Mongolia, China).

Study area

- MP - area of 3 million km^2
- 35°N-55°N latitude, 90°E -130°E longitude
- Mean elevation 1285m and relief range of > 3000m
- Mean annual precipitation (MAP) from 368 mm in the meadow steppe to 166 mm in the desert steppe
- 75% of annual rainfall-peak growing season (June, July, August - JJA)



Vegetation types of the Mongolian plateau with biome boundaries derived from WWF Ecosystems dataset


Coefficient of Variation: TRMM rainfall 1998-2012
Range control model
Non-equilibrium model
High : 0.90
Low : 0
0
250
500 Km
90°0'0"E
100°0'0"E
110°0'0"E
120°0'0"E
55°0'0"N
50°0'0"N
45°0'0"N
40°0'0"N
35°0'0"N

Knowledge gaps

- Changes in land cover/use , level of degradation on MP
- State-Change of grasslands, ecosystem structure/function - %canopy cover & AGB
- Changes in socio-economic conditions-jobs, education, health (i.e., HDI)
- Trends in livestock density & proportional change-herd composition
- Agricultural production
- Changes in the moisture and temperature regimes

Objectives

- Investigate relationship between *in situ* measurements and VI's derived from the combined MODIS (Terra & Aqua) *NBAR* product using Cubist Regression Tree committee models
- Develop models using Cubist regression tree models to estimate spatially-explicit AGB and canopy cover over the MP

Hypotheses/questions

- Does accessibility explain trends in vegetation cover/AGB ?
- Is this owing to sedenterization of herders in response to increased HDI (in cities/towns)?
- We hypothesize that
  - increased grazing intensity (LIVSTKD) will reduce vegetation cover and AGB
  - magnitude of grazing effects on LCLUC varies among steppe types and regulated by combination of land use, and socio-economic, and physical conditions

Methods

Field data samples of % canopy cover and AGB

Year	Steppe type	n	Canopy cover	Canopy height (cm)	AGB ($gm^{-2}.yr^{-1}$)
2006	Meadow Steppe	2	57.50(14.20)	29.85(11.85)	349.40(199.80)
	Typical Steppe	38	42.91(19.47)	17.91(10.68)	207.85(147.79)
2007	Forest Steppe	2	29.17(0.84)	37.50(9.17)	204.60(36.60)
	Meadow Steppe	6	37.53(20.60)	41.10(20.26)	428.93(283.72)
	Typical Steppe	27	16.71(10.59)	27.52(13.75)	303.63(360.76)
	Desert Steppe	29	11.03(4.24)	15.19(6.83)	90.72(69.02)
2010	Meadow Steppe	92	45.98(9.89)	25.10(9.89)	398.75(254.56)
	Typical Steppe	279	47.37(16.88)	23.52(12.20)	415.57(207.44)
	Desert Steppe	117	26.97(12.11)	14.25(5.01)	132.46(73.37)
2011	Meadow Steppe	44	52.67(15.82)	25.78(14.35)	176.14(162.86)
	Typical Steppe	59	46.36(17.92)	33.10(18.23)	239.66(186.21)
	Desert Steppe	32	28.13(16.57)	21.84(8.59)	94.99(64.18)
	Desert	2	36.25(23.75)	4.68(0.28)	26.60(6.60)
2012	Meadow Steppe	10	70(12.25)	62.08(12.65)	145.20(48.32)
	Typical Steppe	53	65.47(12.56)	56.70(22.61)	206.14(102.80)
2013	Meadow Steppe	5	3.30(1.74)	NA	137(52.08)
	Typical Steppe	172	24.48(24.81)	NA	209.62(142.97)
	Desert Steppe	55	7.01(18.38)	NA	89.67(157.80)
	Desert	5	0.24(0.05)	NA	59.60(16.12)
2014	Meadow Steppe	21	78(9.8)	28(4)	139.48(51.60)
	Typical Steppe	20	65.79(15.67)	34.79(13.58)	141.063(63.07)
2015	Meadow Steppe	7	55.71(7.28)	8.43(2.82)	120.22(75.93)
	Typical Steppe	28	50.18(17.35)	11.54(5.10)	126.17(99.75)
	Desert Steppe	2	25(14.24)	13.50(18.03)	21.80(31.34)
2016	Meadow Steppe	29	70.02(18.83)	20.45(12.24)	213.19(106.02)
	Typical Steppe	22	34.32(23.22)	12.57(6.17)	126.30(68.84)
	Desert Steppe	18	9.25(9.54)	8.68(6.58)	89.96(64.41)
	Desert	11	6.53(5.41)	8.72(3.58)	109.14(100.27)

Table 1: The mean canopy cover (±SD, %), canopy height and aboveground biomass (±SD, $gm^{-2}.yr^{-1}$) of different steppe types on the Mongolian plateau between June-August of 2006 -2016 (*n*=1187).

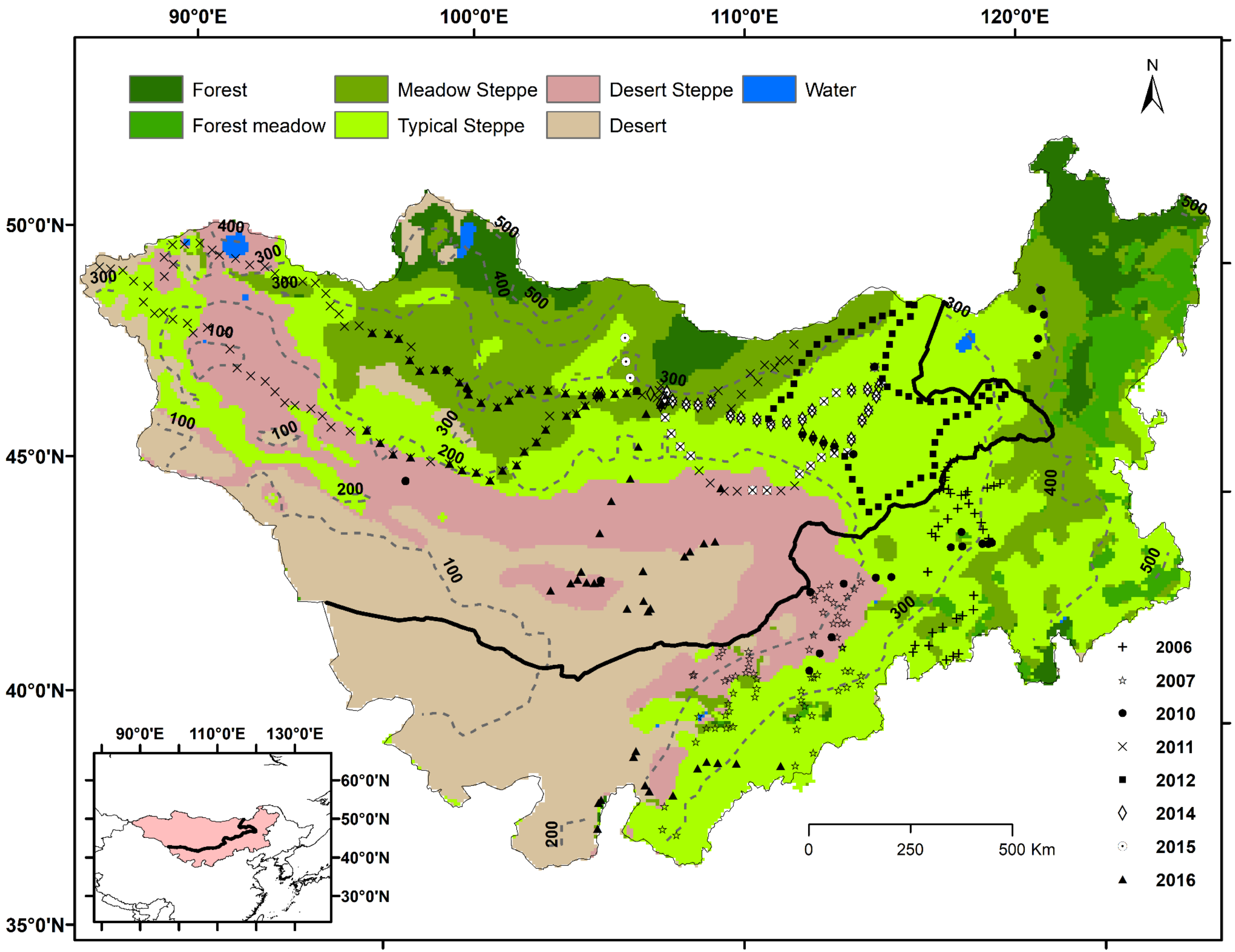
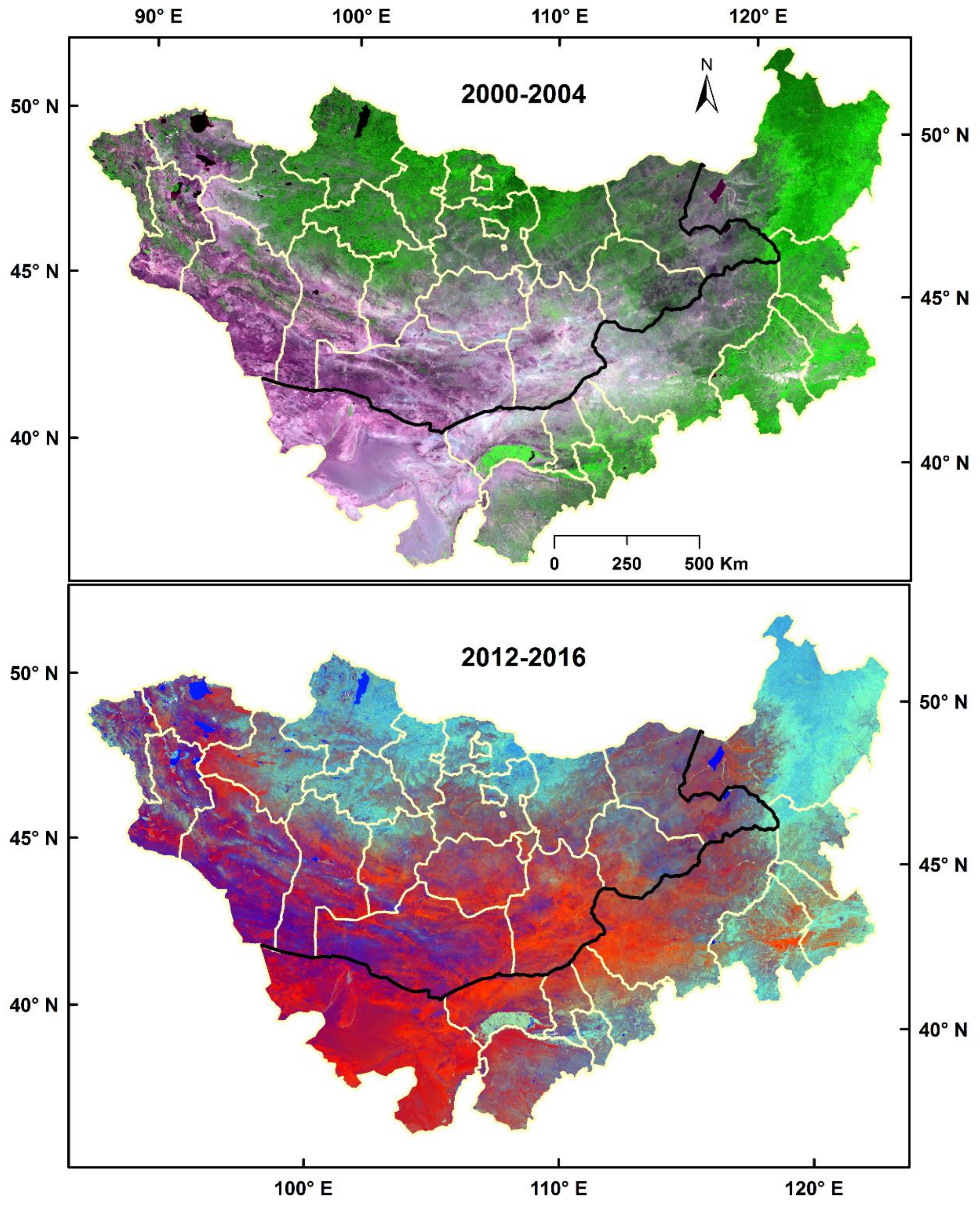


Figure 1: Multi-year *in situ* measurements and isohyets (dashed lines) derived from CRU TS323 mean annual precipitation (1981-2014) overlaid on vegetation types on the Mongolian Plateau. Thick line denotes the border between the Republic of Mongolia and the province of Inner Mongolia, China.

Datasets (geospatial)

- 500m –Satellite derived, MODIS Nadir BRDF-Adjusted Reflectance, 2000-2016
- SRTMGL1 Global 1 arc second (30m res.) V003 DEM
- Modern-Era Retrospective Analysis for Research and Applications (MERRA-2): total surface precipitation (PRECTOTCORR) and 2-meter air temperature (T2M), (0.5° x 0.67° res.) 1981-2016
- Vegetation types -produced by Institute of Botany, Chinese Academy of Sciences and Institute of Botany, Mongolia



500m MODIS NBAR, 280716, FCC 542 (bands 6, 2, 1)

500m Tasseled Cap (brightness-red, greenness-cyan, moisture-blue)

Variables (geospatial)

- Productivity: Derived MODIS vegetation indices (VI) enhanced vegetation index (EVI), enhanced vegetation index-2 (EVI-2), NDVI as proxies
- Water content: Normalized difference water index (NDWI), normalized difference senescence vegetation index (NDSVI), land surface water index (LSWI)
- Dimensionality reduction: Tasseled cap brightness, greenness and wetness components (TC_{bright}, TC_{green}, TC_{wet}) from NBAR bands
- elevation, slope, aspect (DEM) and vegetation type (stratification)

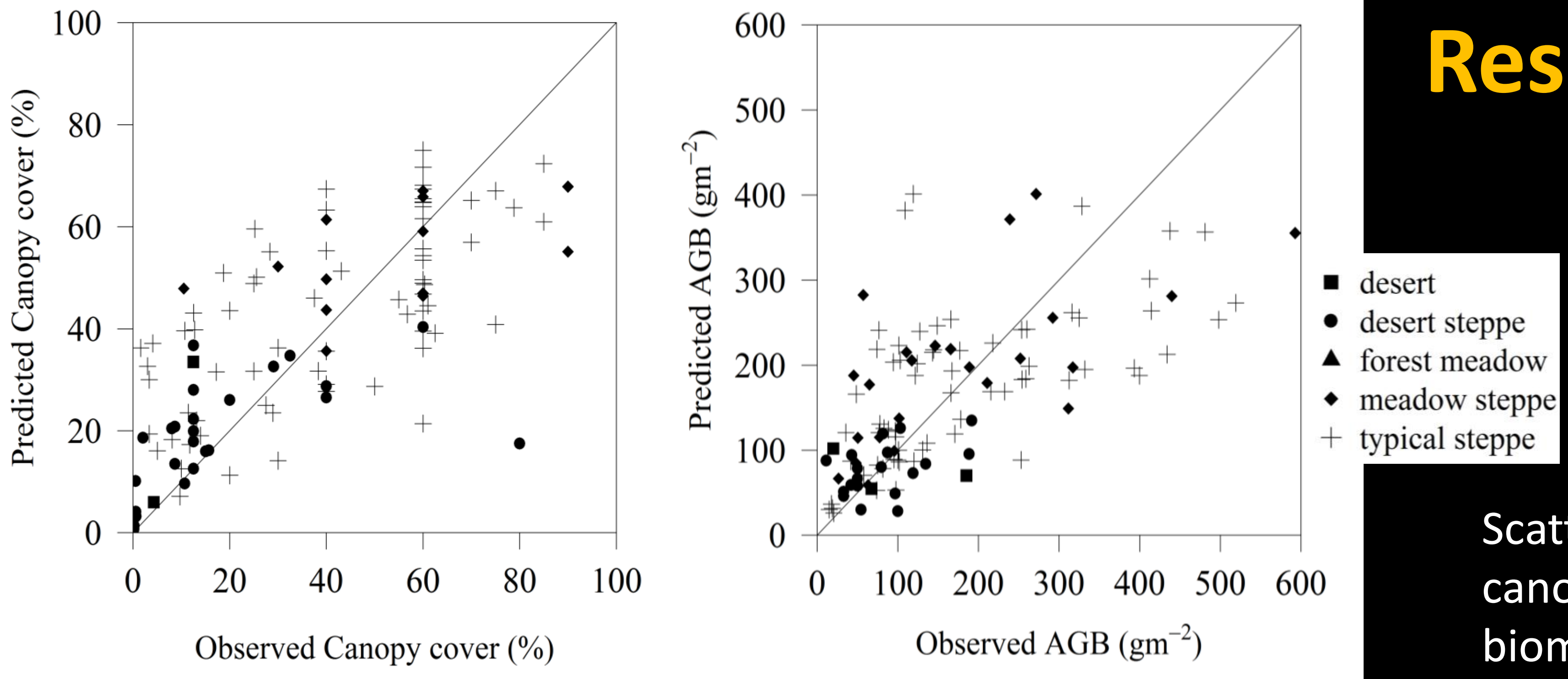
Cubist-R (Machine Learning) advantages

- Regression Tree (RT) algorithms assign class membership through recursive partitioning of input datasets into homogenous subclasses
- RT based models - nonlinear relationships between observed/predicted variable
- More effective than MLR, easier to interpret than neural networks
- Rule-based models based on a set of conditions associated with a multivariate sub-model
- Committee models-several rule-based models. Each member of the committee predicts the target value for a case and the members' predictions are averaged to give a final prediction.

Variables (socioeconomic)

- Total livestock
- Population data
- Level 1(n=12, n=22;), level 2 (n=89, n=367) administrative levels for Inner Mongolia and Mongolia
- 30-year period (1981–2010) and 16-year period (2000-2016)
- Used these var. to explain variability in predicted CC & AGB

Results

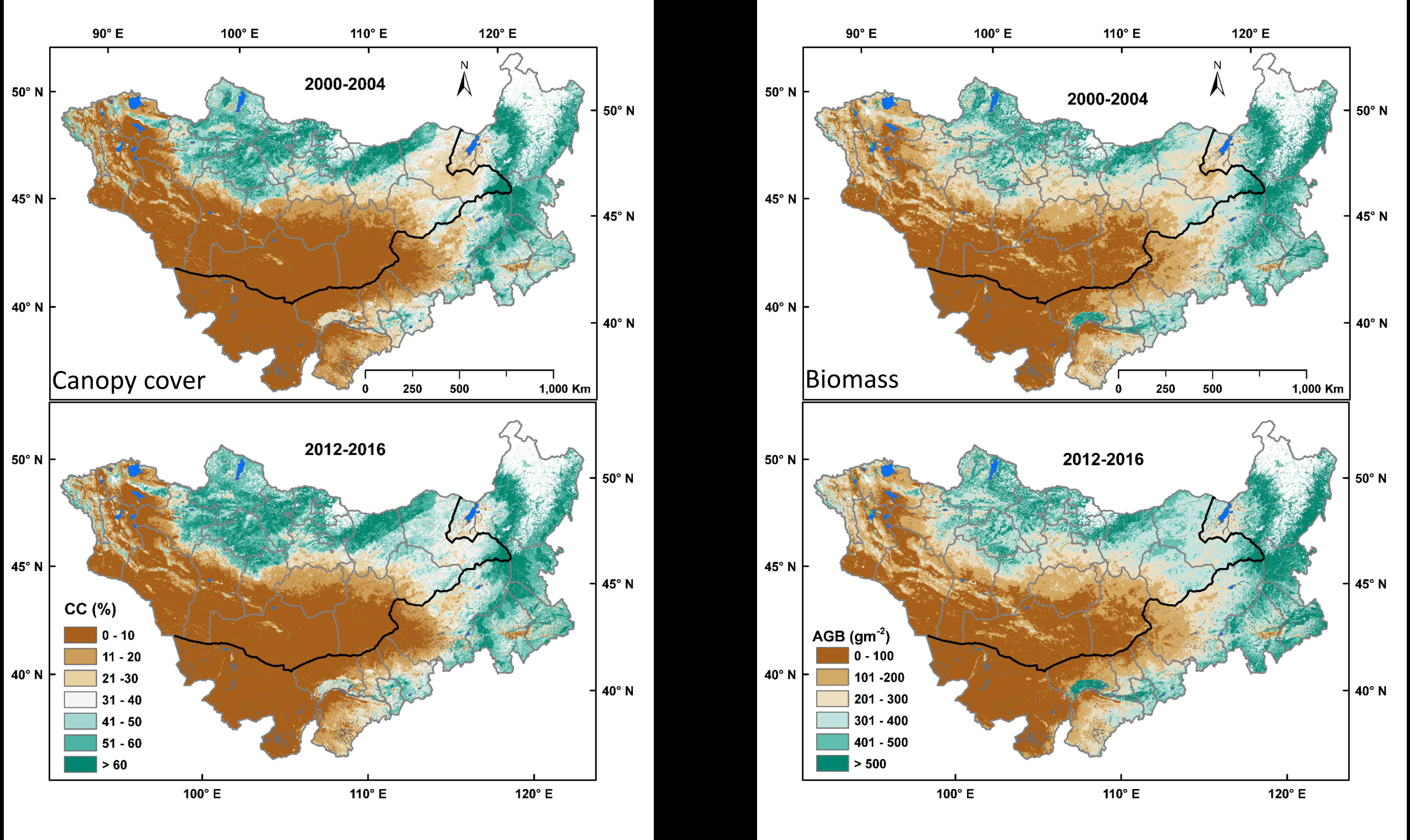


Scatterplot of observed and predicted canopy cover (CC) (%) and aboveground biomass (AGB) (g m^{-2}) by models and validation using Cubist regression trees for the Mongolian Plateau. Solid line depicts the 1:1 line between observed and predicted values

Response variable	R^2	RMSE	RMSEv	Variables of importance
Canopy cover	0.71	13.73	14.44	NDSVI (66.5%), NDWI (58%), Tasseled cap-bright (50.5%)
AGB	0.62	85.87	76.87	LSWI (31%), NDVI (46.5%), Tasseled cap-bright (21.5%), NDWI (13%)

Prediction accuracy

Variable	Category	R^2	RMSE	$RMSE_v$	Variables of Importance
CC	MG	0.77	13.08	14.53	Tasseled cap-green (44.5%), inverse NIR1 (25.5%), Tasseled cap-bright (42.5%)
(%)	IM	0.73	11.44	13.58	Tasseled cap-green (45%), NDWI (48.5%), NDSVI (46%)
	Meadow Steppe	0.43	15.90	15.32	Elevation (30%), EVI (10%), NDVI (0%)
	Typical Steppe	0.46	17.32	17.49	NDSVI (51.5%), inverse NIR1 (38.5%), Tasseled cap-bright (38.5%)
	Desert Steppe	0.82	4.79	17.93	NDWI (34.5%), LSWI (32.5%), inverse NIR1 (20%)
AGB	MG	0.55	63.15	56.00	EVI (30%), NDVI (20%), NDWI (20%)
(g m^{-2})	IM	0.75	73.80	119.64	Tasseled cap-green (38%), Tasseled cap-wet (19.5%), NDVI (55%)
	Meadow Steppe	0.52	109.85	99.87	EVI (20%), Inverse NIR1 (20%), Elevation (20%)
	Typical Steppe	0.72	72.64	73.06	Tasseled cap-green (38%), LSWI (26%), NDWI (6%)
	Desert Steppe	0.66	45.49	84.44	NDVI (42%) NDWI (38%), inverse NIR1 (29%)



90° E
100° E
110° E
120° E
50° N
45° N
40° N
2000-2004
N
Canopy cover
0
250
500
1,000 Km
2012-2016
CC (%)
0 - 10
11 - 20
21 -30
31 - 40
41 - 50
51 - 60
> 60
Biomass
AGB (gm-2)
0 - 100
101 -200
201 - 300
301 - 400
401 - 500
> 500

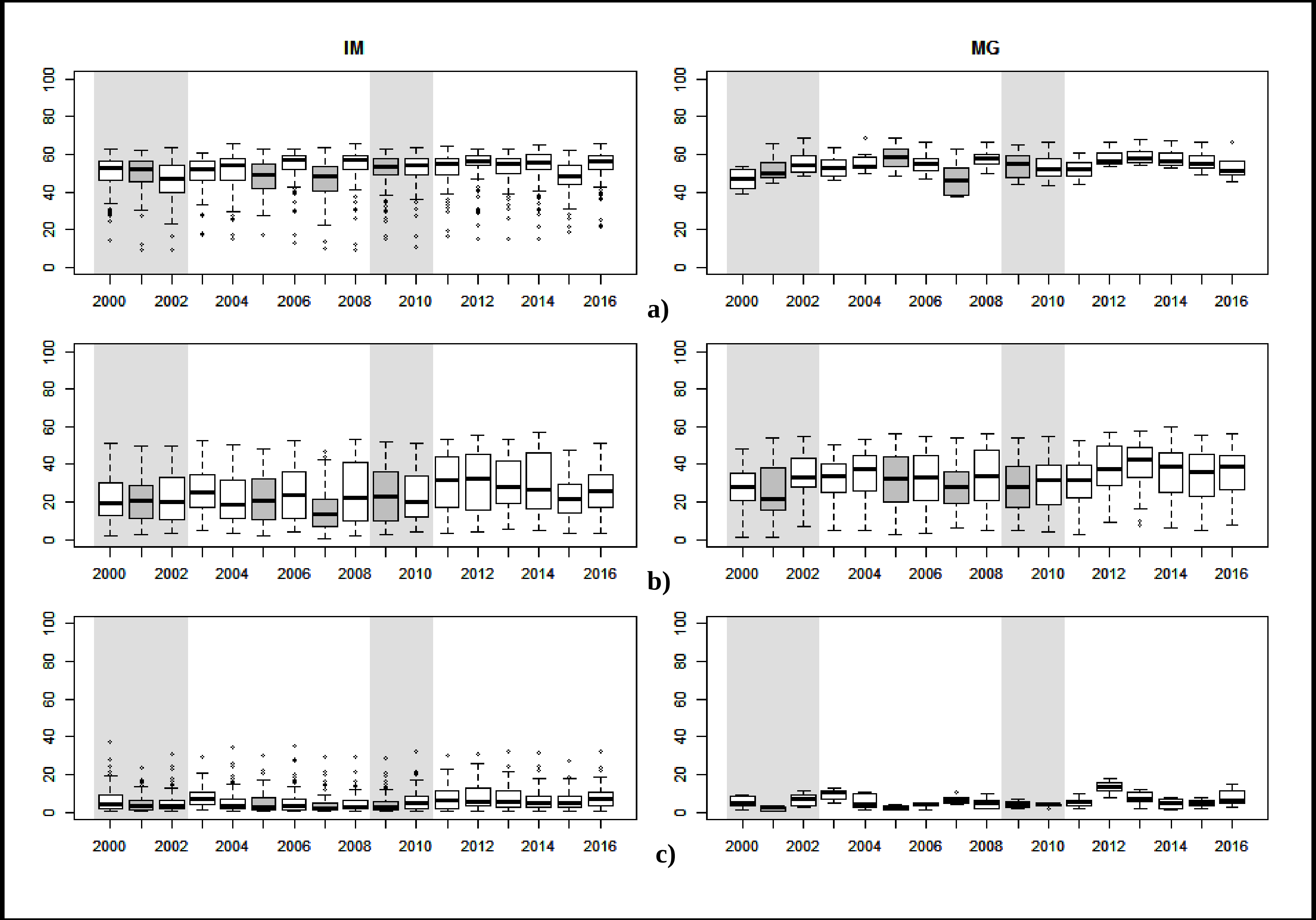


Figure S1: Box-plots of the spatial average of predicted canopy cover (CC) in: a) meadow steppe, b) typical steppe and c) desert steppe. *Dzuds* (extreme winters are shaded in light grey), while drought years (2001, 2005, 2007, 2009) are box plots in dark grey.

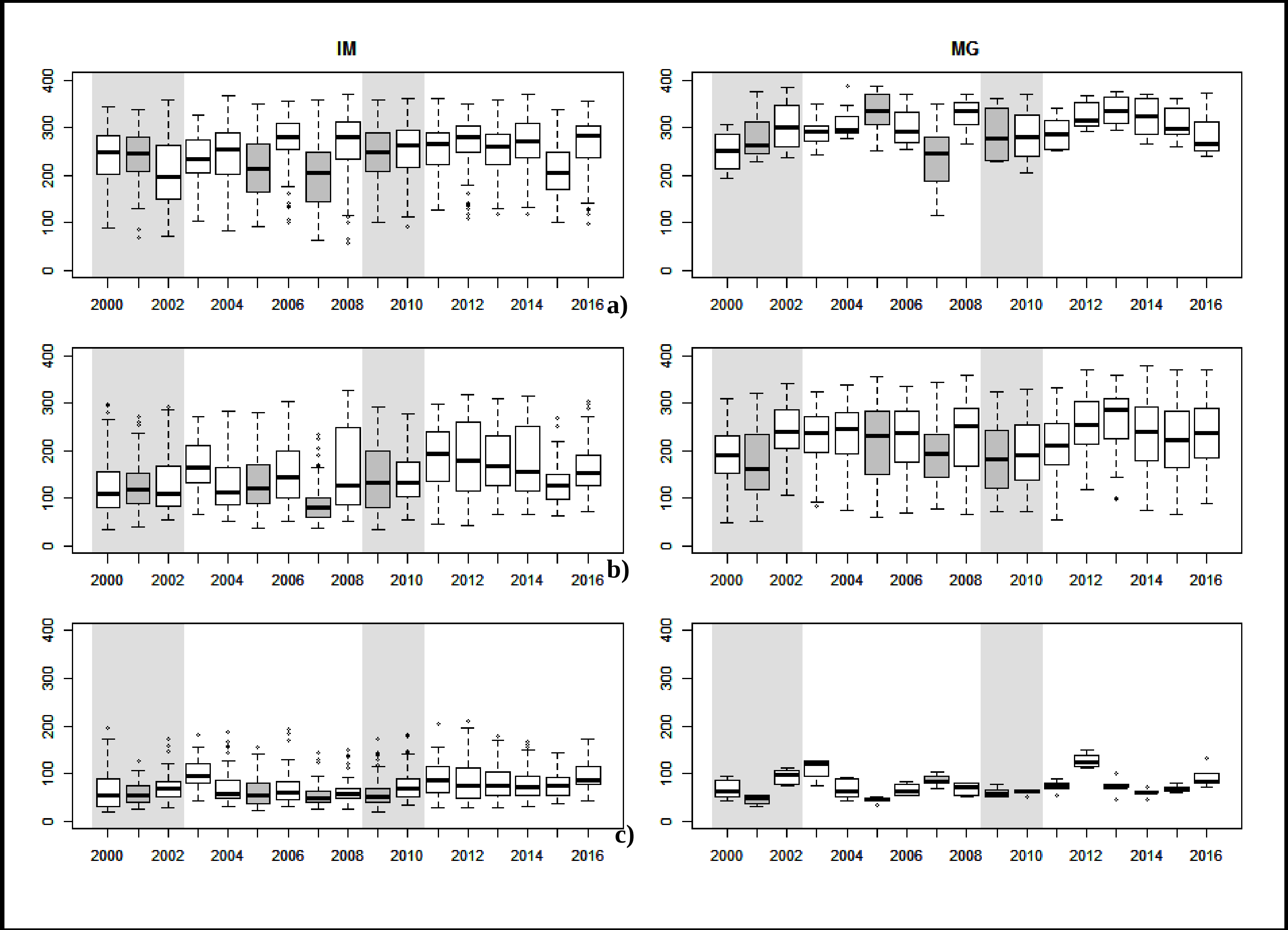
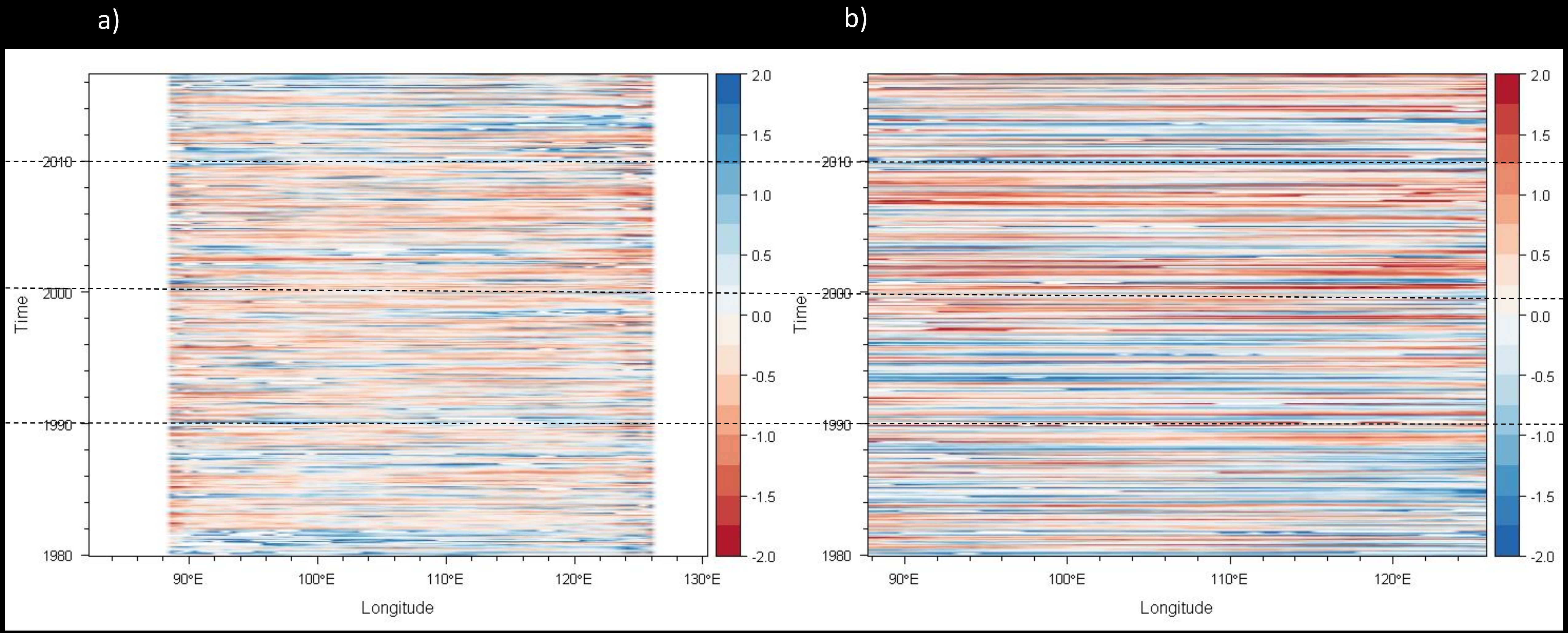


Figure S2: Box-plots of the spatial average of predicted AGB in: a) meadow steppe, b) typical steppe and c) desert steppe. *Dzuds* (extreme winters are shaded in grey), while drought years are 2001, 2005, 2007, 2009.

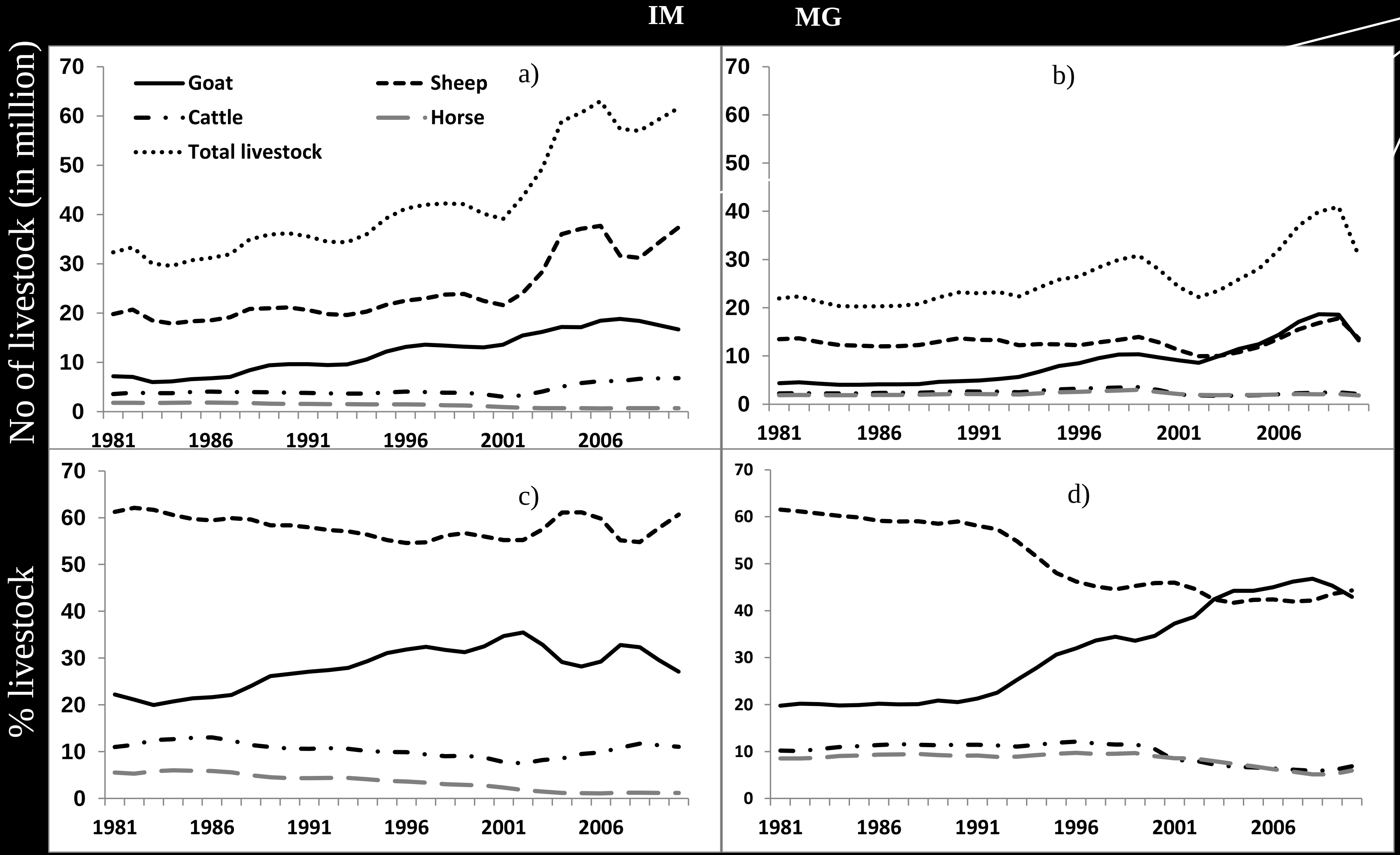


Hovmöller plots of a) Merra-2 precipitation b) 2m tall canopy air temperature that depict climate variability

“Push” factor migration

Socioeconomic drivers

“boom-bust cycles”



Temporal trends of total livestock, goat, sheep, cattle, horse and their proportions in Inner Mongolia (a & c) and Mongolia (b & d).

Figure shows the dramatic proportional increase in goat population in Mongolia as well as increase in total livestock in both Mongolia and Inner Mongolia between 1990 -2010.

John et al 2016, *Landscape Ecology*

Socio-economic trends

- Livestock stocking rates increased in MG after collapse of Soviet Union (1991), loss of state support drove migration away from cities (infrastructure/watering stations not maintained)
- Herders on MG plateau forced to adapt - extreme weather/market forces by limiting frequency-transhumance, a.k.a. *Otor*, sedentary herders, diversified herd composition to minimize mortality risk-increased grazing pressure
- Extreme drought-*dzuds* -migration of herders to cities, record livestock mortality-2000-02 (30%) ,2010 (20%)

Policies – fencing leading to sedenterization

- Deng Xiaoping reforms, 1980s in IM/China – emerging market economy in IM 1990-2000, -agricultural collectives replaced-privatization of herding/farming
- Livestock and Rangeland Double-Contract Responsibility System (LRDCRS) implemented in IM (1980s) – sedentary livestock husbandry within a (strictly) delimited rangeland area/family - fenced pastures.
- 1990-2000 mature market economy, saw the introduction of grassland conservation measures (fencing) and green belts to control desertification and dust storms originating in IM

“Pull” factor migration

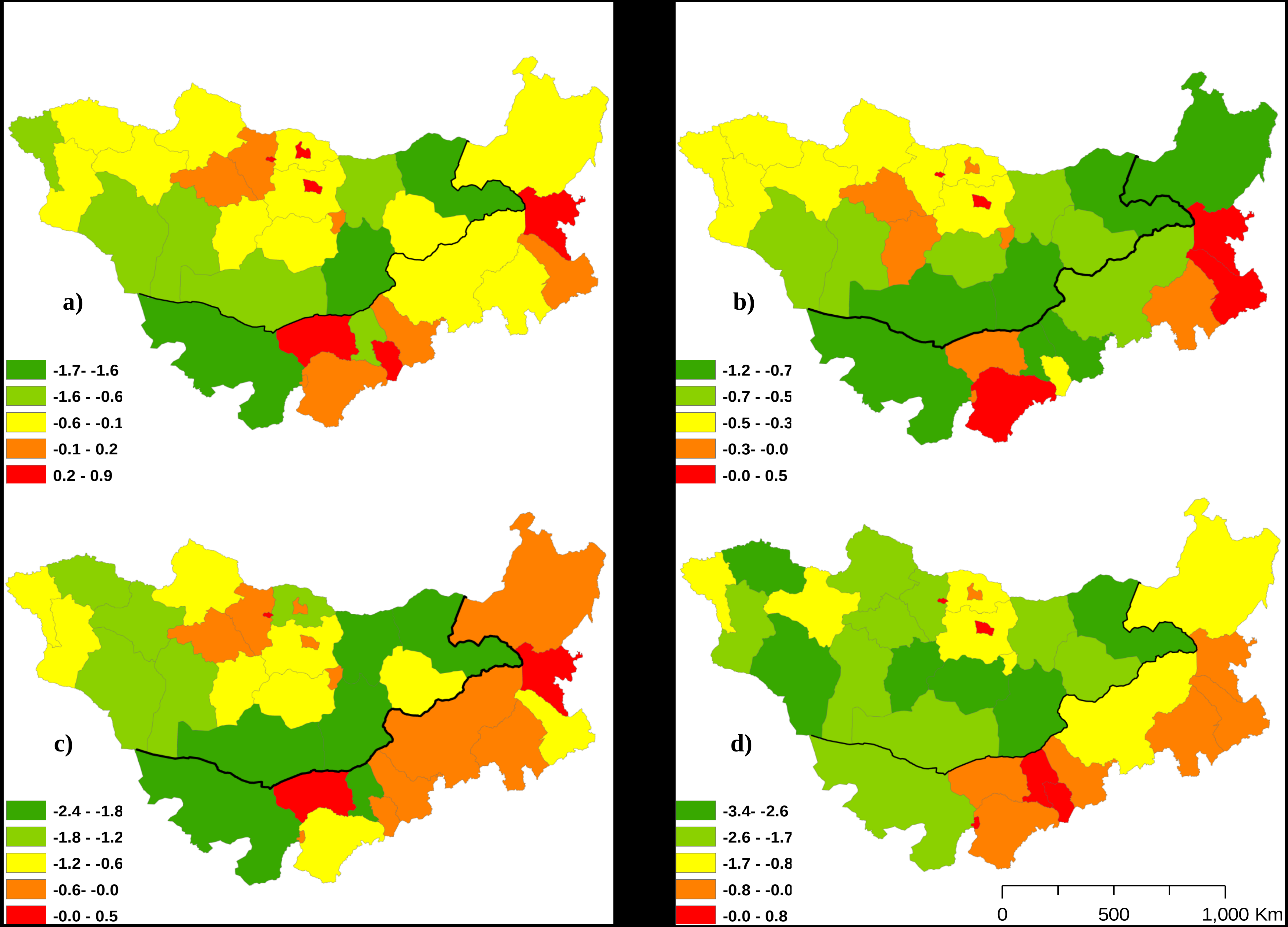
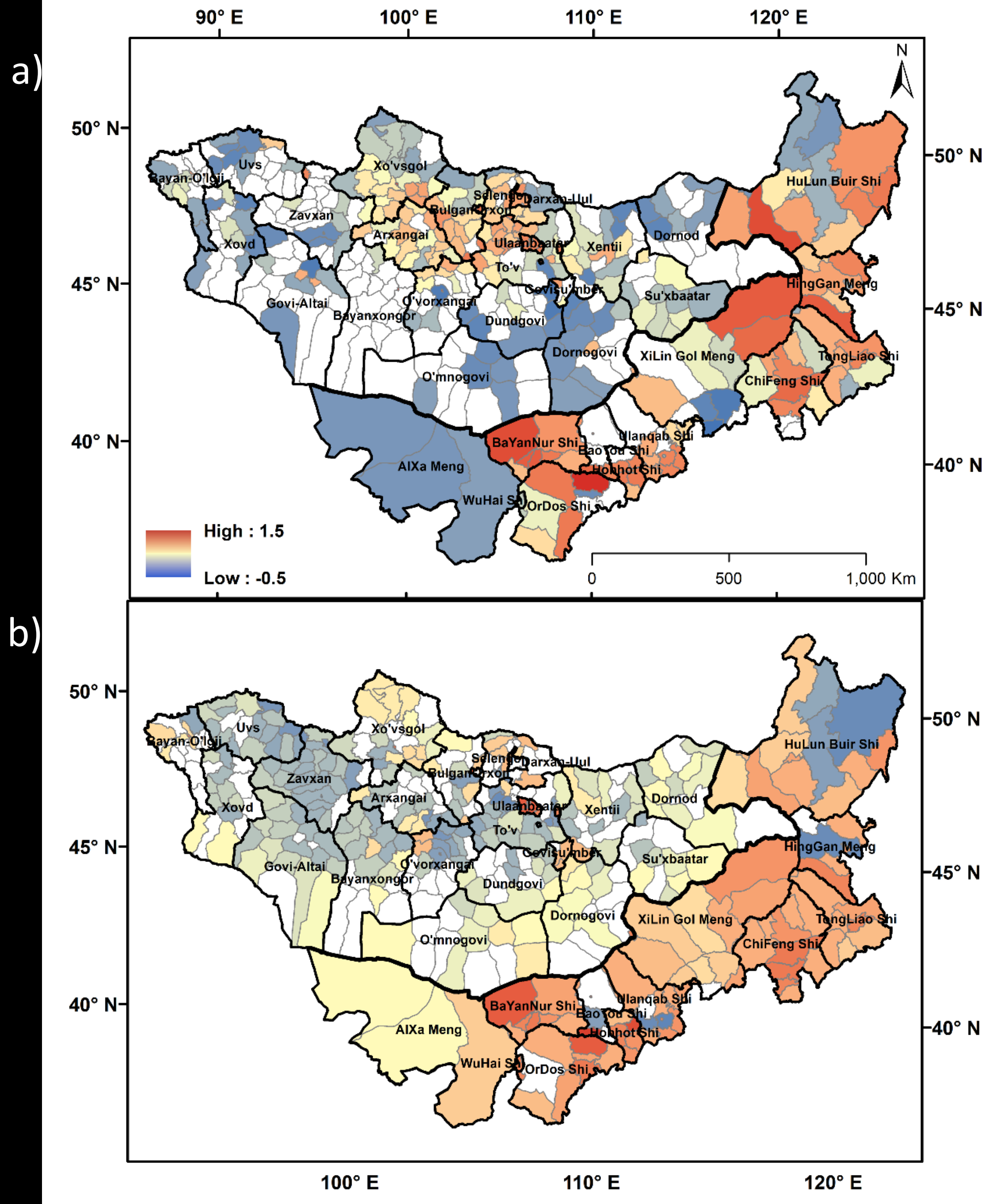
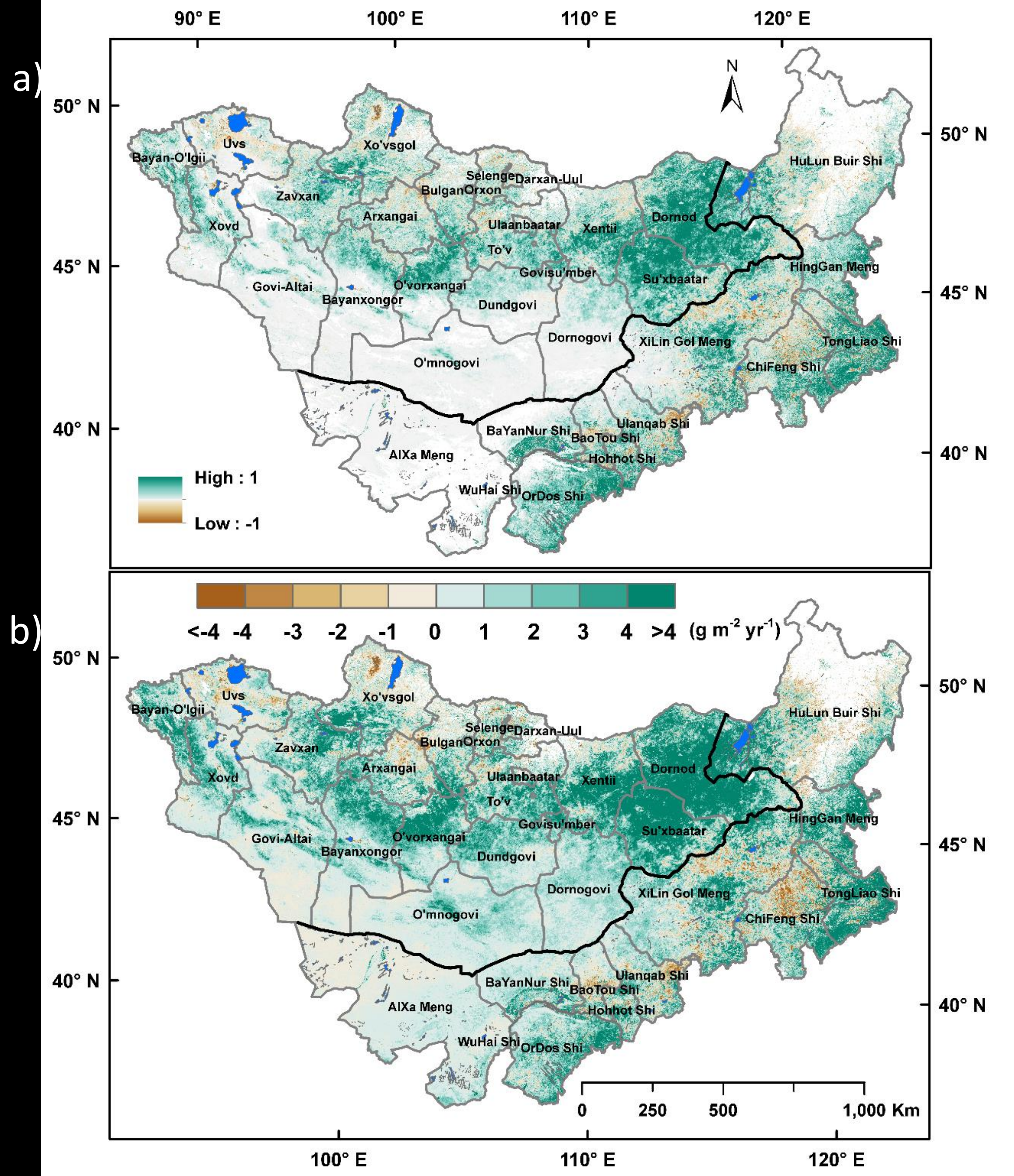


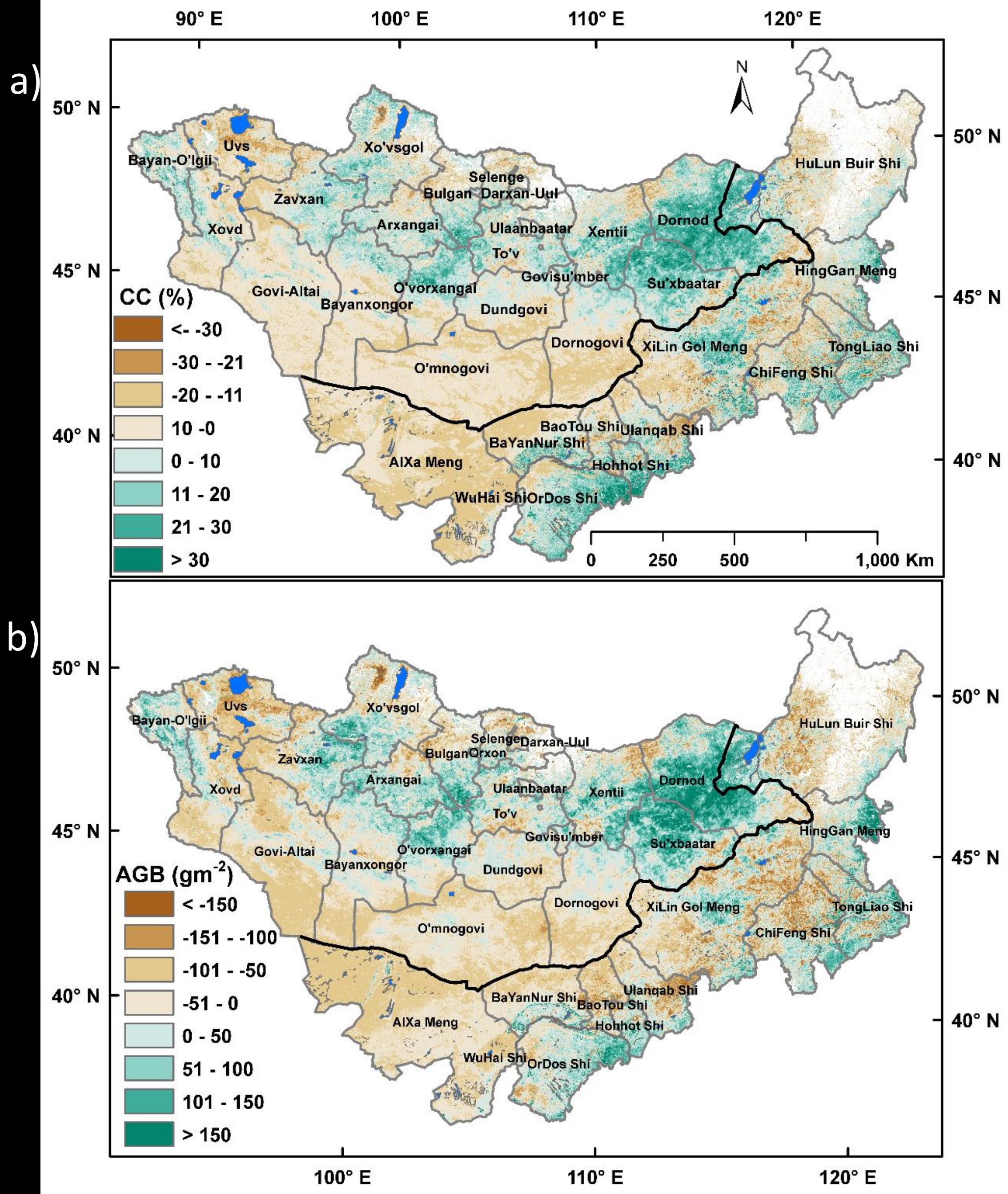
Figure 4: Theil-sen slope trends of a) total livestock density b) goat livestock density, c) sheep livestock density and d) total population density.



Spatial changes in the Theil-Sen slope trends of: a) LSK_D -- total livestock density, and b) POP_D -- total population density. The legend shows positive slope trends in red and negative slope trends in blue. Blank *soums or xiàn* (counties) have slope trends that are not significant.



Spatial changes in Theil-sen slope trends (2000-2016) of: a) canopy cover (CC); and b) aboveground biomass (AGB) derived from metrics based on MODIS MCD43A4 NBAR surface reflectance and ancillary variables.



Difference images for: a) canopy cover (%) and b) aboveground biomass (g m^{-2}) created by subtracting July 2016 from July 2001.

Partial regression coefficients between the predicted canopy cover (CC), above ground biomass (AGB) and climate factors of mean annual precipitation (MAP), mean annual temperature (MAT), mean growing season precipitation and temperature (MGP; MGT), seasonal precipitation and temperature for spring and summer (MAM; JJA), anthropogenic drivers represented by total livestock and population densities (LIV_D; POP_D) and distance to cities and towns in IM and MG (D_city; D_town).

			MAP	MGP	PMAM	PJJA	MAT	MGT	TMAM	TJJA	LIV_D	POP_D	D_city	D_town
ALL	% cover	default	0.59	0.57	0.45	0.54	-0.33	-0.28	-0.31	-0.27	0.29	0.29	-0.10	-0.15
		Prec.					-0.31	-0.27	-0.29	-0.25	0.25	0.24	-0.08	-0.15
		Temp.	0.58	0.56	0.44	0.53					0.29	0.30	-0.10	-0.14
		Anthro	0.59	0.57	0.45	0.54	-0.34	-0.28	-0.31	-0.27				
	AGB	default	0.63	0.61	0.45	0.58	-0.27	-0.21	-0.24	-0.20	0.30	0.34	-0.12	-0.11
		Prec.					-0.24	-0.19	-0.22	-0.18	0.25	0.29	-0.10	-0.09
		Temp.	0.63	0.61	0.45	0.57					0.29	0.34	-0.12	-0.09
		Anthro	0.63	0.61	0.45	0.58	-0.27	-0.21	-0.24	-0.21				
IM	% cover	default	0.49	0.48	0.35	0.50	-0.49	-0.45	-0.44	-0.42	-0.05	0.03	0.05	0.04
		Prec.					-0.47	-0.42	-0.42	-0.39	-0.05	Non	0.06	0.05
		Temp.	0.48	0.47	0.34	0.49					-0.04	0.04	0.03	0.03
		Anthro	0.49	0.48	0.35	0.50	-0.49	-0.45	-0.44	-0.42				
	AGB	default	0.47	0.46	0.32	0.48	-0.35	-0.32	-0.31	-0.30	0.01	0.11	-0.06	-0.02
		Prec.					-0.32	-0.28	-0.28	-0.26	Non	0.10	-0.06	Non
		Temp.	0.47	0.45	0.31	0.47					0.02	0.12	-0.08	-0.03
		anthro	0.47	0.46	0.32	0.48	-0.35	-0.32	-0.31	-0.30				
MG	% cover	default	0.63	0.60	0.47	0.55	-0.44	-0.38	-0.39	-0.34	0.39	0.36	-0.14	-0.26
		Prec.					-0.39	-0.33	-0.35	-0.30	0.35	0.32	-0.12	-0.22
		Temp	0.61	0.59	0.46	0.54					0.37	0.34	-0.14	-0.24
		Anthro	0.62	0.60	0.47	0.55	-0.44	-0.38	-0.39	-0.34				
	AGB	default	0.65	0.63	0.47	0.58	-0.44	-0.37	-0.39	-0.34	0.34	0.32	-0.15	-0.23
		Prec.					-0.38	-0.32	-0.34	-0.31	0.29	0.28	-0.12	-0.19
		Temp.	0.64	0.62	0.46	0.56					0.32	0.30	-0.14	-0.22
		Anthro	0.65	0.63	0.47	0.58	-0.44	-0.37	-0.39	-0.34				

Cross-sectional analysis of the time-series on the impact of livestock density to AGB and CC while considering regional effects, interaction term between livestock density and steppe types, temperature and precipitation fixed effect, and annual fixed effects.

		AGB (g m^{-2})				CC (%)			
		(1) IM	(2) IM	(3) MG	(4) MG	(5) IM	(6) IM	(7) MG	(8) MG
Livestock density		-0.64*** (0.22)	-0.60 (0.43)	-13.97*** (2.34)	139.97*** (13.59)	-0.17*** (0.04)	-0.17*** (0.07)	-0.09** (0.04)	-0.15** (0.07)
Regional effects (dummy)	Desert steppe	-3.79 (9.77)	-3.80 (15.51)	-9.74*** (2.44)	2.53 (4.19)	-7.04*** (1.55)	-8.90*** (2.46)	-5.29*** (0.47)	-5.21*** (0.49)
	Typical steppe	109.56*** (8.08)	110.43*** (8.76)	25.86*** (2.73)	62.19*** (4.63)	12.93*** (1.28)	12.83*** (1.39)	4.15*** (0.52)	5.16*** (0.54)
	Meadow steppe	168.73*** (11.22)	175.41*** (12.65)	71.40*** (3.37)	122.78*** (5.12)	24.38*** (1.78)	24.00*** (2.01)	20.09*** (0.63)	19.93*** (0.63)
Interaction terms (Regional effects * Livestock density)	Desert steppe	-	0.55 (7.03)	-	-92.16*** (14.93)	-	1.07 (1.12)	-	-0.10 (0.17)
	Typical steppe	-	-3.66 (2.65)	-	-151.58*** (14.09)	-	0.01 (0.08)	-	-1.36*** (0.19)
	Meadow steppe	-	-0.02 (0.50)	-	-168.07*** (13.85)	-	0.17 (0.42)	-	0.21** (0.09)
Observations		1094	1094	3896	3896	1095	1095	3860	3860
R-squared		0.59	0.59	0.79	0.80	0.72	0.72	0.85	0.85
Degree of freedom		1073	1070	3875	3872	1074	1071	3839	3836
Temperature - Precipitation Fixed-effects		YES	YES	YES	YES	YES	YES	YES	YES
Time fixed-effects		YES	YES	YES	YES	YES	YES	YES	YES

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. As an unbalanced panel data, the (1), (2), (3), and (4) AGB panel models are composed of (n=73, T=14-15, N=1094), (n=73, T=14-15, N=1094), (n=261, T=5-15, N=3896), and (n=261, T=5-15, N=3896), respectively. The (5), (6), (7), and (8) CC panel models are composed of (n=73, T=15, N=1095), (n=73, T=15, N=1095), (n=259, T=5-15, N=3860), and (n=259, T=5-15, N=3860), respectively. The reference of regional effect dummy is Desert. Temperature - Precipitation fixed-effect include Mean Annual Precipitation (MAP) and Mean Annual Temperature (MAT). The models include time fixed-effects to control annual variability. The models (1), (3), (5), and (7) are models based on the formula (1). The models (2), (4), (6), and (8) have an interaction term controlling the regional impacts on the livestock density.

Conclusion

- Scaling up of canopy cover (CC) & aboveground biomass (AGB) on MP using MODIS NBAR
- Site level predictive models - rule-based methods for upscaling
- Scaled-up estimates explained by climatic variability/socioeconomic drivers
- Distance to urban areas/livestock density explained variability of CC & AGB
- Extensive sampling, robust upscaling, provides unique set of estimates of CC & AGB on the Mongolian Plateau

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Remote Sensing of Environment

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Grassland canopy cover and aboveground biomass in Mongolia and Inner Mongolia: Spatiotemporal estimates and controlling factors

Ranjeet John [a], Jiquan Chen [a], Vincenzo Giannico [a, b], Hogeun Park [a], Jingfeng Xiao [c], Gabriela Shirkey [a], Zutao Ouyang [a], Changliang Shao [d], Raffaele Lafortezza [a, b], Jiaguo Qi [a]

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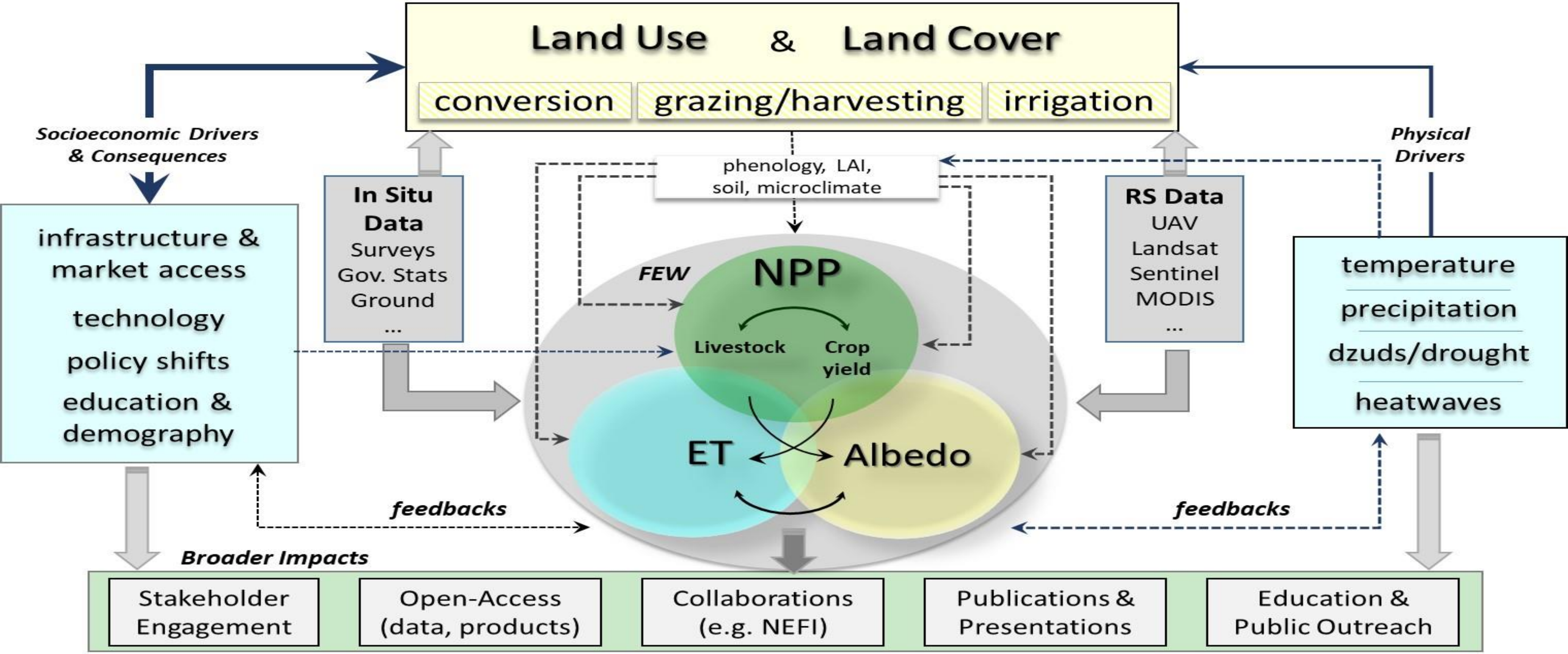
Future Work (NASA FEWS and CNH initiatives)

- *Dynamics of food, energy and water (FEWS) in Kazakhstan and Mongolia: Connecting LULCC to transitional socioecological systems*. Step 1 proposal (approved), NASA LCLUC program. Jiquan Chen (PI), Jinhua Zhao (Co-I) Michigan State University, **Ranjeet John** (**Co-I**), **University of South Dakota**. Step 2 submitted
- NSF CNH2 (Full proposal Nov 15) –FEWS and nomadic herder systems across *Kazakhstan and Mongolia* as well as extension into Kyrgyzstan, and Inner Mongolia



Conceptual framework for understanding the interdependent changes and the inter-connected driving forces on food (NPP, livestock production, crop yield), energy (*albedo*, latent heat) and water (ET) in Kaz and MG.

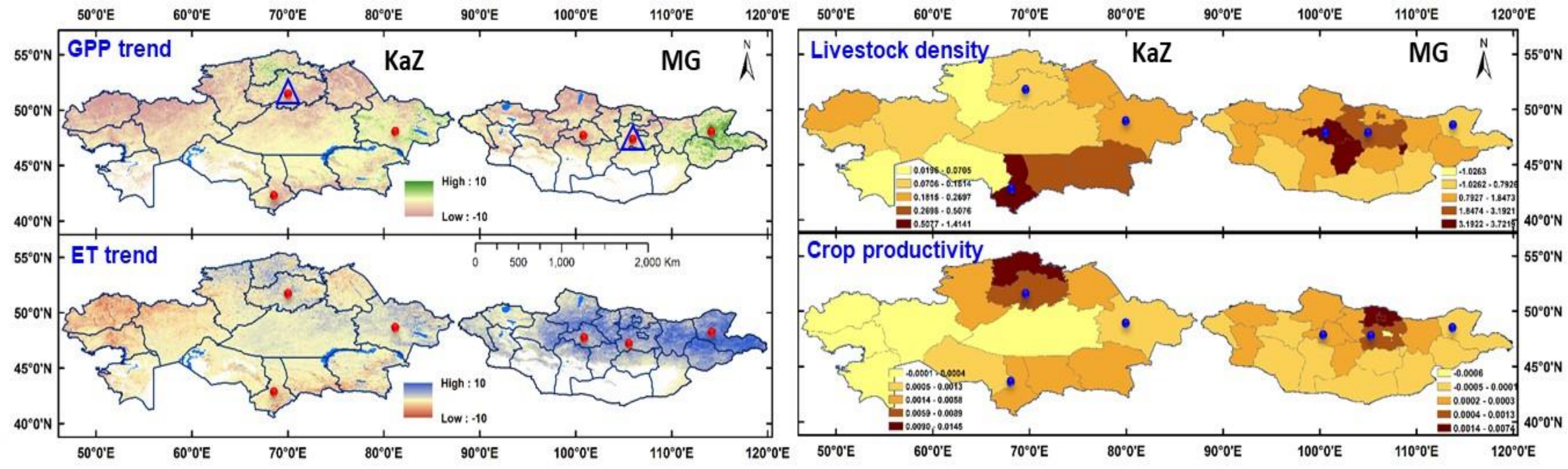
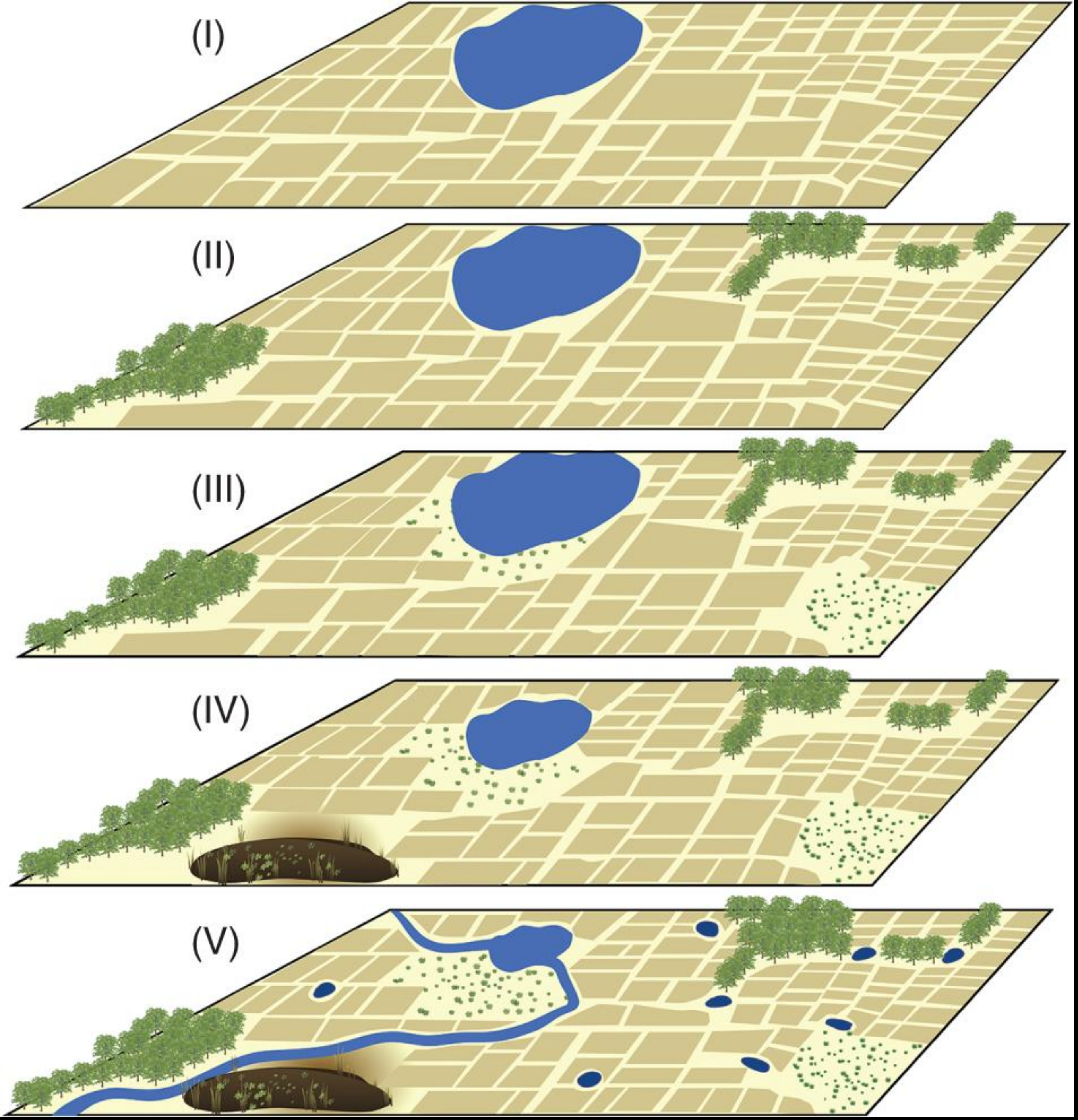


Fig. 1. The Republic of Kazakhstan (KaZ) and Mongolia (MG) are the two largest landlocked (e.g., low access to the global market) countries in the world, with livestock for MG and agriculture/livestock for KaZ serving as the societies' dominant food economies. Both countries have undergone dramatic shifts in governance following the collapse of the USSR and have experienced distinctive socioeconomic changes and severe drought /dzud effects. Highly variable climatic extremes in time and space add additional pressure on these water-limited landscapes. Three provinces (red/blue dots) of each in the "Grassland Biome" along the socioeconomic-climatic gradients will be intensively studied for their interdependent changes and the driving mechanisms during the past four decades. Land use/cover will be used as the mediating variables connecting the causes and consequences of FEW functions within the context of climatic and societal changes (Fig. 2). The manipulative experiments will be conducted in Töv Aimag (MG) and Akmola Region (KaZ) (blue triangles).

Future manuscripts

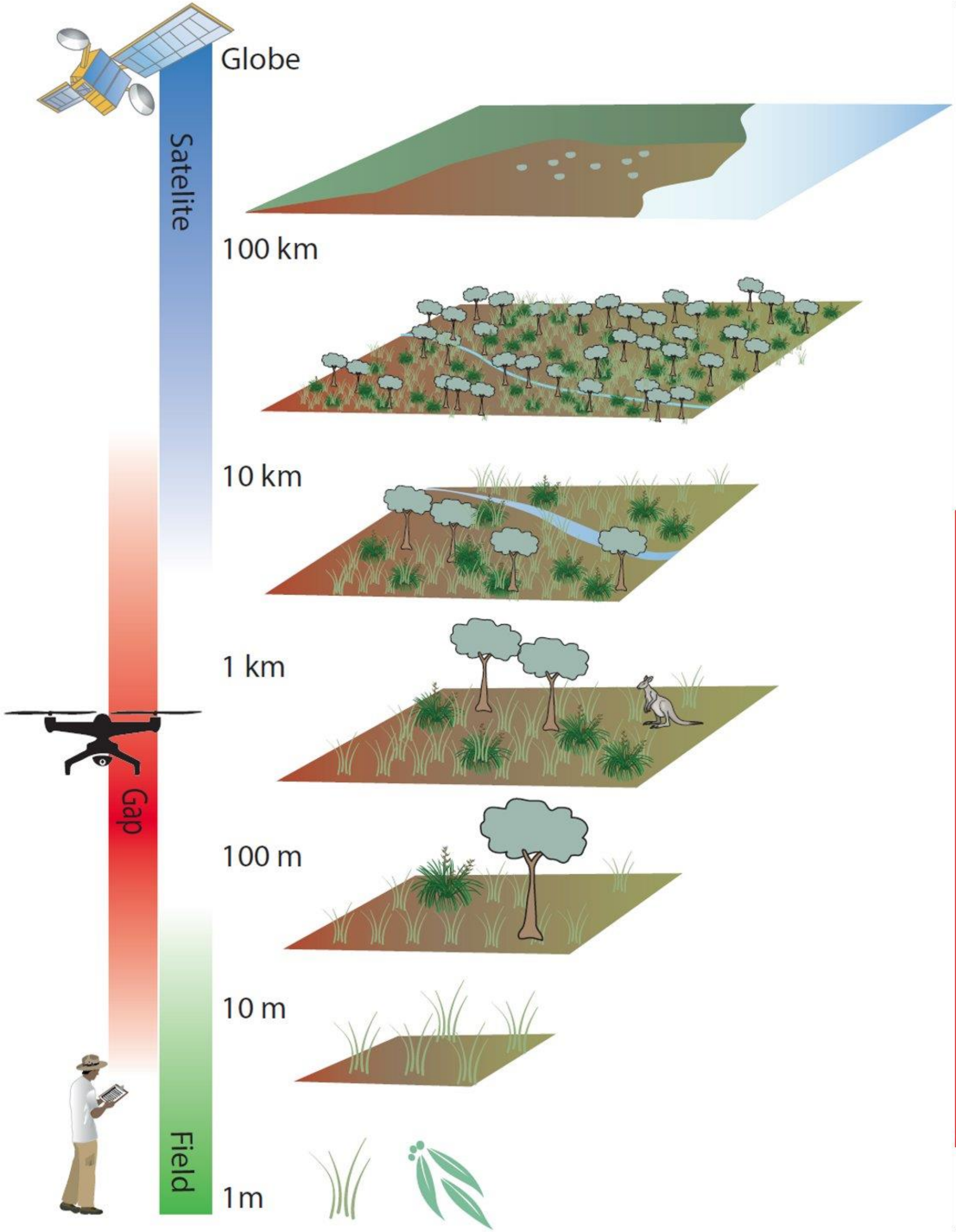
- *Can we untangle the effects of human influence on above ground biomass from background climate change on the Mongolian Plateau/KaZ?*
- *What is the relationship of species diversity-above ground biomass relationship across precipitation and grazing gradients on the Mongolian Plateau/KaZ?*
- *Can breakpoints in long term (NDVI) trends be explained by spatio-temporal trends in socioeconomic data (grazing, population density) in response to extreme climate events?*
- NDVI-land surface temperature relationship to analyze effects of anthropogenic modification on surface energy balance



Landscape Heterogeneity

S-I: homogeneous landscape, only cropland for the terrestrial domain and large lakes for the aquatic domain.
S-II: terrestrial area divided into croplands and forest lands.
S-III: croplands, forest lands and grasslands
S-IV: large lakes and peatlands,
S-V: large lakes, peatlands, rivers and small inland waters. Heterogenous

http://onlinelibrary.wiley.com/doi/10.1002/wat2.1147/full



Essential Biodiversity Variables

- Land cover
- Vegetation phenology
- Ecosystem distribution
- Primary productivity
- Fragmentation and heterogeneity
- Vegetation structure and biomass
- Vegetation height
- Vegetation community composition
- Plant traits
- Species occurrence and distribution
- Taxonomic diversity

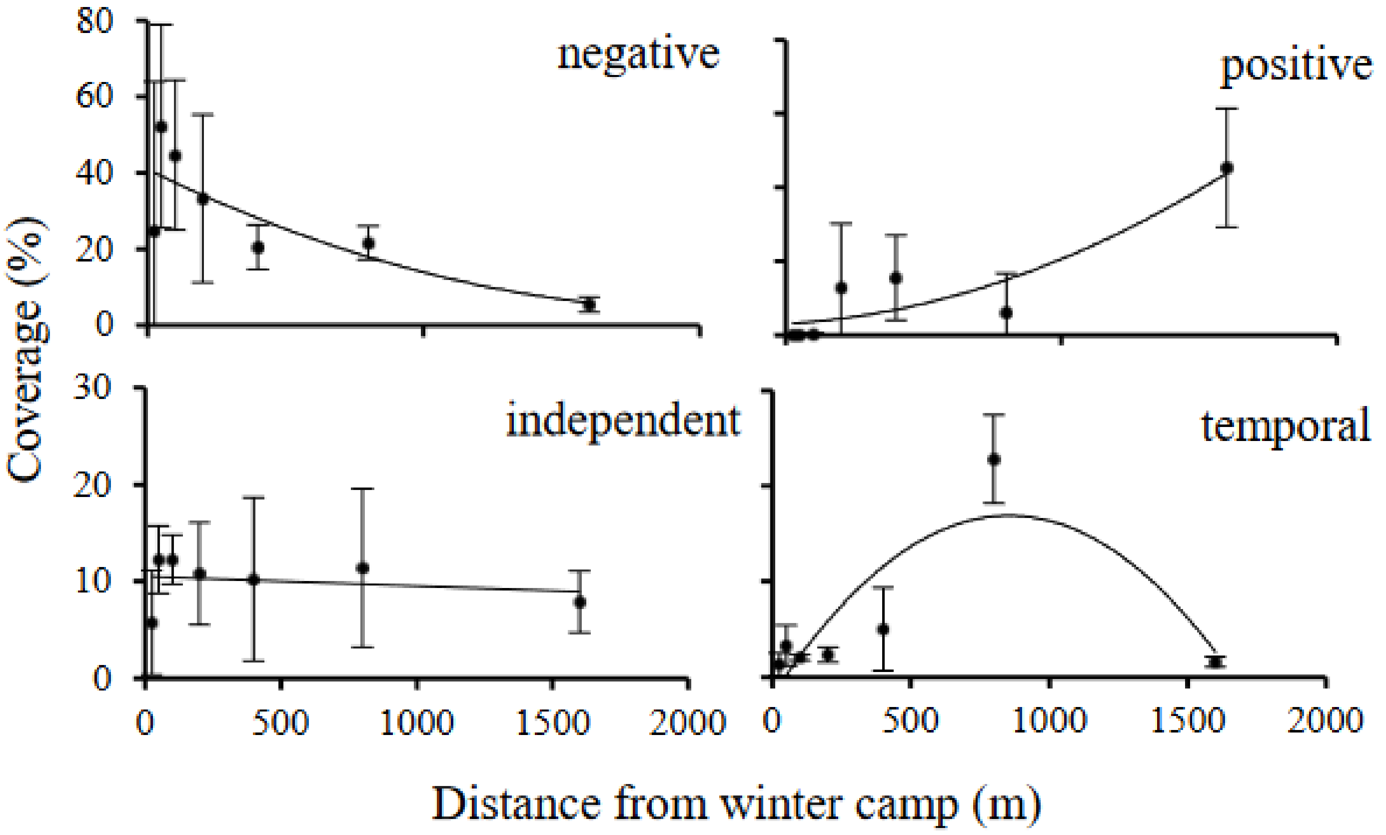


Fig. 2. Relationship types between plant cover and grazing gradient.

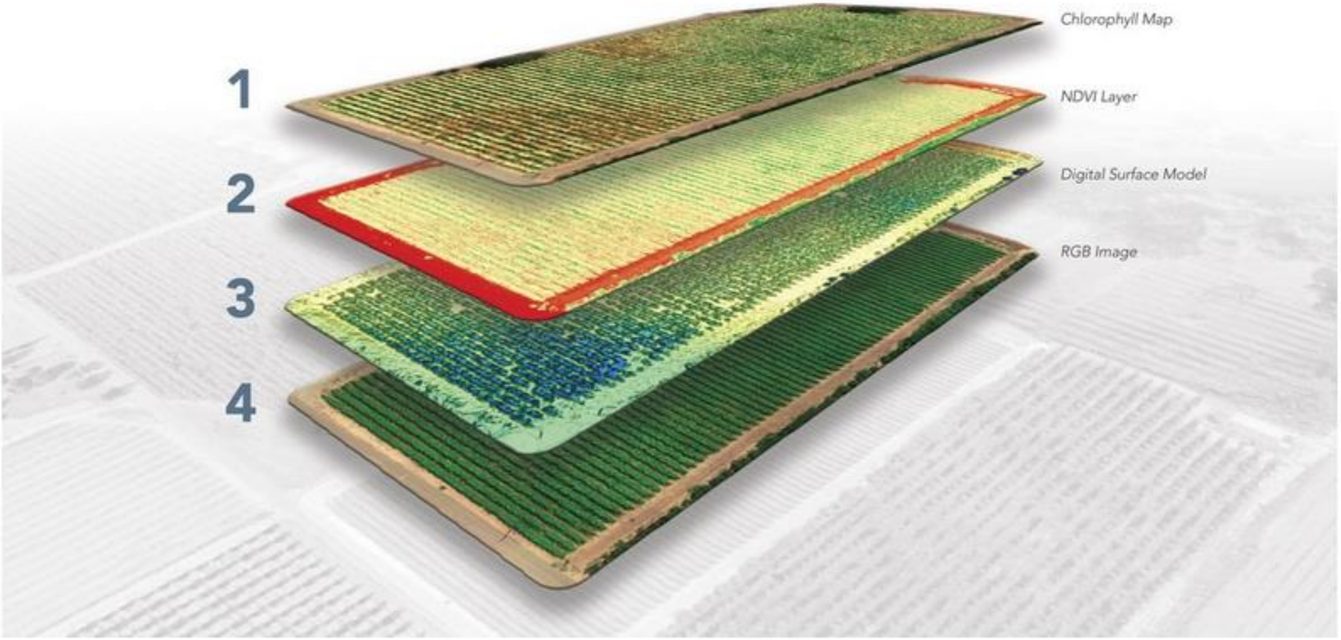
structure of rangeland plant community changing from palatable/ grass species to unpalatable/annuals species with grazing intensity

heavy grazing alters species composition and decreased species richness of plant community

http://nodaiweb.university.jp/desert/pdf/JALS-P37_235-238.pdf

Weight:	231.9 g (8.18 oz.) (includes DLS 2 and cables)
Dimensions:	8.7cm x 5.9cm x 4.54cm (3.4in x 2.3in x 1.8in)
External Power:	4.2 V DC - 15.8 V DC 4 W nominal, 8 W peak
Spectral Bands:	Blue, green, red, red edge, near-IR (global shutter, narrowband)
Wavelength (nm):	Blue (475 nm center, 20 nm bandwidth), green (560 nm center, 20 nm bandwidth), red (668 nm center, 10 nm bandwidth), red edge (717 nm center, 10 nm bandwidth), near-IR (840 nm center, 40 nm bandwidth)
RGB Color Output:	Global shutter, aligned with all bands
Ground Sample Distance (GSD):	8 cm per pixel (per band) at 120 m (~400 ft) AGL
Capture Rate:	1 capture per second (all bands), 12-bit RAW
Interfaces:	Serial, 10/100/1000 ethernet, removable Wi-Fi, external trigger, GPS, SDHC
Field of View:	47.2° HFOV
Triggering Options:	Timer mode, overlap mode, external trigger mode (PWM, GPIO, serial, and Ethernet options), manual capture mode

https://www.pix4d.com/



1 ***Chlorophyll Map:*** *The red edge spectral band is the star here, working in conjunction with the other bands to provide a more accurate measure of not just plant vigor but plant health.*

2 ***NDVI Layer:*** *This commonly known index compares the reflectance of the red band with that of the near-infrared band. However, this index alone provides limited information.*

3 ***Digital Surface Model:*** *A DSM is an astonishingly advantageous tool in any agronomist's arsenal, primarily because of its use in evaluating surface properties and water flow.*

4 ***RGB Image:*** *RedEdge-M features global shutters for distortion-free images, including narrowband red, green, and blue bands for RGB color images that when processed are aligned to all visible and non-visible bands and vegetation indices.*

LCLUC

Land-Cover / Land-Use Change Program

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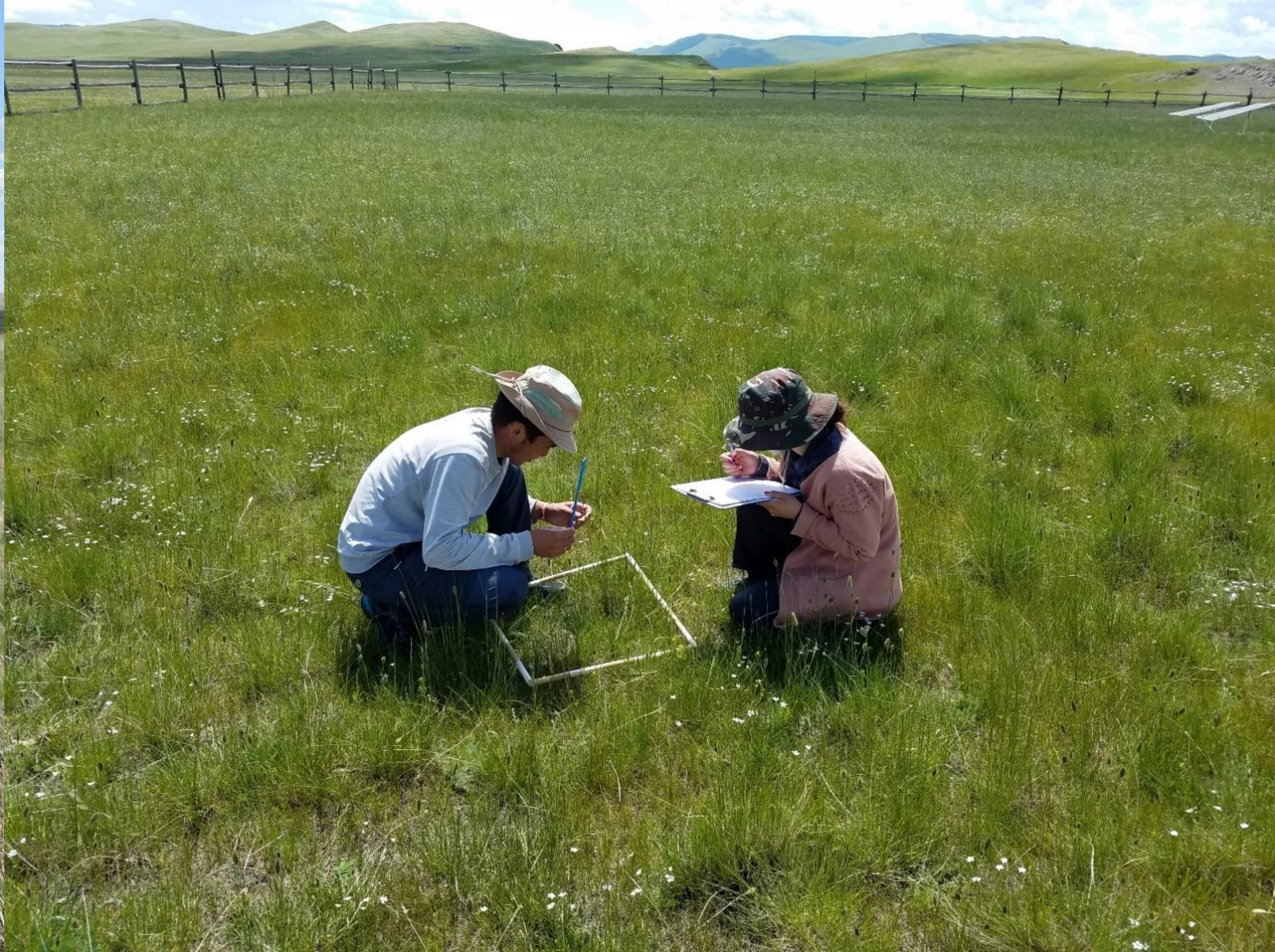
- NSF Dynamics of Coupled Natural and Human Systems (CNH)" Program (#1313761)
- NASA Land Cover Land Use Change program (NNX14AD85G)
- Dr. Ochirbat Batkhishig, Ulgichimig Ganzorig, and student assistants of Institute of Geography and Geo-Ecology, Mongolian Academy of Sciences
- Institute of Botany, Chinese Academy of Sciences & LEES Lab members, Advisors (Dr. Jiquan Chen & Dr. Jiaguo Qi), Mentors, Colleagues



Typical steppe

Grazing exclusion site (Khangai Mountains)

- Typical Steppe, Cold, semi-arid climate type (BSk) of the Köppen classification , MAP of 300 m.
- Vegetation is characterized by *Stipa krylovii, Stipa grandis*, *Carex duriuscula,* and *Cleistogenes spp*.

Meadow steppe

Alpine meadow

Meadow-Mountain Steppe subarctic climate cool summers and severe dry winters (Dwc), Khangaii Mountains of Mongolia, Khingaan Mountains in IM with a MAP of 400 mm

Poa attenuata, *Festucca spp.*, *Elymus chinensis*, *Stipa baicalensis*, *Filifolium sibiricum*, *Leymus Chinenis* and *Artemisia frigida*

Desert steppe

- desert steppe Cold desert climate (BWk), MAP of 150-200 mm
- characterized by *Caragana spp*., *Artemisa xerophytica* and *Artemisia ordosica*

Typical Steppe

Low-grazing

Stipa grandis

Agropyron cristatum

Typical Steppe

Medium-grazing

Iris bungeii

(not eaten by cattle and sheep, horses only as last resort)

Achnatherum splendens

Typical Steppe

“medium-high” grazing

Leymus chinensis

Cleistogenes squarrosa

Heavy grazing- *Artemisia adamsii, A. frigida*

Institutional Changes

Collective 1960-1991	Early privatization 1992-2000	Post-dzud 2001-present
• Negdel* regulates land use & stocking rates • Support for movements • Supplemental fodder • Services provided	• 1994 Land Law • *De facto* open access • No regulation of seasonal movements • Services privatized • Urban – rural migration • ↑ herding households • ↑ poverty • ↓ Pastoral movement • ↑ "trespassing" & out-of-season grazing	• 2002 Land Law • > 2000 community-based rangeland mgt .groups • Rural-urban & periphery to center migration • ↑ X-boundary movements • ↑ pasture conflicts • National Livestock Program

Key contributors: D. Sneath and C. Humphreys, M. Fernandez-Gimenez, B. Batbuyan, C. Upton, R. Mearns.
More recent: T. Sternberg, B. Batkhishig, A. Marin, D. Murphy, A. Erickson.

* Agric. Co-operative

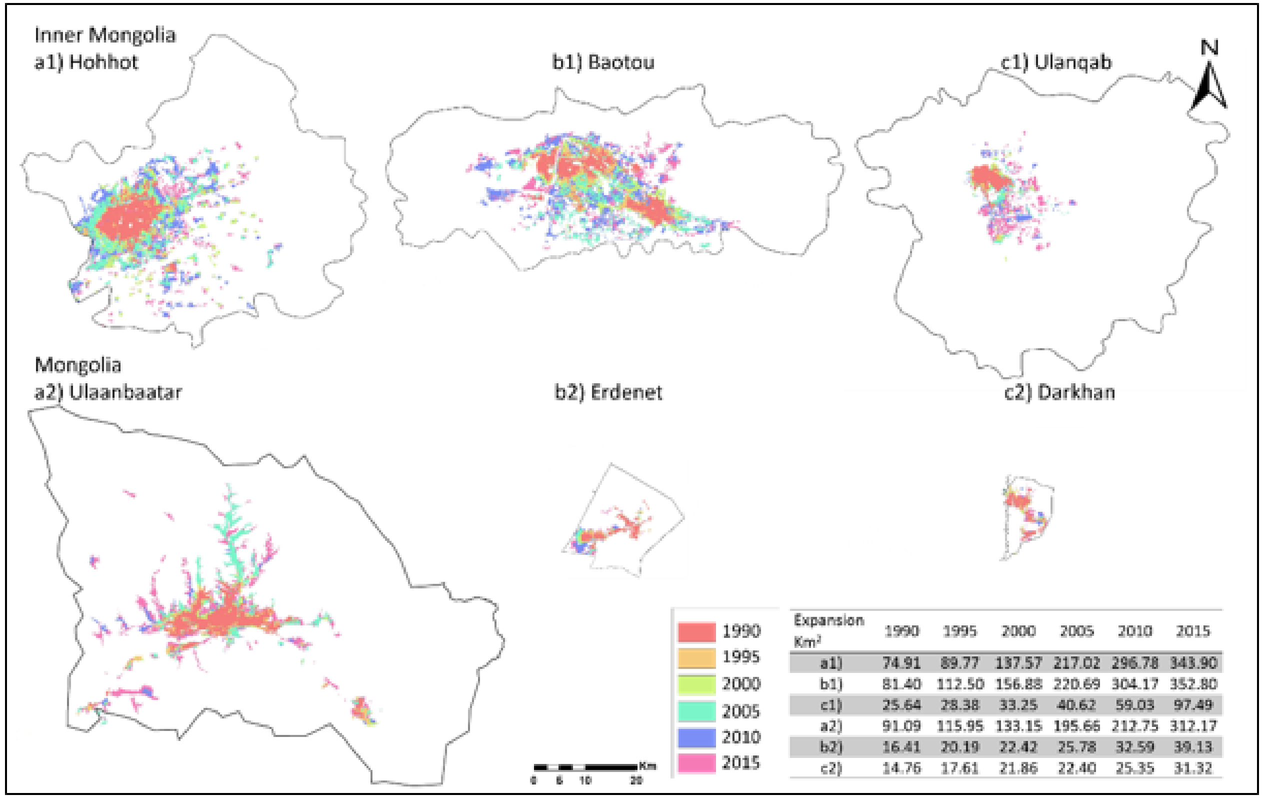
Policies -sedenterization

- Deng Xiaoping reforms, 1980s in IM/China – emerging market economy in IM 1990-2000, -agricultural collectives replaced- privatization of herding/farming
- Livestock and Rangeland Double-Contract Responsibility System (LRDCRS) implemented in IM (1980s) – sedentary livestock husbandry within a (strictly) delimited rangeland area/family - fenced pastures.
- 1990-2000 mature market economy, saw the introduction of grassland conservation measures (fencing) and green belts to control desertification and dust storms originating in IM

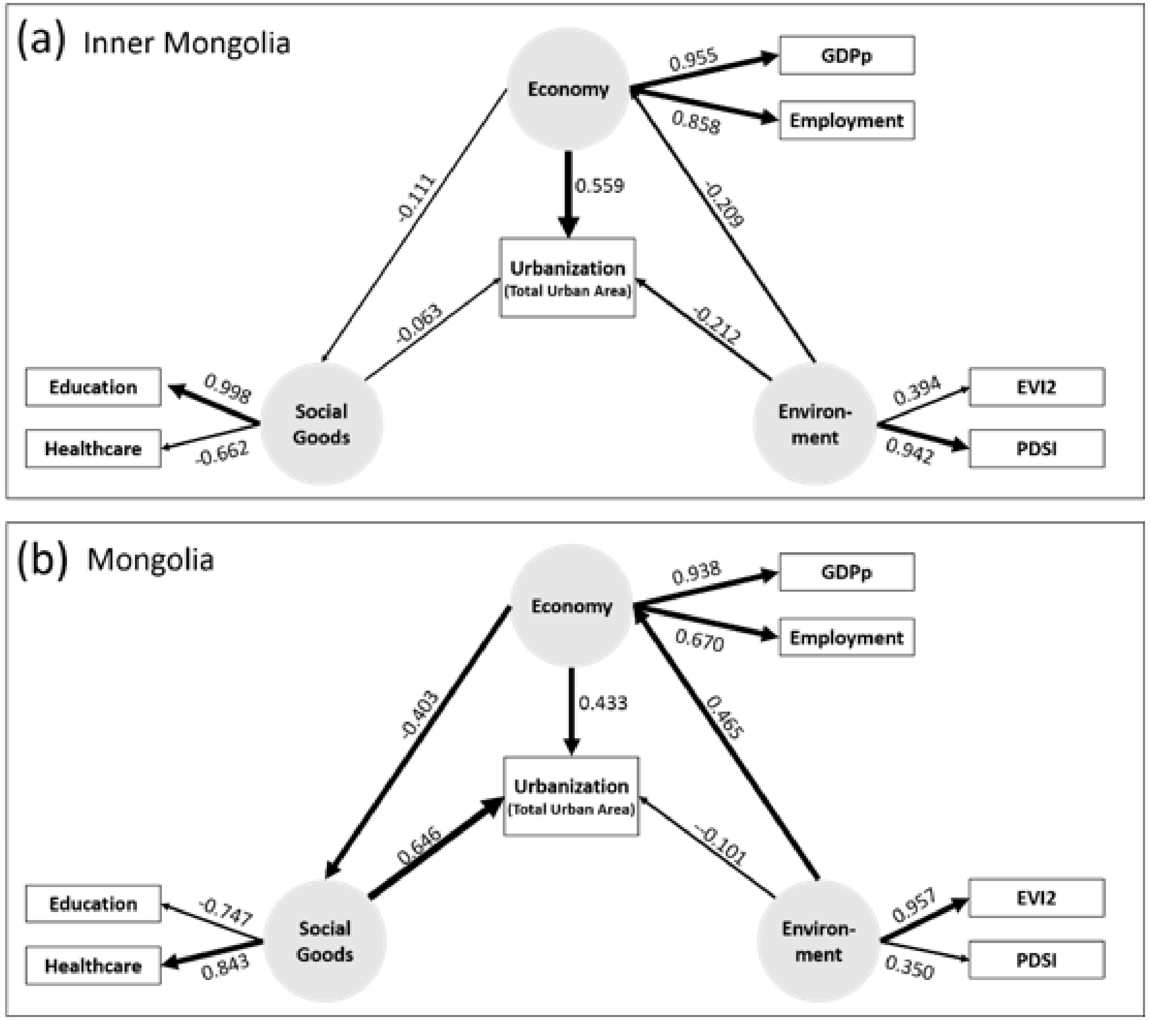
Nomadic herding – decrease in range

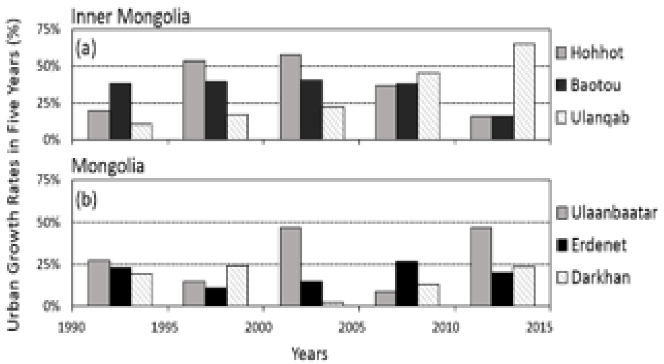
- *Otor* -herders adaptation to cope with highly variable climate.
- Studies suggest LRDCRS* in IM /privatization in MG cannot replace traditional herd mobility practices
- semi-privatization of grazing land results in loss of access to key resources, reciprocal bonds weakened for conducting *otor,* both low carbon foot print pastoral livelihoods and sustainable use of grazing lands suffer

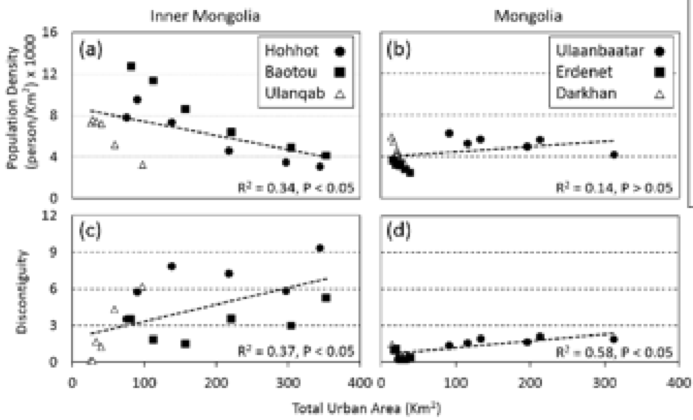
*Livestock and Rangeland Double-Contract Responsibility System (*LRDCRS*)



Expansion Km²	1990	1995	2000	2005	2010	2015
a1)	74.91	89.77	137.57	217.02	296.78	343.90
b1)	81.40	112.50	156.88	220.69	304.17	352.80
c1)	25.64	28.38	33.25	40.62	59.03	97.49
a2)	91.09	115.95	133.15	195.66	212.75	312.17
b2)	16.41	20.19	22.42	25.78	32.59	39.13
c2)	14.76	17.61	21.86	22.40	25.35	31.32







Park et al 2017

Partial Least Squares Structural Equation Modeling (PLS-SEM) of socioeconomic and biophysical drivers on urbanization in both Inner Mongolia (IM), Mongolia (MG)

Latent variables-circular shapes, and measured variables-squares. Path coefficients describe relationships between variables. IM model illustrates that economy is major driver of urbanization ($R2 = 0.422$) whereas the MG model demonstrates that both economy and social goods drive urbanization ($R2 = 0.342$).