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Introduction

Similar to other regions in northern high latitudes, the intensity of climate change (e.g., surface air temperature) in the Mongolian Plateau tends to be above the global average. Furthermore, the feedbacks of the Mongolian Plateau to the East Asia summer monsoon systems may accelerate climate change in this region. The atmospheric CO₂ sink/source activity of the terrestrial ecosystems in the Mongolian Plateau, especially grasslands, at an annual or decadal scale will depend heavily on how climate changes in this region and the associated responses of ecosystems to this change. Because of its sensitive ecosystems and the vast area they cover, the Mongolian Plateau has been contemplated to play an important role in the global carbon cycle in an altering climate system. To date, some progress has been made in investigating terrestrial ecosystem productivity and C exchange in the Mongolian Plateau. However, relatively little attention has been paid to the carbon budget of the Mongolian terrestrial ecosystems at a regional scale. Further, no information has been available so far concerning how the regional carbon cycle will respond to the transient changes in climate and atmospheric CO₂ concentration in the future.

Here we apply a process-based biogeochemistry model, the Terrestrial Ecosystem Model (TEM; Zhuang *et al* 2003) to estimate the carbon budget for the entire Mongolian Plateau. By using historical and modeled future climate data, we examine how climate change has affected C dynamics in the Mongolian Plateau during the 20th century and how these dynamics may respond to the variations in atmospheric CO₂ concentration and climate under different scenarios over the 21st century. The study also strives to identify the key controls to terrestrial ecosystem C dynamics in this region.

Methods

For this application of TEM, we have developed a set of parameters specifically for grasslands, the major vegetation type in the plateau, based on field observation data collected within the region (Sui *et al* 2009). After calibration, the TEM was evaluated with the observed data of ecosystem C fluxes and pools at other sites in this region (Sui *et al* 2009). To run TEM for the Mongolian Plateau for the 20th and 21st centuries, we organize data for climate, vegetation, soil texture, and elevation at a 0.5° latitude x 0.5° longitude resolution from 1901 to 2100. Specifically, the vegetation data over the Mongolia Plateau are derived from the International Geosphere-Biosphere Program (IGBP) Data and Information System (DIS) DISCover Database (Belward *et al* 1999, Loveland *et al* 2000). The 1km x 1km DISCover dataset is re-classified into the TEM vegetation classification scheme (Melillo *et al* 1993) and then aggregated to the 0.5° x 0.5° spatial resolution. The soil texture data are based on the Food and Agriculture Organization/Civil Service Reform Committee (FAO/CSRC) digitization of the FAO-UNESCO (1971) soil map. For elevation, we use the 1km x 1km elevation data derived from the Shuttle Radar Topography Mission (SRTM) (Farr *et al* 2007). The SRTM data are re-sampled to match the resolution of other input data.

The driving climate data sets include the monthly air temperature, precipitation, and cloudiness. The historical climate data sets from 1901 to 2000 are based on the data from the CRU (Mitchell and Jones 2005). Due to lack of meteorological data before the 1950s in the Mongolian Plateau, the data of the first half century in this dataset may not well represent the actual climatic conditions in the region. To simulate C dynamics in the future, we use four scenarios among the IPCC SRES (IPCC 2000, 2001), which are A1FI, A2, B1, and B2 respectively. Under those scenarios, the global climate has been simulated with HadCM3 at a 0.5° x 0.5° spatial resolution (Mitchell *et al* 2004). We extract the Mongolian climate data from the output of these GCM simulations based on the boundary of the plateau. The annual atmospheric CO₂ concentrations data from 1901 to 2000 are based on atmospheric CO₂ observation data (Etheridge *et al* 1996, Keeling *et al* 1995) and data from our previous studies (Zhuang *et al* 2003). For the period of 2001 to 2100, we retrieve the information of annual CO₂ concentrations projected by a fast carbon cycle model, ISAM (Jain *et al* 1995) for the four SRES scenarios (IPCC 2001).

Results

Soil thermal and moisture dynamics

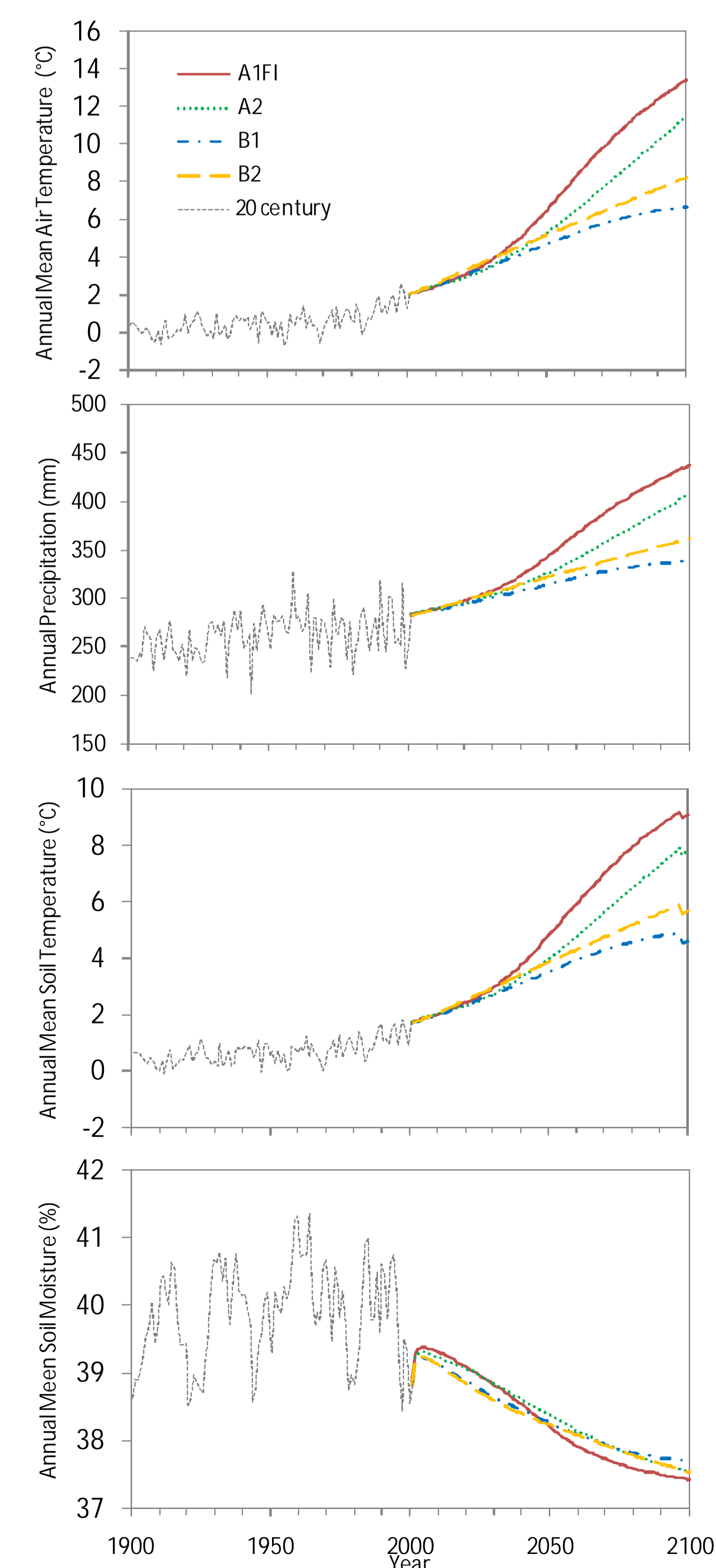


Figure 1. Annual air temperature, precipitation, soil temperature at 20 cm depth, and soil moisture from 1901 to 2100 in the Mongolian Plateau.

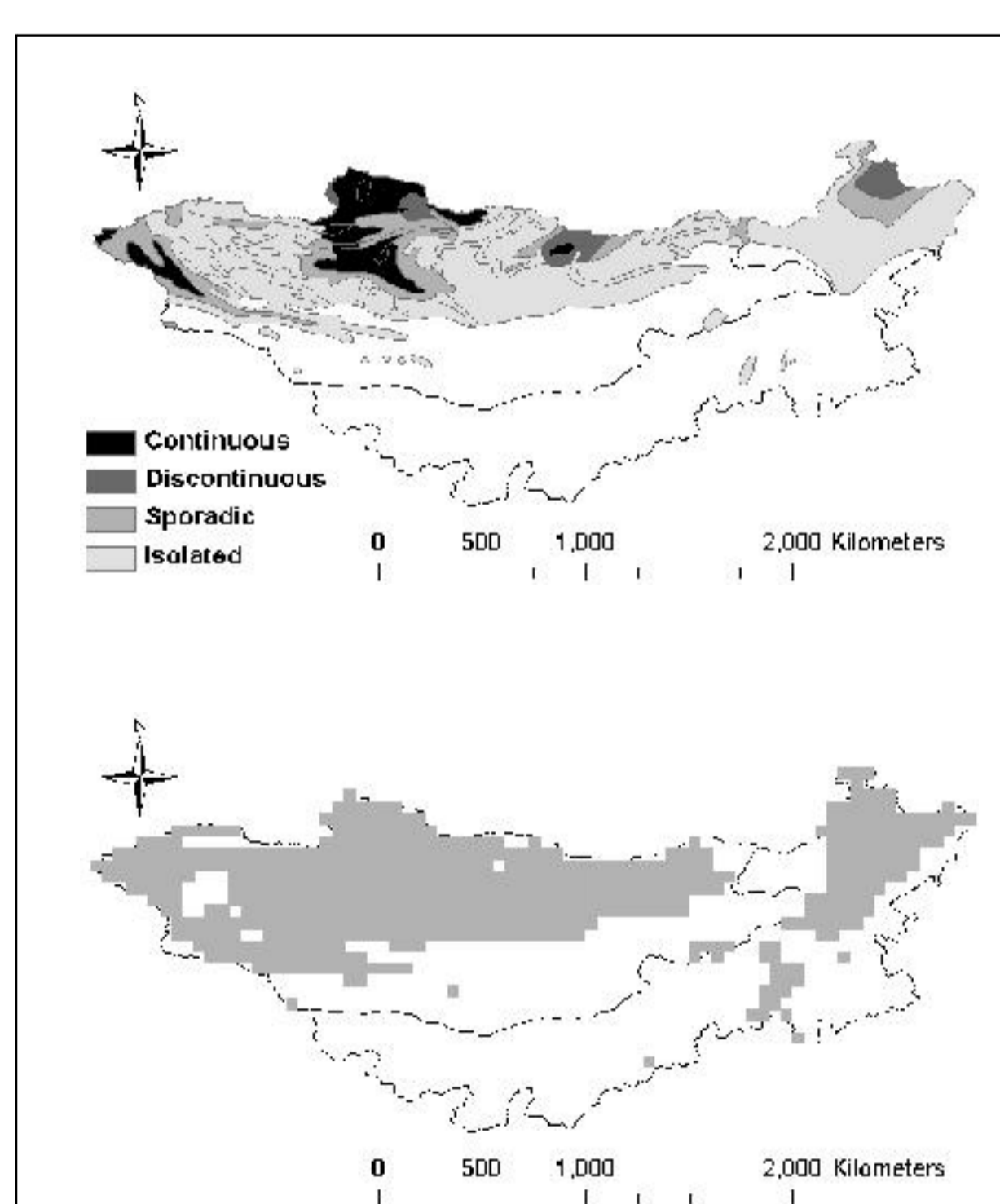


Figure 2. Permafrost distribution following Brown *et al.*, (1998) (left panel) and TEM simulation by using soil temperature at 200 cm depth during 1990s (right panel) in the Mongolia Plateau.

Carbon dynamics

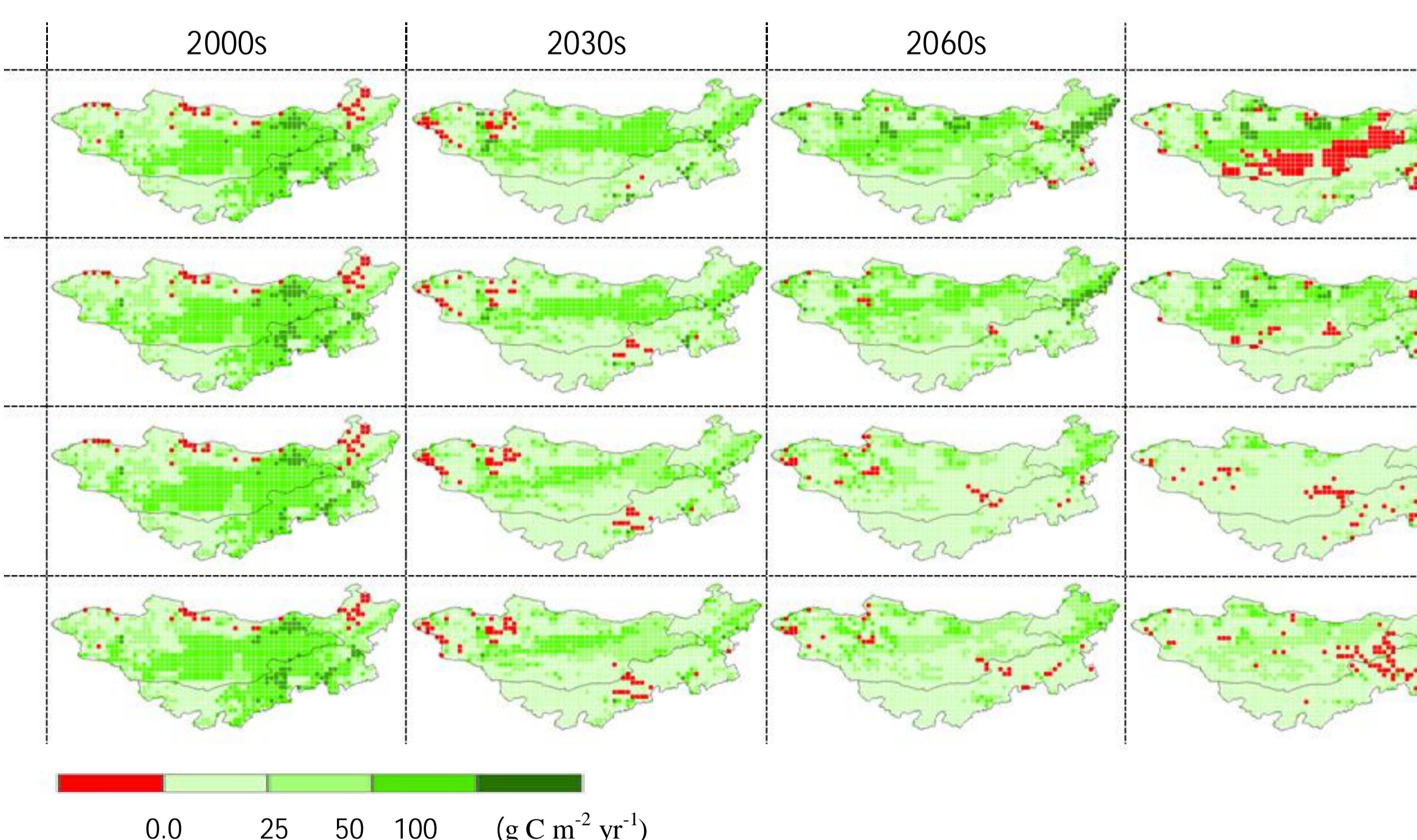
C fluxes and pool sizes for different ecosystems in the Mongolian Plateau during the 1990s. C_v represents the vegetation C pool and C_s represents the soil C pool for the region

Type	Area (10 ³ km ²)	NEP (Tg C yr ⁻¹)	NPP (Tg C yr ⁻¹)	R _H (Tg C yr ⁻¹)	GPP (Tg C yr ⁻¹)	C _v (Pg C)	C _s (Pg C)
Alpine tundra	9.8	0.03	0.73	0.70	1.47	0.01	0.06
Wet tundra	4.0	0.07	0.99	0.92	1.72	0.01	0.09
Boreal forests	158.1	1.51	46.01	44.50	101.00	1.81	1.88
Temperate forests	204.5	3.34	79.23	75.89	169.62	1.80	1.69
Temperate grasslands	1661.4	21.84	711.22	689.39	1566.48	2.87	6.94
Xeric shrublands	515.4	3.45	50.68	47.24	98.49	0.24	1.53
Xeric woodlands	100.3	1.14	17.92	16.78	29.35	0.14	0.53
Deserts	24.8	0.02	1.74	1.71	3.50	0.01	0.05
Total	2678.3	31.40	908.54	877.14	1847.96	6.88	12.78

Spearman correlations between physical variables and C fluxes as well as C pool sizes in the Mongolian Plateau. The coefficients were calculated by Spearman correlation analysis of the regional aggregated results from 1901 to 2000.

	CO ₂ level	Air Temperature	Precipitation	Soil Temperature	Soil Moisture
NEP	0.01	-0.09	0.40*	-0.15	0.02
NPP	0.11	0.03	0.46**	-0.02	0.09
R _H	0.46**	0.71**	0.30*	0.70**	0.29**
C _v	0.89**	0.55**	0.37**	0.53**	0.27**
C _s	< 0.05	0.21* 0.01	0.15	0.00	0.13

Figure 4. Spatial patterns of NEP during the 2000s, 2030s, 2060s, and 2090s in different future scenarios. Red color indicate carbon source and green color indicates carbon sink (g C m⁻² yr⁻¹)



Conclusions

Our model simulations indicate that the permafrost in this region is relatively stable due to thick top soil layer above permafrost table in spite of increases in air temperature. The rising temperature increases ground evapotranspiration, drying soils even in a wetter climate condition. These dynamics determine why the Mongolian Plateau acted as a C sink of 31.40 Tg C yr⁻¹ in the 1990s along with large inter-annual and spatial variabilities in this sink/source behavior. During the 21st century, warming will likely induce the decline of the C sink on the Mongolian Plateau. Future research priorities: 1. the use of Regional Climate Models; 2. development of spatially-explicit time series data sets of land-use change; 3. development of data sets describing peatlands distribution and their fluxes of carbon and water and energy and further quantifying their role in regional C dynamics

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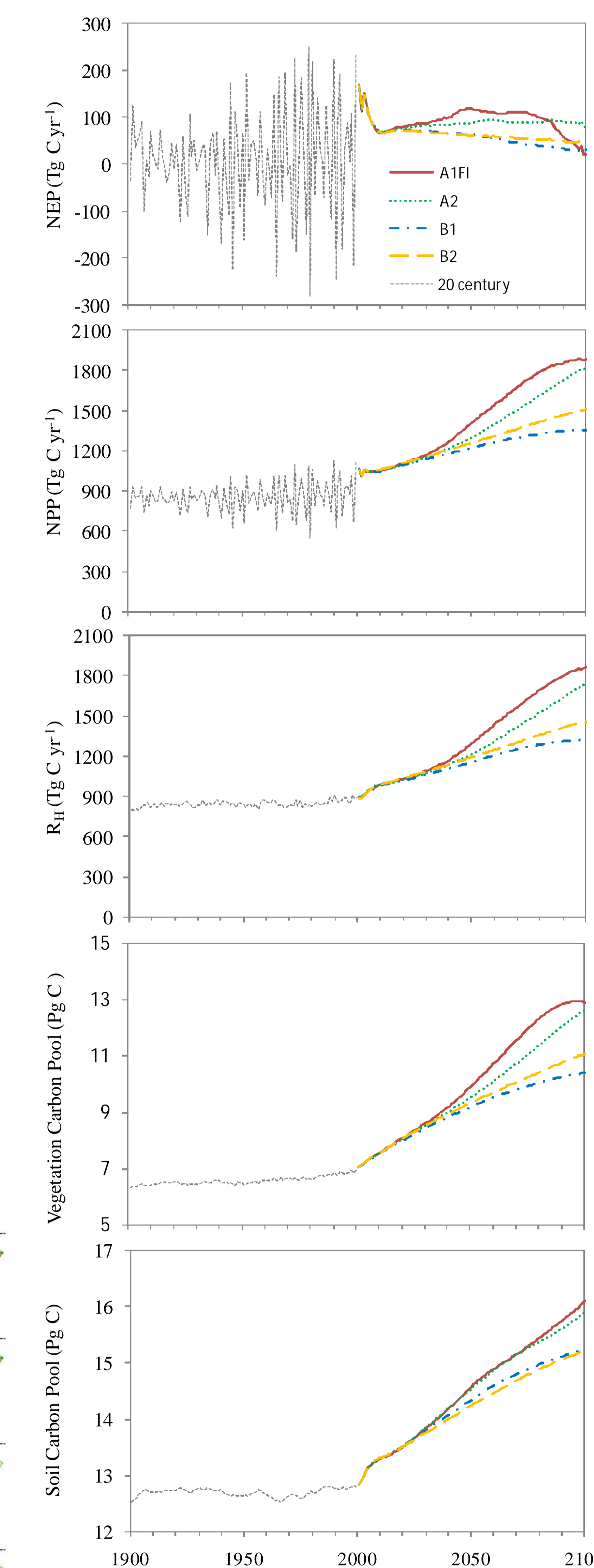


Figure 3. Annual C fluxes and pool sizes from 1901 to 2100 in the Mongolia Plateau.