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Net primary productivity in Kazakhstan, its spatio-temporal patterns and relation to meteorological variables☆

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ABSTRACT

Arid and semiarid environments are susceptible to environmental degradation and desertification. Modelling net primary productivity (NPP) and analysis of spatio-temporal patterns help to understand ecological functioning especially in these areas. In this study, we apply the Biosphere Energy Transfer Hydrology Model (BETHY/DLR) to derive NPP for Kazakhstan for 2003–2011. Results are analyzed regarding spatial, monthly, and inter-annual variations. Mean annual NPP for Kazakhstan is 143 g C m^{-2} and maximum productivity is reached in June. Most monthly NPP anomalies occur in semiarid North of Kazakhstan. These regions seem to be most strongly affected by changes in meteorology and are likely to be vulnerable to changing climate. Arid ecosystems show lower inter-annual NPP variability than semiarid lands. Correlations between NPP and meteorological parameters reveal variable influence of temperature, PAR, and precipitation on vegetation productivity during the year. Reaction of vegetation growth to precipitation is delayed 1–2 months. Temperature is most critical in spring and precipitation in summer affects NPP in August–October. The results presented in this study help to identify regions that are vulnerable to global change. They allow predictions on possible effects of expected future climate change on vegetation productivity in arid and semiarid Kazakhstan and support sustainable land management.

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1. Introduction

Arid and semiarid environments cover almost one third of the terrestrial world (FAO, 1989). These lands are especially susceptible to environmental degradation and desertification (e.g. Eswaran et al., 2001; UN, 1994; Verstraete, 1986). Environmental degradation has been identified as one of the major threats by the High Level Panel on Threats, Challenges and Change of the United Nations (UN, 2004). The vegetation cover in semiarid and arid regions is of high importance for protection against wind and aeolian erosion (Calvão and Palmeirim, 2004). The reduction in plant biomass lowers the soil quality and fertility, which in turn reduces the capacity for agriculture and keeping livestock. Reduction in biomass therefore has a negative effect on human well-being (e.g. Köchy et al., 2008; UNEP, 1999).

Quantification of biomass and monitoring of net primary productivity (NPP) are essential to identify and monitor those areas under high risk of degradation and desertification (e.g. Moleele et al., 2001; Niklaus et al., 2012). NPP is the dry matter production by green vegetation per unit area and unit time. It is a key variable for ecological monitoring activities and a sensitive indicator of climate and environmental change (Niemeijer, 2002; Schimel, 1995). NPP has therefore been identified by the Commission on Geosciences, Environment and Resources as a primary variable for observing ecological functioning and on-going degradation processes (CGER, 2000).

Large areas in Central Asia, including almost entire Kazakhstan, are characterized as arid or semiarid (Eisfelder et al., 2012; Lioubimtseva and Adams, 2004). Kazakhstan is an especially important area to study because land degradation and desertification already pose large ecological challenges (ADB, 2010). The country has experienced varying human influences and political decisions with dramatic ecological and environmental consequences such as the decline of the Aral Sea (ADB, 2010). Large areas in Kazakhstan were undergoing land cover change, especially

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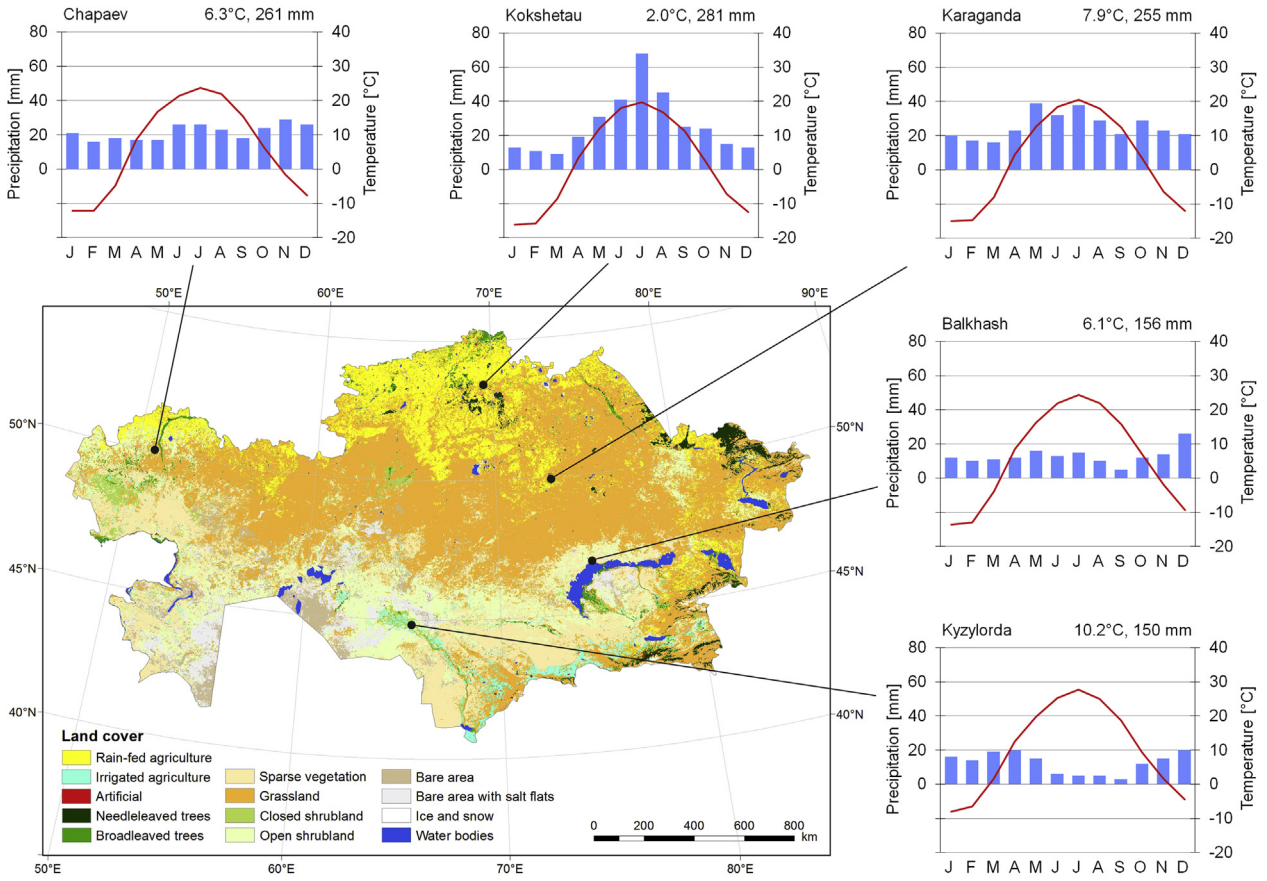

Fig. 1. Land cover and land use map of Kazakhstan (Klein et al., 2012) and representative precipitation (average monthly precipitation) and temperature (average daily mean temperature) diagrams.
Extracted from Hijmans et al., 2005.

during the second half of the 20th century when the 'Virgin Lands Programme' was initiated to transform traditional pasture lands of the Kazakh Steppe into crop agriculture (de Beurs and Henebry, 2004). The extensive land use led to dramatic steppe deterioration. After the breakdown of the Soviet Union, vast areas of ploughed land were abandoned. In recent years, the grazing impact on vegetation has decreased and undergrazing rather than overgrazing was reported. This was due to a reduction in the livestock population (de Beurs and Henebry, 2004; Lioubimtseva et al., 2005). In addition to human impacts on the environment, there are also the effects of changing climate. Increased annual and winter temperatures have been recorded since the beginning of the 20th century (Lioubimtseva et al., 2005). Temperatures in Central Asia are expected to further increase 1–2 °C by 2030–2050 (Lioubimtseva et al., 2005). Aridity is expected to intensify, especially in western Kazakhstan (Lioubimtseva et al., 2005). Trends in precipitation are highly variable, but indicate a small overall decrease (Lioubimtseva and Henebry, 2009).

In the context of these diverse influences on the arid and semiarid lands in Kazakhstan, it is of great interest to observe large-scale vegetation dynamics. In this study, we applied the Biosphere Energy Transfer Hydrology (BETHY/DLR) model, which has been adapted at the German Aerospace Center (DLR) to be driven by remote sensing data (Wißkirchen et al., 2013), to calculate NPP for Kazakhstan. The objectives were to (i) present the results of mean annual and monthly NPP for the period 2003–2011, (ii) locate areas with frequent NPP anomalies within the time period of interest, as well as areas of low and high NPP variability, and (iii) analyze temporal correlation between NPP and meteorological parameters.

Such detailed analyses of NPP time-series for Kazakhstan have not been published before. The methods and analyses presented here would be applicable to other arid environments in the world as well. The derived information helps to obtain knowledge about spatial distribution and temporal variation of vegetation productivity. Derivation of anomalies and relation between NPP and climate form valuable base information for understanding which areas might be most strongly affected by changing climate. This information may help to identify regions that are more vulnerable to global change, and thus, support sustainable land management.

2. Materials and methods

2.1. Study area

Kazakhstan is the world's ninth largest country with an area of 2.72 million km^2. It is mainly characterized by arid and semiarid conditions (Eisfelder et al., 2012; Lioubimtseva and Adams, 2004). It spreads between 40° and 56°N and 46°–88°E and reaches from the Caspian Sea and Volga plains in the West to the Altay Mountains in the East. In the South and Southeast, the country is bordered by the Tian Shan Mountains and in the North, the geologically diverse steppe reaches the Western Siberian lowland (ADB, 2010).

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