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Using the Köppen classification to quantify climate variation and change: An example for 1901–2010

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ABSTRACT

The Köppen climate classification was developed based on the empirical relationship between climate and vegetation. This type of climate classification scheme provides an efficient way to describe climatic conditions defined by multiple variables and their seasonalities with a single metric. Compared with a single variable approach, the Köppen classification can add a new dimension to the description of climate variation. Further, it is generally accepted that the climatic combinations identified with the Köppen classification are ecologically relevant. The classification has therefore been widely used to map geographic distribution of long term mean climate and associated ecosystem conditions. Over the recent years, there has also been an increasing interest in using the classification to identify changes in climate and potential changes in vegetation over time. These successful applications point to the potential of using the Köppen classification as a diagnostic tool to monitor changes in the climatic condition over various time scales. This work used a global temperature and precipitation observation dataset to reveal variations and changes of climate over the period 1901–2010, demonstrating the power of the Köppen classification in describing not only climate change, but also climate variability on various temporal scales. It is concluded that the most significant change over 1901–2010 is a distinct areal increase of the dry climate (B) accompanied by a significant areal decrease of the polar climate (E) since the 1980s. The areas of spatially stable climate regions for interannual and interdecadal variations are also identified, which have practical and theoretical implications.

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1. Introduction

Due to various factors limiting the distribution and abundance of organisms on Earth, each species and ecological community have a limited distribution. One of the most critical and variable determinants of the distribution of Earth's major ecosystem types is climate, which provides a source of energy and water (Zhou and Wang, 2000). Box (1981) suggests that general macroclimatic conditions influencing plant energy and water budgets are much more important than any other factors in determining the general ecological structure.

Climate is often defined as a comprehensive statistical description of weather over a sufficiently long period of time (usually 30 years) and varies at a wide range of temporal scales. Climate is determined by external forcings (e.g. solar radiation) and internal dynamics in the climate system (e.g. atmospheric and oceanic circulations and earth surface–atmosphere interactions).

In terms of the internal dynamics, there are atmospheric modes of circulation that have time scales of up to about two years (e.g. the quasi-biennial oscillation). We also have coupled ocean-atmospheric modes that have time scales from weeks to several decades (e.g. the El-Niño phenomenon which has a time-scale of about four years). These modes altogether can produce climate variations at various time scales, in addition to the long term changes which are often associated with different long term forcings.

For vegetation and ecosystems, climate can be considered general patterns of temperature, precipitation, humidity, wind, and radiation that characterize a region. But most climate classification schemes only use near-surface air temperature and precipitation as the two major variables in describing energy and water balance (e.g. Thorthwaite, 1948), mainly due to the limited accessibility of climate data.

Based on empirical observations, Köppen (1900) established a climate classification system which uses monthly temperature and precipitation to define boundaries of different climate types around the world. Since its inception, this system has been further developed (e.g. Köppen and Geiger, 1930; Stern et al., 2000) and widely used by geographers and climatologists around the world. The popularity of the system lies in its power in linking climate and natural vegetation (Bailey, 2009), and in its simplicity (Wilcock, 1968). Although there have been many efforts from German scientists to find alternative ways to classify the climate, the Köppen system remains one of the most widely used climate classification systems (e.g. Domroes, 2003).

Most applications of the Köppen system are concerned with mapping the geographic distribution of the world's climate or vegetation with the help of a long term climate dataset. Depending on the data used, the mappings may have different details and qualities for such a stationary description of the world's climate. Recently, Kottek et al. (2006) provided a well documented and easily accessible update of the world climate classification map using gridded climate data during 1951–2000. Taking a station-based approach in terms of the input climate data, Peel et al. (2007) presented another update of the Köppen climate classification scheme by using long-term station records of monthly precipitation and temperature from the Global Historical Climatology Network version 2 (GHCN2) dataset (Peterson and Vose, 1997). This update only gives long term averaged climate distributions over the whole period covered by the GHCN2 dataset.

Although most stations in the GHCN2 dataset have data that cover a period much longer than 30 years, some stations have data much shorter than 30 years. Peel et al. (2007) used all stations with at least 30 years data in their analysis, which means that the climate types in different parts of the world may represent different climates over different time periods. This is especially true for transitional zones between two different climate types.

Climate change can cause changes in the spatial extent of a climate type and plant community (e.g. Elmendorf, 2012). This kind of changes may also be reflected by changes in the areas occupied by the Köppen climate types (Wang and Overland, 2004). As an example, Diaz and Eischeid (2007) compared areas of the climate type “alpine tundra” over the 1901–1930 period with that of 1987–2006 for the mountainous western United States. They found that this type has a dramatic decline (~73%), indicating the regional warming and its possible effect on the ecosystem.

Owing to the fixed and objective set of predefined rules, the Köppen system can be easily applied in places where the necessary climate information is available. Because of the objectivity, the system