CONCEPTUAL FRAMEWORK FOR CHANGES OF EXTREMES OF THE HYDROLOGICAL CYCLE WITH CLIMATE CHANGE

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Abstract. A physically based conceptual framework is put forward that explains why an increase in heavy precipitation events should be a primary manifestation of the climate change that accompanies increases in greenhouse gases in the atmosphere. Increased concentrations of greenhouse gases in the atmosphere increase downwelling infrared radiation, and this global heating at the surface not only acts to increase temperatures but also increases evaporation which enhances the atmospheric moisture content. Consequently all weather systems, ranging from individual clouds and thunderstorms to extratropical cyclones, which feed on the available moisture through storm-scale moisture convergence, are likely to produce correspondingly enhanced precipitation rates. Increases in heavy rainfall at the expense of more moderate rainfall are the consequence along with increased runoff and risk of flooding. However, because of constraints in the surface energy budget, there are also implications for the frequency and/or efficiency of precipitation. It follows that increased attention should be given to trends in atmospheric moisture content, and datasets on hourly precipitation rates and frequency need to be developed and analyzed as well as total accumulation.

1. Introduction

The character of precipitation, with highly variable rain rates and enormous spatial variability, makes simply determining mean precipitation difficult let alone how it will change as the climate changes. For instance, a detailed examination of spatial structure of daily precipitation amounts by Osborne and Hulme (1997) shows that in Europe the average separation distance between climate stations where the correlation falls to 0.5 is about 150 km in summer and 200 km in winter — the more convective nature of summer precipitation is responsible for the difference. In addition, this complexity also makes it difficult to model precipitation reliably, as many of the processes of importance can not be resolved by the model grid (typically 200 km) and so sub-grid-scale processes have to be parameterized. Yet there are some overall aspects of precipitation related to the hydrological

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cycle that can be clarified and for which expectations as to how they will change are physically based. Here the processes involved that influence precipitation and link it to evaporation and heating are outlined along with the importance of dealing not just with accumulated amounts, but also precipitation rates (or intensity) and precipitation frequency. The relative roles of moisture stored in the atmosphere, its advection, and resupply have been examined in detail in Trenberth (1998), and only a brief summary of those aspects are included here.

The term "global warming" is often taken to refer to global increases in temperature accompanying the increases in greenhouse gases in the atmosphere. In fact it should refer to the additional global heating (sometimes referred to as radiative forcing, e.g., by the IPCC (1996)) arising from the increased concentrations of greenhouse gases, such as carbon dioxide, in the atmosphere. Increases in greenhouse gases in the atmosphere produce global warming through an increase in downwelling infrared radiation, and thus not only increase surface temperatures but also enhance the hydrological cycle, as much of the heating at the surface goes into evaporating surface moisture. This occurs in all climate models regardless of feedbacks, although the magnitude varies substantially (see section 3).

Temperature increases signify that the water-holding capacity of the atmosphere increases and, together with enhanced evaporation, the actual atmospheric moisture should increase, as is observed to be happening in many places (Hense et al., 1988; Gaffen et al., 1991; Ross and Elliott, 1996; Zhai and Eskridge, 1997). Of course, enhanced evaporation depends upon the availability of sufficient surface moisture and over land, this depends on the existing climate. However, it follows that naturally-occurring droughts are likely to be exacerbated by enhanced potential evapotranspiration. Further, globally there must be an increase in precipitation to balance the enhanced evaporation but the processes by which precipitation is altered locally are not well understood.

It is shown that precipitating systems of all kinds feed mostly on the moisture already in the atmosphere at the time the system develops, and precipitation occurs through convergence of available moisture on the scale of the system. Hence, the atmospheric moisture content directly affects rainfall and snowfall rates, but not so clearly the precipitation frequency and thus total precipitation, at least locally. Thus, it is argued that global warming leads to increased moisture content of the atmosphere which in turn favors stronger rainfall events, as is observed to be happening in many parts of the world (Karl et al., 1995), thus increasing risk of flooding. It is further argued that one reason why increases in rainfall should be spotty is because of mismatches in the rates of rainfall versus evaporation. The arguments assembled here imply the need for new observations, datasets,