Journal of Hydrology 511 (2014) 350–358

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Attribution of floods in the Okavango basin, Southern Africa

Piotr Wolski [a,b,*], Dáithí Stone [a,c], Mark Tadross [a,d], Michael Wehner [c], Bruce Hewitson [a]

[a] Climate System Analysis Group, University of Cape Town, Private Bag X3, 7701 Rondebosch, South Africa
[b] Okavango Research Institute, University of Botswana, Private Bag 285, Maun, Botswana
[c] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Mail Stop 50F-1650, Berkeley, CA 94720, USA
[d] Green-LECRDS, United Nations Development Programme – GEF, NY, USA

ARTICLE INFO

Article history:
Received 3 February 2013
Received in revised form 16 October 2013
Accepted 25 January 2014
Available online 2 February 2014
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Michael Bruen, Associate Editor

Keywords:
Anthropogenic climate change
Attribution
Flood
Okavango

SUMMARY

In the charismatic wetlands of the Okavango Delta, Botswana, the annual floods of 2009–2011 reached magnitudes last seen 20–30 years ago, considerably affecting life of local populations and the economically important tourism industry. In this study, we analyse results from an attribution modelling system designed to examine how anthropogenic greenhouse gas emissions have contributed to weather and flood risk in our current climate. The system is based on comparison of real world climate and hydrological simulations with parallel counterfactual simulations of the climate and hydrological responses under conditions that might have been had human activities not emitted greenhouse gases. The analyses allow us to address the question of whether anthropogenic climate change contributed to increasing the risk of these high flood events in the Okavango system.

Results show that the probability of occurrence of high floods during 2009–2011 in the current climate is likely lower than it would have been in a climate without anthropogenic greenhouse gases. This result is robust across the two climate models and various data processing procedures, although the exact figures for the associated decrease in risk differ. Results also differ between the three years examined, indicating that the "time-slice" method used here needs to be applied to multiple years in order to accurately estimate the contribution of emissions to current risk. Simple sensitivity analyses indicate that the reduction in flood risk is attributed to higher temperatures (and thus evaporation) in the current world, with little difference in the analysed domain's rainfall simulated in the two scenarios.

1. Introduction

The Okavango basin in southern central Africa (Fig. 1) has experienced high floods in 2009–2011, with considerable economic and societal impacts: villages and houses were flooded, bridges closed or washed away, water and electricity supply interrupted. These events coincided in time with much more destructive floods in Pakistan and elsewhere, and a question arose: to what extent were the events of 2009–2011 caused by climate change driven by greenhouse gas emissions, with the implication on whether events of similar or higher magnitude should be expected to occur (more frequently) in the future? This question provided motivation for this study.

There are a number of ways this question can be posed in a scientific format (Otto et al., 2012; Stott et al., 2013). In this paper we adopt the "risk-based" approach, which examines how the probability of exceeding a threshold has been altered due to emissions (Stone and Allen, 2005). This approach was first applied by Stott et al. (2004) in a study of the hot southern European summer of 2003 by examining how the frequency of hot summers differed in the 2003 era between simulations of an atmosphere–ocean climate model with and without anthropogenic drivers of climate change. However, Pall et al. (2011) noted that such an approach cannot be applied to very rare events where assumptions behind statistical extrapolation may not be justifiable (because large ensembles are infeasible with atmosphere–ocean climate models), nor to events which occur on small spatial scales or require high-resolution modelling (because high spatial resolution is infeasible with atmosphere–ocean climate models). In the study of 2000 UK floods, Pall et al. (2011) and Kay et al. (2011) adopted a time-slice modelling approach using an atmospheric global circulation model (AGCM) only. This approach is limited to events for which oceanic dynamics play at most a minor role (e.g. for which El Niño events have little influence), for it is not able to account for possible influence of anthropogenic warming on frequency and

* Corresponding author at: Climate System Analysis Group, University of Cape Town, Private Bag X3, 7701 Rondebosch, South Africa. Tel.: +27 (021) 650 2784; fax: +27 (021) 650 5773.

E-mail address: wolski@csag.uct.ac.za (P. Wolski).

http://dx.doi.org/10.1016/j.jhydrol.2014.01.055
0022-1694/

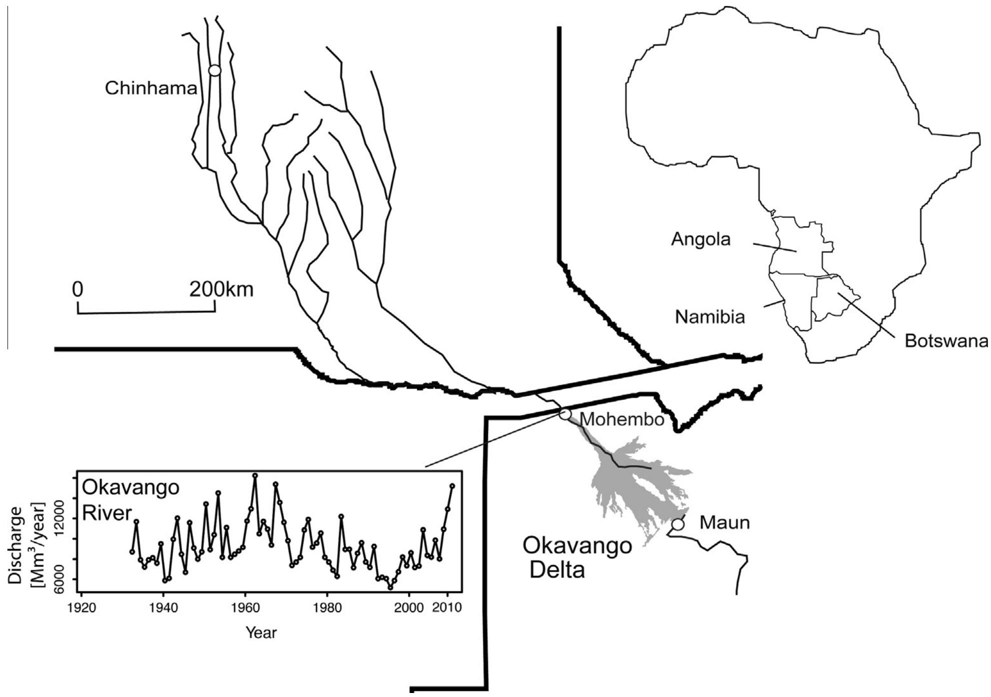

Fig. 1. The Okavango basin.

timing of dynamic sea surface temperature anomalies. In this approach, assessment of risk of occurrence of an event based on ensemble simulations of an AGCM of the climate we are experiencing are compared with simulations for the climate we might have experienced without emissions. For the former, an initial condition ensemble of the AGCM is run with observed ocean temperatures for the given year and external drivers on the climate system (such as greenhouse gas concentrations); for the latter, the greenhouse gas concentrations are reduced and the same ocean temperatures are used except with an estimate of the warming attributable to emissions removed. The advantage of this approach is that it allows much larger ensembles of simulations run at higher spatial resolution than would otherwise be possible. Here, we use this approach to investigate the risk of large annual floods in the Okavango system.

1.1. Study area

The Okavango basin is located in central Southern Africa and extends across a climatic gradient from a high rainfall zone in the highlands of Angola, towards the semi-arid north of Botswana. The system is broadly divided into two parts: the upper, having a character of a typical river catchment, runoff from which contributes 2/3rd of water balance inputs to the lower part; and the lower part consisting of the Okavango Delta wetlands and terminal rivers, where the water's ultimate sink is evaporation to the atmosphere. The system is relatively pristine, partly due to conservation-supporting wildlife-oriented eco-tourism in Botswana, poor soils providing little support for extensive agriculture and a civil war ravaging the area of the catchment in the 1970–2000s. In recent years, however, the system has been subject to rapid development, with current population estimated at 0.5 million.

The Okavango basin is characterised by relatively smooth regional spatial gradients in rainfall and temperature, which results primarily from the lack of significant topographic relief. The climate of the basin is affected by the interaction of three air masses: cold dry air from the southern Atlantic, warm moist air from the southern Indian Ocean and warm moist air from the equatorial Atlantic, and influenced by the movement of the Inter-tropical Convergence Zone (ITCZ) and the Zaire Air Boundary (ZAB). The rainy season occurs during the austral summer (October–April) and accounts for 95% of total annual rainfall. The annual flood takes the form of a mono-modal (only in higher rainfall years bimodal) event, with flood peak progressively delayed in the downstream direction, such that in terminal parts of the system it occurs 6–7 months after the middle of the rainy season.

2. Methods

2.1. General

This study follows the attribution method developed by Pall et al. (2011). In this method a global atmospheric model (AGCM) is run in two modes: "real world" and "non-GHG world". The simulations in the "real world" mode are based on the observed boundary conditions to the atmospheric system, i.e. observed variations in sea-surface temperature (SST), and observed atmospheric greenhouse gases concentrations. In the "non-GHG world" counterfactual mode, these are modified to reflect conditions that might have existed had human activities never emitted greenhouse gases. This involves decreasing the greenhouse gas concentrations in the model, as well as cooling the ocean surface temperatures by a spatially- and seasonally-varying estimate of how much the ocean has warmed due to the emissions. This estimate is obtained, following the methodology established by Stott et al. (2006) and Pall et al. (2011), from simulations of the HadCM3 climate model driven only with historical variations in greenhouse gases, other anthropogenic forcings and natural forcings. The magnitude of the SST responses to each of those forcing sets is estimated by regressing the corresponding modelled SST patterns against the observed SST. The attributable ocean warming is then the linear combination of these patterns. In the attribution GCM runs, uncertainty of the initial state of the climate system and effects arising from internal variability of the atmosphere and land surface systems are accounted