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Original paper

Hydro-climatic variability and forest fires in Mexico's northern temperate forests

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Resumen

Los cambios globales en las temperaturas pueden estar modificando el ciclo hidrológico de las cuencas forestales. Este reporte tuvo como objetivos estimar las variables del ciclo hidrológico interceptación, I, la evapotranspiración actual, E, y potencial, Et, la escorrentía, Q, y los cambios en el contenido del agua del suelo, θ; así como evaluar si las variables del ciclo hidrológico están presentando tendencias u oscilaciones que pudieran estar asociadas al calentamiento global en cuencas forestales del centro de Durango, México. El procedimiento del balance de masas sirvió para calcular las variables diarias del ciclo hidrológico con el uso de los sub-modelos de I y Et para evaluar finalmente la Q y θ. Los datos se sujetaron a un análisis de regresión y a técnicas auto-regresivas y de promedios móviles, ARIMA, para evaluar la significancia estadística de las tendencias. El valor acumulado del valor estándar de z magnificó y los modelos ARIMA proyectaron estadísticamente bien las oscilaciones mensuales y anuales de las variables del ciclo hidrológico. Las ecuaciones de regresión y las tendencias de los modelos ARIMA mostraron que las variables mensuales y anuales de P, I, E y Et, Q, y θ no siguen tendencias claras en tiempo con significancia estadística; éstas a su vez, siguen oscilaciones que pudieron ser predichas adecuadamente con modelos ARIMA. Se encontró una asociación consistente ($p \leq 0.05$) entre θ y el número de incendios y la superficie forestal incendiada a pesar de las diferentes escalas en las cuales se evaluaron estas variables. El análisis muestra que el calentamiento global está contribuyendo a incrementar la variabilidad hidrológica estacional al aumentar los pulsos de sequía y humedad en tiempo. Sin embargo, se requiere de investigaciones adicionales para probar esta hipótesis con el uso de series de tiempo más largas, con otro tipo de técnicas estadísticas y con la incorporación de otras variables en el análisis.

Palabras clave: análisis de regresión, modelos auto-regresivos con promedios móviles, precipitación, interceptación, evapotranspiración, escorrentía y contenido del agua del suelo, incendios forestales, plagas y enfermedades.

Abstract

Global warming is likely modifying the hydrological cycle of forested watersheds. This report set as objectives to: a) assess the hydrological variables interception loss, I, potential and actual evapo-transpiration, E, Et, runoff, Q, and soil moisture content, θ; b) evaluate whether these variables are presenting consistent trends or oscillations that can be associated to global warming or climate variability; and c) relate θ to the number of wildfires and the burned area in Durango, Mexico. A mass balance approach estimated daily variables of the water cycle using sub-models for I and Et to calculate Q and θ for a time series from 1945 to 2007. Regression and auto-regressive and moving averaging (ARIMA) techniques evaluated the statistical significance of trends. The cumulative standardized z value magnified and ARIMA models projected statistically similar monthly and annual time series data of all variables of the water cycle. Regression analysis and ARIMA models showed monthly and annual P, I, E, and Et, Q, and θ do not follow consistent up or downward linear tendencies over time with statistical significance; they rather follow oscillations that could be adequately predicted by ARIMA models ($r^2 \geq 0.70$). There was a consistent statistical association ($p \leq 0.05$) of θ with the number of wildfires and the area burned regardless of the different spatial scales used in evaluating these variables. The analysis shows seasonal variability is increasing over time as magnifying pulses of dryness and wetness, which may be the response of the hydrological cycle to climate change. Further research must center on using longer time series data, testing seasonal variability with additional statistical analysis, and incorporating new variables in the analysis.

Key words: regression analysis, autoregressive moving average models, precipitation, interception loss, evpo-transpiration, runoff, soil moisture content; forests fires, pests and diseases.

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Introduction

Global warming by the continued build up of greenhouse gasses, GHG, in the atmosphere is predicted to lead to significant changes in climate (Ritter, 2009). The IPCC (2001; 2009) reported how Earth temperature has increased in the last century in contrast to the previous 200 years. Transient increasing temperatures of 0.6-0.8^{0}C in the last 150 years may already be magnifying climate as Held and Sodden (2006) predicted robust hydrological responses to global warming by additional increases of GHG in the atmosphere. In the present, instrumental records show increased precipitation of 0.5 to 1.0% per decade in much of the Northern Hemisphere mid and high latitudes; in contrast to the subtropics where rainfall has decreased during the 20th Century by 0.3% per decade (Folland *et al*., 2002).

Forests, as oceans regulate and buffer climate changes at the expenses of increased pressure. The world forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition. The complex and non-linear forest-atmosphere interactions are issues widely studied since these connections can be dampened or amplified (Bonan, 2008). The effect of regional warming and consequent increases in water deficits as likely contributors to the pervasive boost in tree mortality rates of forests of western United States is one issue of these interactions recently reported (van Mantgem *et al*., 2009). Recent drought-related and warming has also been implicated as contributing to pulses or episodes of regional forest dieback such as those caused by bark beetle outbreaks in southwestern North America (Breshears *et al*., 2005; Raffa *et al*., 2008) and northern Mexico (SEMARNAT, 2005). Increased pulses of wildfire activity in the Rocky Mountains temperate forests has also been associated to increased spring and summer temperatures (Westerling *et al*., 2006).

Forest fuels, heat and oxygen are necessary for a fire to burn. Ground (organic soil, duff, and moss), slash (litter), living trees and miscellaneous (grass) are classifications of forest fuels (Reinhardt and Crookston, 2003). Drought desiccates all kinds of fuels; living fuels, large dead fuels, deep duff layers, and organic soils and it has an obvious effect on wildfires; spread rates and fire intensities. Intense wildfires occur when drought and frosts happen continuously since these perturbations add large amounts of young foliage onto the soil; and the burn probability increased with the presence of young fuels in Portugal (Fernandes *et al*., 2012).

In northern Mexico, increased tree mortality rates have not been documented so far. However, significant pulses of wildfire events have been recorded during the last three decades (SEMARNAT, 2005). Although these pulses of tree mortality have been associated to drought elsewhere, there is no information on the drought episode itself, its magnitude, frequency, and how it could be related to global or regional warming. Large wildfires in the region are believed to have increased in extent, frequency, magnitude and duration due to the likely effect of land-tenure changes and the suppression of frequent light fires (Fulé and Covington, 1997; Drury and Veblen, 2008) although the potential effect of global warming cannot be ruled out. Consensus has been that increasing temperatures causing soil dryness beyond normal thresholds are responsible for the pervasive tree mortality rates as well as for tree mortality by wildfire activity. However no evidence of soil dryness and its magnitude has ever been reported.

In spite of this information, little research has gone toward determining whether environmental changes are contributing to chronic, long-term shifts in variables of the hydrological cycle as an aid to quantify water deficits in Mexico's northern temperate forests in order to assess global warming impacts. Neither has the water deficit issue been documented in the region and associated to global warming-related events. Since forests regulate the hydrological cycle by redistributing precipitation; climatological drought reported as a reduction of precipitation in contrast to its mean value is different than soil water deficit that is the most important variable for tree survival and dieback. Therefore, this report aimed at: a) evaluating the variables of the hydrological cycle daily interception loss, potential and actual evpotranspiration, runoff and soil moisture content; b) assessing whether the mean values of these variables in addition to instrumental precipitation and pan evaporation are transiently changing over time; c) relating large-scale climatic events to wildfires, and d) associating assessments of soil moisture content to wildfires in a forested watershed near El Salto, Durango, Mexico.

The hypothesis tested was that variables of the hydrological cycle do not follow consistent trends in dryness or water deficits. If the null hypothesis is rejected, then these findings suggest forests of Northern Mexico are under increasing drought-related stress that could lead to the potential increased continuous mortality rates as those observed in western North America by van Mantgem *et al*. (2009). The acceptance of the null hypothesis would lead to the conclusion that cycles or oscillations in hydrological variables cause forest stress that produce pulses of tree mortality such as those noted by increased wildfire activity reported by Breshears *et al*. (2005) in southwestern U.S.A as well as those observed for