CLIMATE IMPACTS OF LAND DEGRADATION IN THE WORLD'S DRYLANDS

R. C. Balling, Jr.
Office of Climatology, Arizona State University, USA

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Summary

Drylands throughout the world have always undergone periods of degradation due to naturally-occurring fluctuations in climate. However, over the past century, the human population in drylands has grown exponentially and the resulting pressures on the landscape have exacerbated various desertification processes, particularly in Africa. The degradation of drylands has led to changes in local, regional, and even global climate. In the driest areas, increased albedo associated with degradation leads to cooling which can stabilize the atmosphere and reduce precipitation. In other drylands, desertification reduces soil moisture, and this change in surface hydrology leads to a warming that accelerates evapotranspiration and further reduces soil moisture levels. The nations of the world recognize the severity of the desertification issue, and most have ratified the "United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa".

1. Introduction

Even before a time of any human activity, drylands of the world were degraded periodically due to natural causes, and interactions occurred between desertification and climate. However, with literally one billion people now living in drylands, the effects of human-induced desertification are more pronounced today than at any time in the Earth's history. More of the world's drylands are being degraded more than ever before, and we are now witnessing a complicated set of feedbacks between dryland surface conditions and the local, regional and global atmosphere. While a great deal of attention is being placed on how anthropogenic climate changes (e.g. enhanced greenhouse effect) may alter dryland areas, the ongoing land degradation in the drylands is having a profound impact on local and regional climate conditions. The nations of the world clearly recognize the overarching importance of the desertification issue, including its direct link to climate change, and they recently adopted a convention to combat desertification.

The focus of the scientific community on desertification and climate can be traced, in substantial part, to a fluctuation in climate that occurred this century in Sahelian Africa. For nearly five decades, precipitation levels in this region remained relatively high, allowing local inhabitants to sustain or even increase crop yields, cattle herds, and human population levels. However, in the early 1960s, the precipitation levels fell in the region (Figure 1), and by the early 1970s, the human and ecological tragedy of the Sahel was a serious matter receiving considerable attention worldwide.

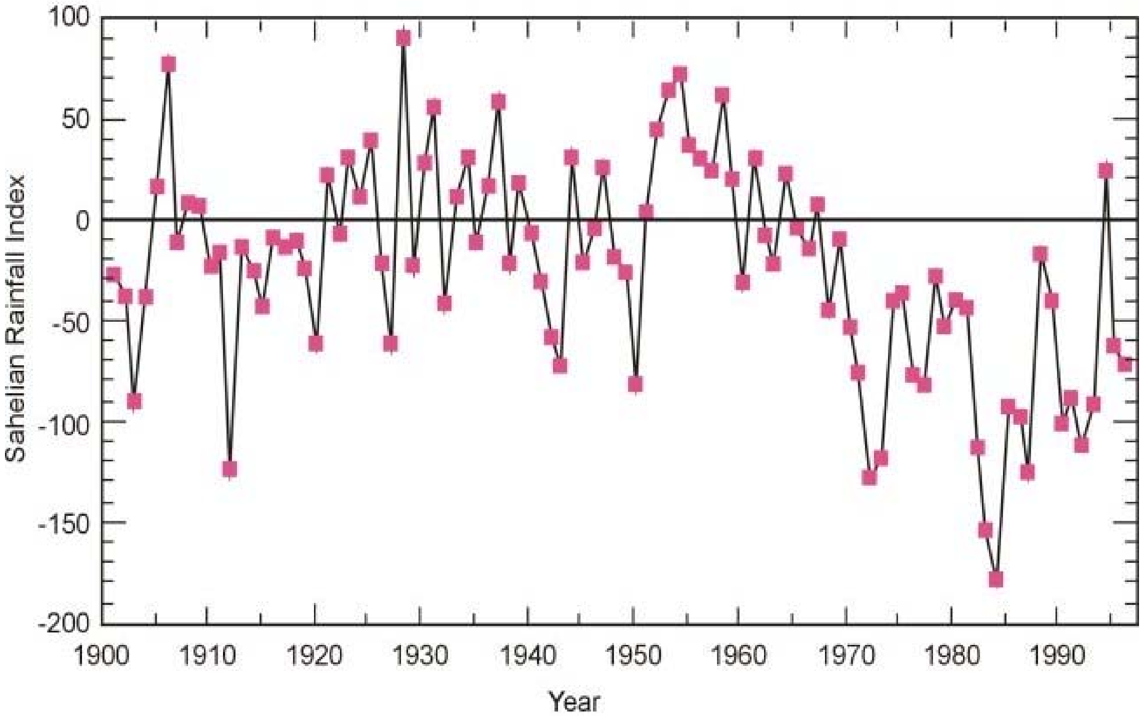

Figure 1: The precipitation levels fell in the region

In one of the first attempts to explain the climate "failure" in the Sahel, noted climatologist Reid Bryson proposed that pollution in the Northern Hemisphere was creating a "human volcano," causing a cooling at a hemispheric level. In Bryson's view, that cooling was causing a southerly migration of the northern circumpolar vortex (the jet stream), as well as a southerly migration of the subtropical high-pressure belt. This pattern would restrict the ability of the rain-producing intertropical convergence zone to move northward into the Sahel, and lower precipitation levels during the summertime rainy season would result. Bryson's argument placed the blame for the tragic Sahelian drought on industrial activity in the developed nations of the Northern Hemisphere.

Shortly afterwards, others began presenting the argument that overgrazing in the Sahel could increase both the surface albedo (reflectivity) and the soil compaction leading to an increase in surface runoff and a reduction in available soil moisture. The "expanding Sahara" could be the result of local activities and not the industrialization of the midlatitudes of the Northern Hemisphere. Others argued that overgrazing in dryland areas could increase albedo, reduce surface temperatures and near-surface air temperatures, stabilize the atmosphere, and reduce local rainfall levels. Although supporting measurements for this claim came from Sinai, the arguments seemed transferable to the Sahel.

A landmark article was published in 1975 by Jule Charney in which he presented a complex biogeophysical feedback model of desertification in the Sahel. The work received considerable attention in the popular press and scientific community, and the basic ideas put forth in this and related articles became known as the "Charney hypothesis." Charney and his associates developed a physically-based numerical representation of a biogeophysical feedback mechanism that could initiate and/or reinforce drought in sub-Saharan Africa as a result of vegetation depletion. In their numerical model, the degradation of vegetation by natural or anthropogenic causes would increase the surface albedo, decrease the net shortwave radiation, decrease the surface temperature, and increase the relative emission on longwave radiation due to a slight increase in the emissivity of the surface. These processes would reduce the net radiation at the surface, leaving less energy for warming the surface and the overlying atmosphere. Changes in heat transfer would stabilize the lower layers of the atmosphere and suppress local convection. The reduction in local rainfall would further stress the remaining vegetation, thereby, initiating a positive biogeophysical feedback.

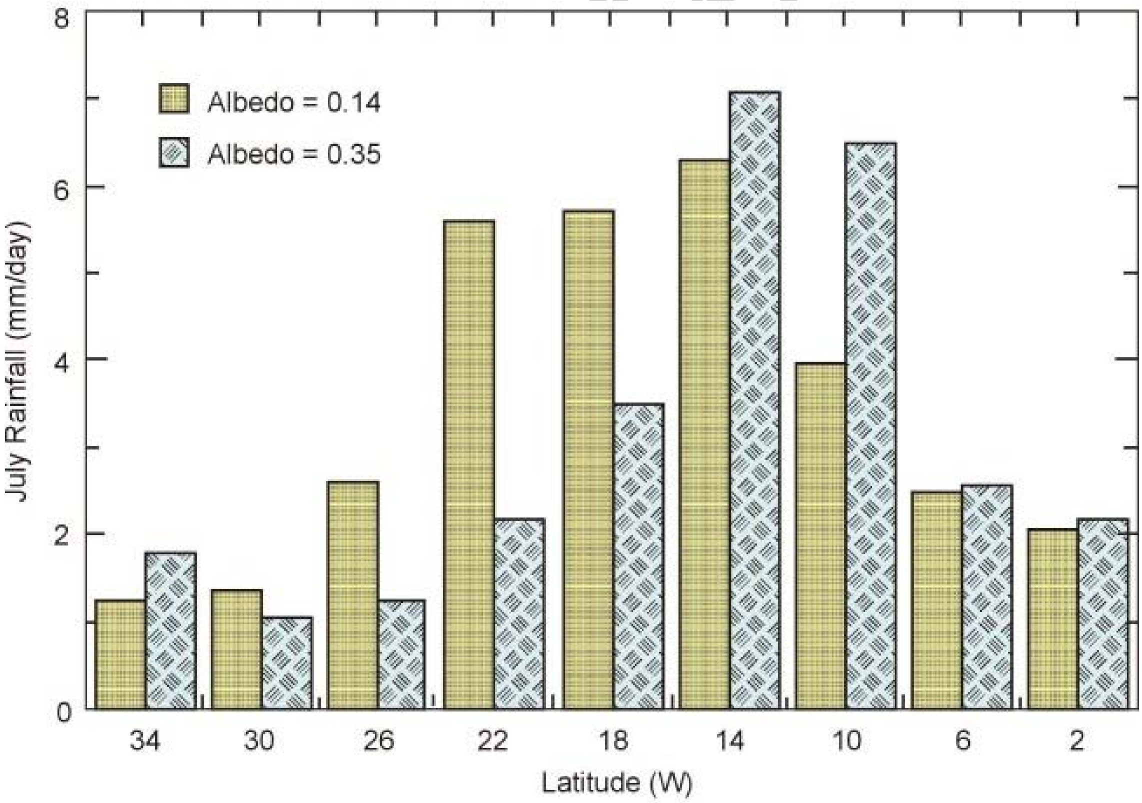

Figure 2: Albedo effect

When Charney and his colleagues increased Sahelian albedo from 0.14 to 0.35, their model showed a southerly shift of the Intertropical Convergence Zone of several degrees of latitude in the Sahel during the normally rainy summer season. In some latitudinal bands, rainfall decreased by more than 50 percent due to this albedo effect (Figure 2). Within a few years, similar results were being reported by other investigators and for other dryland areas of the world.

However, despite the support from a variety of modeling studies, the Charney hypothesis was challenged immediately on theoretical and empirical grounds. Some scientists argued that removal of vegetation in drylands would lower soil moisture levels, decrease radiant energy used to evaporate and transpire water, and increase surface and near-surface temperatures. In areas where vegetation was reduced, the local surface and near-surface temperatures would increase, not decrease as proposed in the Charney hypothesis. Hydrological processes, not albedo effects, would dominate the surface energy balance changes associated with vegetation removal in most dryland environments.

The debate surrounding the Charney hypothesis continues to this day, but fundamentally, several important interrelated questions may be raised concerning climate change and desertification. Firstly, there is the question of whether desertification in drylands actually changes the local climate. As we see in the Charney debate, desertification may produce feedbacks that lead to warming or cooling of the surface and the near-surface air. Secondly, there is a question regarding whether desertification in drylands impacts regional, hemispheric, or even global climatic conditions? While the literature is dominated by research on how the buildup of greenhouse gases may alter future climates, including those of dryland areas, there remains a substantial literature on how land degradation in drylands has an impact on the climate system. And while the greenhouse issue is certainly an important one, understanding the impact of desertification on climate is essential in determining future climate change in dryland areas of the world.

2. Local and Regional Climate Changes Caused by Desertification

2.1 Simulation Studies

Approximately 100 articles have appeared in the professional literature of the 1980s and 1990s dealing directly with questions regarding the Charney hypothesis. Many of these articles describe numerical modeling efforts to improve upon the simulation work first performed by Charney. In general, modeling efforts have supported Charney's work; however, most of the research has shown that soil moisture is at least as important as any realistic changes to surface albedos in altering local climate.

The 1990s was a decade of substantial theoretical research on this issue. Scientists have linked a detailed local surface energy balance model to a global climate model and found that Sahelian-area temperature and precipitation patterns are very sensitive to soil moisture levels in the region. Others have used a general circulation mode and found that desertification leads to: a) a reduction in moisture flux and rainfall in the Sahel; b) an increase in moisture flux and precipitation to the south of the Sahel; c) a reduction in the strength of the tropical easterly jet; d) a strengthening of the African easterly jet; and

e) a decrease in the intensity of easterly waves in the region. In a somewhat opposite approach, researchers have shown that afforestation could increase local precipitation in the Sahel. The use of even more sophisticated general circulation models has revealed that in the Sahel, land degradation would cause both an increase in local temperatures and a decrease in rainfall levels. The results are linked to changes in local latent heat fluxes, moisture flux convergence, and subsidence in the atmosphere; the radioactive effects of albedo changes seem secondary in causing a reduction in precipitation.

Other recent research incorporates an atmospheric model coupled with a simple land surface scheme to investigate the sensitivity of West African monsoons to perturbations in the meridional distribution of vegetation. The results of the numerical experiments demonstrate that West African monsoons and therefore rainfall distribution depend critically on the location of the vegetation perturbations. Changes in vegetation cover along the border between the Sahara desert and West Africa, which was assumed to represent the end result of desertification processes, would have only a minor impact on the simulated monsoon circulation. However, coastal deforestation may cause the collapse of the monsoon circulation and have a dramatic impact on the regional rainfall. Human impacts on vegetation influenced climate, but deforestation, and not desertification, dominated the feedbacks.

The role of vegetation disruption on local climates usually involves perturbations to the surface energy balance, which in turn alter energy, and moisture fluxes in the lower atmosphere. However, once the vegetation is depleted, increased dust loads further influence the local atmosphere. The role of locally-generated dust in altering the local climate remains a significant issue in establishing the linkage between land degradation in drylands and its impact on local climate. However, the literature on the subject is inconclusive, although most modeling efforts lead to a conclusion that increased mineral aerosol loads will cool the surface, warm the lower atmosphere, stabilize the atmosphere, and reduce local precipitation.

The Sahel does not represent all drylands, and therefore, investigators have run numerical models for other dryland areas of the world. Generally, the results are the same, but for a variety of reasons, the Sahel appears to be in a particularly sensitive position allowing even small changes at the surface to create substantial changes in local temperature and precipitation. Charney may have provided us some very useful ideas about desertification, local climate change, and feedbacks to the desertification processes. The many other scientists who continued to run simulation models regarding this issue have shown that the desertification-climate linkage is far more complex than that which Charney originally proposed.

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Biographical Sketch

Dr. Robert C. Balling, Jr. is currently the Director of the Office of Climatology and Professor in the Department of Geography at Arizona State University. He received a Ph.D. in geography from the University of Oklahoma in 1979. Prior to accepting a position in Arizona, he was a faculty member in the climatology program at the University of Nebraska. Throughout the 1990s, Dr. Balling has been involved in a variety of interrelated climatological issues. He has published 100 articles in the professional scientific literature, received over $3 000 000 in research grants, presented lectures throughout the United States and more than a dozen foreign countries, and appeared in a number of scientific documentaries and news features. In 1996, Dr. Balling co-authored a book entitled *Interactions of Desertification and Climate* published by the United Nations Environment Program and the World Meteorological Organization.