Land Use Change Study in RegCM3 to See the Effect of HKH Glaciers Melt over Agriculture Areas of Pakistan

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Abstract

In the era of global warming, how long Himalayan glaciers will survive is an issue of concern but equally important concern is impact of deglaciation on the regional climate for adaptation and mitigation. Therefore, to study impact of Himalayan de-glaciation on the regional climate and agriculture of Pakistan, a strive is made to analyze glacier retreat or total elimination of glaciers from the Northern Areas of Pakistan, by using the facility of Regional Climate Model (RegCM3). Glacier class in Biosphere-Atmosphere Transfer Scheme (BATS) classification of Land-use is replaced by the Tundra class to see potential changes in different climatic zones of the country. Model simulation records significant increase (2-6 °C) in surface air temperatures of Northern Areas (especially formally glaciated areas) of Pakistan. Model has also simulated change in total precipitation and convective precipitation patterns in the whole Pakistan, July precipitation in monsoon is simulated with significant difference (decrease) over North- east Punjab, where as, increase in the costal areas of Sindh is forsee. However, decrease in Balochistan with slight increase in elevated area such as Quetta region is evident from model output. Also the convective precipitation is simulated showing increasing trend in Northern Pakistan. Such differences in wide area depict a significant influence of landuse change especially deglaciation on the climatic features of the neighboring regions.

Key words: Glaciers melting, RegCM3, BATS, Land use change, Pakistan, Deglaciation

Introduction

Global warming due to anthropogenic activities in this era of rapid development is imposing the terrifying threat to the environment. Climate change due to global warming is evident on all over the globe. Biodiversity of the several regions is changing, fauna and flora is either disappearing or migrating else where to survive, but in some area change is so rapid that it is not possible for many species to migrate or no other suitable habitat is available to them, for instance, Polar ice is melting and its area is reducing but no alternate habitat is available to bio diversity of the area. Similarly flora and fauna is shifting toward high altitudes in mountainous area of mid and low latitudes.

As, Glaciers at poles or in mountains of mid and low latitudes are retreating and loosing their mass due to global warming without discrimination, Himalays are no exception. Water resources of subcontinent (Pakistan, India, Nepal etc) will be severely endangered if glacier melting continues with current speed, in consequence, water will be available only seasonally or in rainy season (monsoon), as temperature is already rising in northern area of Pakistan (Rasul and Chaudhry, 2006) and extreme events of precipitation are also reported to be increasing in trend. Northern areas of Pakistan will suffer due to flash flood caused by rapid snow melting. Although there are studies that glacier in Karakurum are not retreating due to decrease in diurnal variation of temperature (Fowler, et, al, 2005), but temperature rise will ultimately affect Karakurum's glacier in future, as well (Rasul, et al., 2008).

Effect of snow cover has significant role in climate of regions (Cohan and Rind, 1990; Namias, 1985; Vavrus, 2007) Eurasian Snow cover effects the monsoon (Barnett, et, all. 1988) in Pakistan and India, as well. Scientists are also working on glacier models to evaluate the retreat in different future scenarios (Shehneeberger, et al., 2001; Oerlemans, et al., 1998.). Therefore, identification of possible change on regional climate due to elimination of glaciers is a matter of deep concern.

Glaciers are among most vulnerable landscape, of globe, to climate change. Pakistan is among a few countries in world having high mountain (K2, 8611 meter). Further Northern Pakistan is host to top 8 mountains out of world's highest 10. this area is a big repository i.e. above 5000 small and large, of glaciers, feeding the main Indus basin. Second and third longest glacier (Siachen 74 km and Batura 64

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km) outside poles are in the Karakurum range of Pakistan. Scientists are working to identify the impact of global warming on glaciers of poles and continents, but on other hand, it is equally serious to discuss the impact of glaciers on climate, especially in case of total elimination of glaciers. For evaluation of impact of Himalayan deglaciation, the application of Climate Models is highly suitable, as they have ability to simulate future climate under a variety of variation in input.

As climate is sensitive to biosphere and its interaction with atmosphere (Henderson- Sellers, 1990, 1992; Pitman, 1994; Adelmo, 1997; Omer, 2000), therefore, climate model incorporates the different Biosphere-Atmosphere Transform Schemes. Model used in this study is RegCM3 with Biosphere-Atmosphere Transform Scheme BATS1e (Dickinson et al., 1993) which is one of the tested, reliable, (Menglin 1996; Adelmo, 1997; White, 1998; Omer, 2000) and modern scheme. Glacier class in BATS classification is replaced by tundra class as it is the nearest of Glacier class if ice deposits are depleted or totally eliminated.

Data

European Center for Medium Range Weather Forecasting (ECMWF) data set ERA-40 (ECMWF Re-analyzed 40 years) was used in the model simulation. The year 1993 was selected for simulation because Land use classification of BATS was prepared for 1992-93 (from NOAA satellite). Hence, it was more realistic approach to use the climate/weather data (ERA-40) for the same year.

Methodology

To simulate the effect of glacier elimination on climate of Pakistan, a Regional Climate Model (RegCM3) is used in this study.

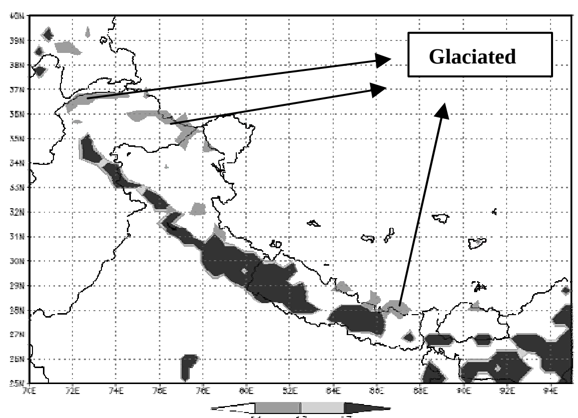

Figure 1: Showing the Glacier class in domain/area of study, used for the first simulation

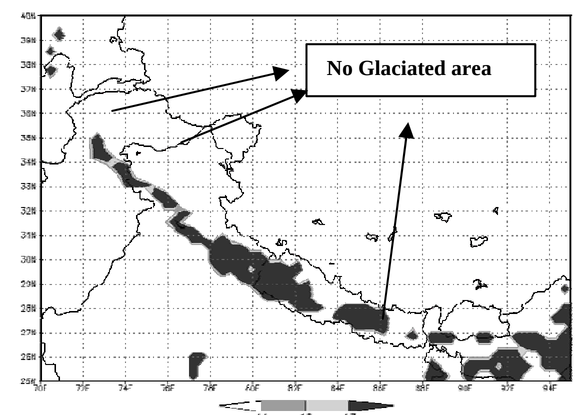

Figure 2: Showing the Replaced/modified Glacier class with Tundra class in domain/area of study, used for the second simulation

There are four main components of the model, Terrain (which is the beginning of simulation; where domain, projection, land use scheme i.e., BATS, user defined land use i.e., true or false, aerosol type, soil scheme and period of simulation are specified), ICBC (initial conditions and boundary conditions, are set according to the setting mentioned in Terrain parameterization), RegCM (duration to simulate i.e., if change needed, time steps to resolve, convective scheme etc), and postproc; post-processing (changing sigma level to pressure level, 4-time daily to daily or monthly etc).

To evaluate the maximum effect in simulation large domain was selected, as it helped to reduce the boundary noises in model simulation. The MIT-Emanuel convective scheme was chosen (as it is improved convective scheme used in RegCM3).

For the second simulation all other parameters were taken in same way, but, only Glacier class in BATS classification was replaced by Tundra class.

Results and Discussions

Simulations were carried out to investigate the monthly characteristics of thermal regimes of mountains glaciers of Hindukush-Karakurum-Himalaya (HKH) region. The differences were identified when original land use characteristics were replaced with the changed pattern of land use i.e., after removal of glaciers. The results are discussed below month-wise for surface air temperature and precipitation.

Effect on Total and Convective Precipitation

Model had simulated no significant change in Total precipitation as well as in convective precipitation of January. But, in February, little decrease in Kashmir area (Jhelum river catchments) was observed, whereas, model had simulated no significant change in Precipitation, overall (Figure 3). But, in month of March, model had simulated little change in Southern part of Northern Area. In rest of study area model has simulated no significant change in total precipitation also no significant change in convective precipitation. So the effect of precipitation in presence of Tundra class in northern Pakistan will be vary little in the rain-fed wheat growing areas in winter months.

April and May are main transition month for precipitation; water stored in these months is used for irrigation for Kharif season. Model had given no significant change in total precipitation as well as in convective precipitation for April and May. On contrary, for June, model simulates Decrease in Kashmir area and increase in western Khybar-Pakhton-Kha (KPK) (Peshawar region) for total precipitation, and shift in convective precipitation in Kashmir region was also observed.

Much difference in July (Monsoon) precipitation was simulated by model, there was increase of precipitation simulated in costal areas of Sindh and Southern part of Northern Area, also decrease of precipitation in main monsoon area of upper Punjab was simulated by model, precipitation of Balochistan was simulated as decreased and increase in upper Balochistan is also simulated by model. Same results for convective precipitation were simulated by model (Figure 4). In contrast, No significant change was simulated for month of August in total precipitation but increased convective precipitation was simulated by model in North eastern Punjab. This change in precipitation pattern for main monsoon months is alarming for agricultural areas of country as more rain in up stream (Jhelum and Indus river) can be stored for irrigation and more rain in down stream can only case flooding.

Total precipitation and convective precipitation of North East Punjab and Desert area of Sindh was simulated as increased by model for the month of September (Figure 5). This shows the stretching of monsoon in September and prolonged monsoon season. Similarly, Model had simulated increase in total as well as convective precipitation in upper parts of KPK and decrease in Kashmir Area for month of October. The October precipitation in plane areas of Punjab especially rain-fed, increase soil moisture and timely crop sowing is possible in such favorable conditions.

For November, Model had simulated decrease or shift in precipitation patterns in costal areas of Sindh and plane areas of Punjab but no significant change in convective precipitation was simulated by model (Figure 6). But for month of December, model had simulated no significant change in overall precipitation but decreasing trend in Northern Part of country, as it observed for Month of Januray. Normal rain fall patterns in upper Punjab i.e non irrigated, provide good condition for winter wheat in this area, which seems not disturbed by the tundra class in northern parts of the country.

On the season base the model simulate significant change in monsoon period i.e JAS in plane areas of country which may cause the flush floods and damage the crops in field.

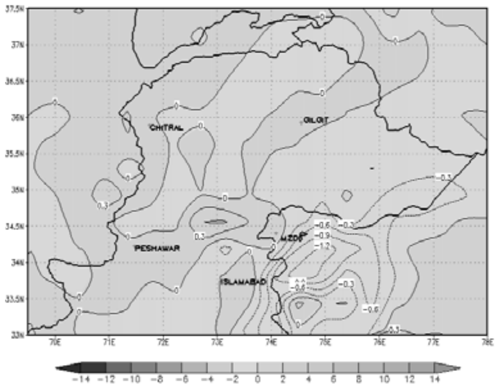

Figure 3: Showing the difference in total precipitation for the month of February for Northern Pakistan and Kashmir region (difference between second simulation and first simulation)

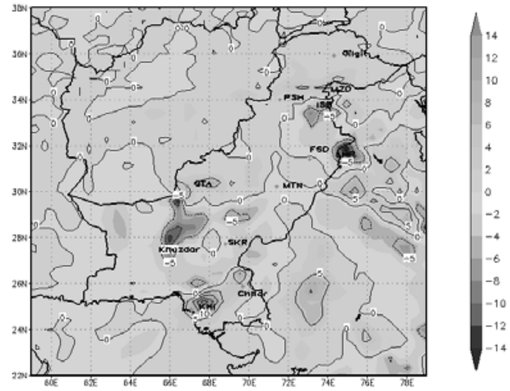

Figure 4: Showing the difference in total precipitation for the month of July

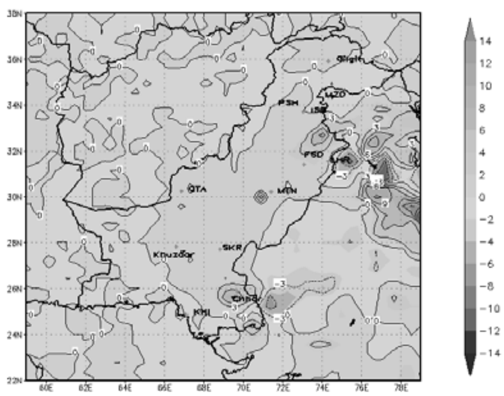

Figure 5: Showing the difference in total precipitation for the month of September

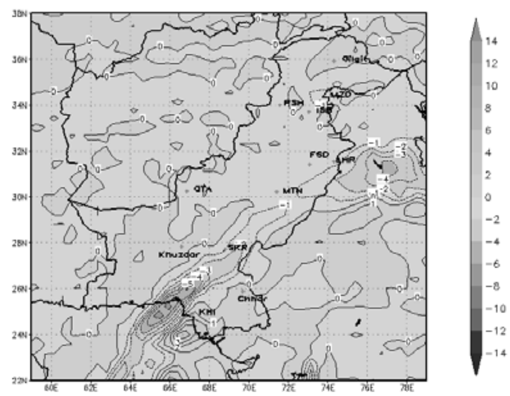

Figure 6: Showing the difference in total precipitation for the month of November

Table 1: Summary table of difference in total and convective precipitation between Simulation 2 and Simulation 1

Month of year	**Difference in two Simulations (simulation 2 – simulation 1)**	
	Total Precipitation	**Convective Precipitation**
January	No significant difference	No significant difference
February	Little decrease in Kashmir Area	No significant difference
March	Increase in south part of Northern Area	No significant difference
April	No significant difference	No significant difference
May	No significant difference	No significant difference
June	Decrease in Kashmir, Increase in Northern part of KPK	Slight Shift in Kashmir Area

July	-ve effect on Monsoon areas of Punjab and +ve effect on costal area of Sindh	Increase in costal Sindh and KPK and decrease in Upper Punjab and Balochistan
August	Little increase in Upper Punjab	Increase in Upper Punjab
September	Increase in north east Punjab and Deserts of Sindh	Increase in north east Punjab and Deserts in Sindh
October	Decrease in Kashmir and increase in upper KPK	Decrease in Kashmir and increase in upper KPK
November	Decrease or shift in costal areas of Sindh and planes of Punjab	No significant difference
December	No significant difference	No significant difference

Effect on Surface Air Temperature

Model had simulated significant change i. e. 1 °C, in month of January and March and no significant change in February, for surface air temperature at 2 meter height in study area due to Tundra Land use in the glaciated area of the northern mountains. Other parts of country bear no significant change in these months. These three months (January February and March) are very crucial for the wheat crop, which is the major crop of the country and heat sensitive especially in the month of march, if temperature increase in the last stage i.e. fruit maturity, so it is expected that there will be no such effect of temperature in the country except Northern Parts, where the rise in temperature will reduce the wheat growing season.

The Model had shown increase of 1.8 °C in April for glaciated area's surface air temperature. Also in May, up to 2°C increase in surface air temperature was simulated in upper areas (mainly glaciated) by the model (Figure 7a). This increase in temperature for northern area may case early crop growth and the season will reduce in this case, which may allow for more crops to be grow in short time period, but water shortage in other part of country due to the early snow melt.

a **b**

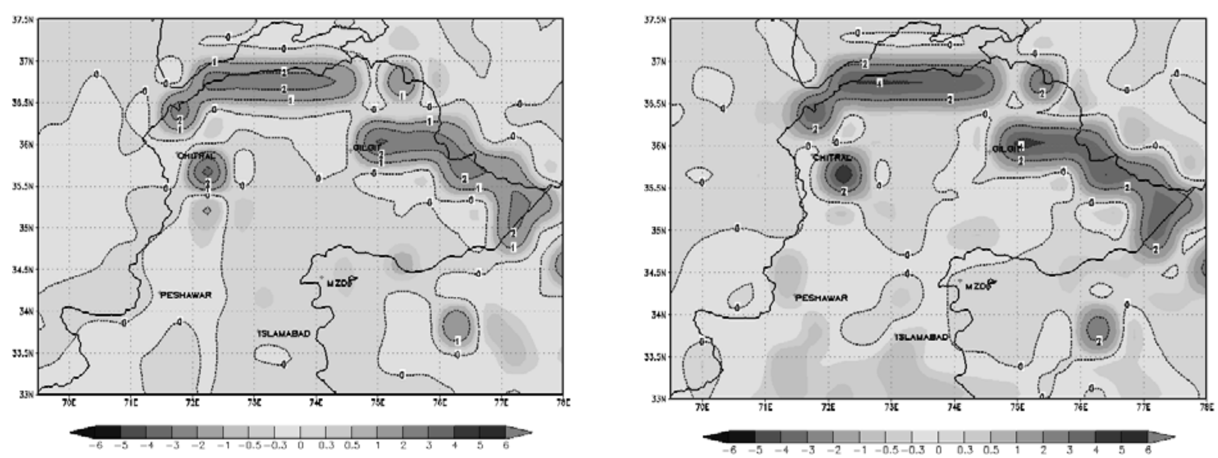

Figure 7: a & b Showing the difference in Surface Air Temperature for the month of May and June respectively (difference between second simulation and first simulation) for Northern Pakistan and Kashmir region

a **b**

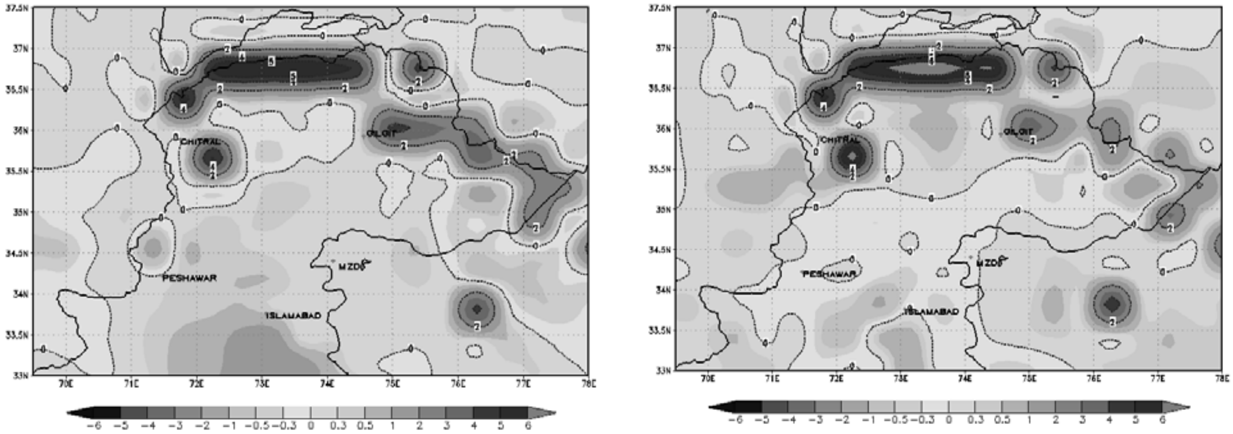

Figure 8: a&b Showing the difference in Surface Air Temperature for the month of July and August respectively for Northern Pakistan and Kashmir region

Average Surface air temperature found increased up to 3 °C, in model output for month of June, in glaciated areas (Figure 7b). Where as, in July Model had simulated 2 °C to 5 °C increase in surface air temperature in extreme Northern parts of country, around 2 °C in Punjab and Balochistan but on other hand in lower sindh temperature decrease by 2 °C (Figure 8a). The low temperature in some areas i.e lower sindh, is because of precipitation increase in such areas.

Table 2: Summary Table showing the difference in Land use change simulation (sim2) and original land use simulation (sim1).

Month of year	**Difference in two Simulations (simulation 2-simiulation 1)**
	Mean Air Temperature
January	1 °C in upper Northern Area and no significant change in other parts
February	1 °C in upper Northern Area and no significant change in other parts
March	1 °C in upper Northern Area and no significant change in other parts
April	Up to 1.8 °C increase in Upper Northern Area
May	2 °C in upper Northern Area and no significant change in other parts
June	Up to 4 °C in upper Northern Area and no significant change in other parts
July	2 to 5 °C in upper Northern Area, around 2 in Punjab and Balochistan but upto -2 in lower Sindh.
August	2 to 6 °C in upper Northern Area and no significant in other parts of country.
September	2 to 5.5 °C in upper Northern Area and -2 to -1 in Punjab and Sindh areas.
October	-1 °C in upper Northern Area and no significant change in other parts
November	Up to 0.6 °C increase in Upper Northern Area
December	1 °C in costal area of sindh and no significant change in other parts

Model had simulated surface air temperature, for August, 2 °C to 6 °C higher than first simulation, in northern parts of the country, up to 2 °C increase in Kashmir valley, but no significant change in other parts of country (Figure 8b). Similarly, Model ha simulated the almost same result for the September as for July and August (2 °C to 5 °C increase in surface air temperature in extreme northern parts of country, except –ve (-2 °C to -1 °C) impact on increased precipitation receiving areas, but, no significant change in other parts of country. The result of model simulation in case of tundra class reveled that glaciated area temperature will increase in case of glacier elimination and also in case of precipitation decrease. Increase in temperature of elevated areas may cause late snow fall and early snow melting. Change in temperature, on one hand will benefit in crop growth and better yield by extending the growing season length, but, on other hand, will badly affect biodiversity of the region. Wild animals and plants will migrate or shift further North or elevated areas to survive. Water scarcity will pose a challenging threat to the survival of the people and to their livelihood earning. Further, due to increase in precipitation the same areas show decrease in temperature. Therefore for adaptation, building of small dams will be the only solution for the area.

In October model had simulated 1°C decrease in surface air temperature in upper Punjab and in north-eastern part of Northern areas. The Model simulation for November showed up to 0.6 °C change in surface air temperature. Whereas there was no significant change in surface air temperature, of month of December, except in costal areas of Sindh, and up to some extent of Balochistan.

In seasonal perspective, like wise above months, the average of JAS monsoon season was the highest i.e 6 °C in northern parts with slight cooling in excessive rain receiving areas such as northeast punjab (due to cloud cover). Other seasons also showed the increase in temperature for present Glaciated Areas which will look like a tundra climate after removal of glaciers.

Conclusion

Effect due to Precipitation

Change in precipitation/convective precipitation pattern, its intensity, and shift, simulated by the model, will result in climate change, indirectly. Drought in center and lower parts of Balochistan may increase as monsoon precipitation decrease. Where as, Flush floods in upper Balochistan, Northern KPK and mountain area may increase due to increase in convective precipitation especially in monsoon season, which will cause land sliding and destruction of resources and lives. Furthermore, enhanced soil erosion will damage the top fertile soil resulting in to decrease in crop yields.

Major monsoon zone including upper and eastern Punjab area (Lahore, Murree, Islamabad etc.) is likely to receive less rain in the absence of glaciers. This is an interesting result to be noted that due to glaciers and substantial vegetation cover of the North, North Eastern Punjab and Northern KPK are receiving increasing amount of rainfall even under global warming scenarios.

Effect due to Surface Air Temperature

Model simulations show an addition of significant amount of heat in thermal regime of Pakistan if tundra type landuse become successor of glaciated area by keeping all other parameters remain in same pattern. It seems that the summer season will have early onset and late end. Like wise peak summer months will be much hotter than existing conditions if glaciers are eliminated and tundra is introduced. An increase of 6 °C is simulated by the model on Northern Area of Pakistan if glaciers are totally removed. However, a minor increase is temperature has been estimated over the low elevation agricultural plains of the country including east west stretched coastal belt bounding North Arabian Sea.

The differences in the precipitation and the temperature also give evidence of landuse influence on the climate models simulations, so an improper landuse may cause false climate parameters values.

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