Climate Variability and International Migration: what are the links?

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ABSTRACT

Climate change and international migration flows are phenomena which attract a great deal of attention from policymakers, researchers and the general public around the globe. Are these two phenomena related? Is migration an adaptation strategy to sudden or gradual changes in climate? In this paper our aim is to investigate whether countries that are affected by climatic shocks with respect to long-term mean experience larger outmigration flows toward rich OECD countries in the period 1990-2001. Contrarily to the bulk of existing studies we use a macro approach and analyse the determinants of international bilateral migration flows employing an augmented gravity-like equation and test the relevance of climate anomalies in temperature and precipitation. One important novelty in our approach is the explicit consideration in the empirical analysis of the heterogeneous nature of climate shocks (type, size, sign of shocks and seasonal effects). Our results show that the occurrence of climate anomalies in origin countries might have relevant effects on outmigration from poor to rich countries.

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1. Introduction

The debate on climate change attracts a great deal of attention from policymakers, researchers and the general public around the globe. Although there is still a large degree of uncertainty on future climate scenario, there is a growing consensus in the scientific community that substantial changes in climatic conditions – including a growing frequency of extreme weather events - will occur.

Our knowledge on the potential socio-economic impacts of climate change is still limited not only as a consequence of uncertainty over future scenario but also as a consequence of the complex and heterogeneous behaviours of individuals and communities affected by climatic shocks. The complexity of adaptation dynamics (or resilience and vulnerability to changes) is well identified in the IPCC 2007 report: "Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints" (IPCC 2007, Ch. 17).

In fact individuals might put in place different adaptation strategies in order to cope with the consequences of climate change. One of the adaptation strategies that raises a lot of concern is migration. The anxiety of governments and public opinion is not surprising given the relevant economic and social consequences of immigration flows both in sending and receiving areas/countries.

Human mobility is one among several possible adaptation strategies and it is fundamental to understand under which conditions migration is the preferred option, for which individuals within a community affected by adverse climatic conditions and which kind of migration (if any) is more likely to be observed (international versus internal; temporary versus permanent relocation). Only few studies have tried to answer to these questions and to quantify the links between the two phenomena, in particular as a consequence of the limited availability of reliable data on migration flows.[1] Many case studies and household-level surveys have contributed to our knowledge on the micro-level decisions and behaviours of individuals and communities affected by climate shocks. Although insightful, these studies give us findings that are highly heterogeneous (and often contradictory) given their unavoidable case specific nature.

In this paper we take a macro-approach and our aim is to investigate whether countries that are affected by climatic anomalies experience, ceteris paribus, larger outmigration flows toward rich OECD countries. Hence we focus on country-level data and our interest is restricted to international immigration flows (and not internal migration).[2] In particular, we analyze the role of climate variability as a push factor of international migration flows. We employ a modified version of the pseudo-gravity model of Ortega and Peri (2009) in order to investigate the effects of climate shocks of different size and nature on bilateral international migration from a large sample of emerging and developing countries to OECD countries between 1990 and 2001.

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[1] A growing research effort has been devoted more recently to these research issues from a variety of discipline and with different methodological approaches. See Piguet 2010 for a methodological survey of the existing literature.

[2] According to Piguet (2010) a limitation of studies employing our methodological approach is given by the so called "ecological fallacy", ie the fact that "correlations measured at the aggregated level might not hold true at the individual level". We believe that – given our research question – it is irrelevant whether or not migrants are precisely those who have been directly affected by climate shocks. On the contrary, a micro-level approach might be misleading in the sense that it is likely to underestimate the links between climate shocks and geographical relocation since by definition does not observe individuals and communities that are affected only indirectly (for instance through market dynamics, ie changes in price/factor rewards).

Our results show that the occurrence of climate shocks in origin countries might have heterogeneous impacts on outmigration flows depending on the exact nature of the shocks and on the socio-economic characteristics of the country (level of development, past immigration history, vulnerability of the agricultural sector). In general, countries with a lower level of development and with a relatively larger agricultural sector are more sensitive to climate anomalies. Interestingly we find that diasporas (network of established migrants) plays a complex role. In fact, in case of certain climate shocks - such as excessively abundant precipitation - networks seems to make origin countries more resilient to climate shocks (for instance through remittance inflows as documented in other studies). In the occurrence of other climatic events - negative precipitation anomalies and extreme temperature anomalies – the existence of a large network of migrants is positively related with the subsequent size of international migration outflow. Hence, established network of migrants play a complex role; they represent both a bridge to new migration flows but also a way to cope with the adverse impacts of large shocks.

The paper is organized as follows. In *Section 2* we briefly discuss the links between climate change (and extreme weather events) and human mobility and we outline a selective literature review. In *Section 3* we present an empirical analysis on the role of climate change as a determinant of international migration flows. Some conclusive remarks are reported in *Section 4*.

2. Climate and migration: what are the links?

Every year in poor and rich countries millions of individuals change their place of residence (see SOPEMI 2011 for recent data on international migration flows). Human mobility might assume very different forms: within or across countries, voluntary versus forced, temporary versus permanent, legal or illegal. The common trigger in all cases has to be found in changes in individual/ family conditions and / or changes in economic and social opportunities in the origin and destination locations.

Can we consider changes in climatic conditions as push (or pull) factors of human migration? While the answer is certainly positive, the definition of the exact nature and a quantitative assessment of the links between climate change and migration is a complex task. Whether a change in climatic conditions in a specific location is sufficient enough to induce individuals to geographically relocate will depend on multiple factors such as the nature of climatic shocks, the characteristics of the population affected and the vulnerability of economic and social systems (including the ability to undertake alternative coping strategies).

Economic systems – and individuals within them – might have different degree of vulnerability to different kind of climatic shocks (temperatures, precipitations, extreme events). For instance, extreme climatic events such as droughts, floods or hurricanes are likely to have severe impacts - at least in the short run - on the economic resources of a given community and, as a consequence, might severely limit the adoption of adaptation strategies alternative to migration. On the other hand, gradual changes such as the reduction of precipitation over time might have a smaller impact on the well being of a community if individuals will adjust their productive strategies over time (for instance through investment in irrigation systems or use of drought resistant agricultural varieties).

The economic consequences of climatic changes might also be highly non-linear: the increase in temperature or reduced precipitations might have trivial or no effects up to a certain threshold and, on the contrary, very severe effects when such threshold is crossed. An interesting work by le Blanc and Perez (2008), using GIS data on rainfall and population density in Sub-Saharan Africa for year 2000, shows that water scarcity constraints human density only below a certain threshold[3]. This result suggests that vulnerability of population to water stress (caused by climatic or population pressures) depends upon the level of water resources.

Another aspect that should be consider is the asymmetric impact that climate anomalies might have across the affected population. While some individuals or industries might experience negative effects, others might benefit from climate anomalies (both as a direct consequences of such changes or due to indirect effects taking place through market mechanisms). As recent evidence on adaptation strategies in a sample of African countries shows, counteracting effects might be also present in highly vulnerable communities. Analysis based on micro-level data on a sample of African farmers point out that higher annual temperatures are associated with positive variation of net revenues for livestock owners and negative variations of net revenues from crop production (CEEPA 2008). If climate change affects asymmetrically the productivity or the endowment of different factors of production (labour, capital, land) also the structure of production and factors' rewards will change in a asymmetric way.

The choice on whether to undertake or not adaptation strategies (including outmigration) will also depend on the perceived duration of climate anomalies. Given that migration is a costly adaptation strategy – in particular migration across borders – if individuals perceive changes as transitory they might decide to adopt alternative strategies even if the climatic changes are highly destructive. On the contrary, if changes are perceived as permanent they might be more inclined to opt for costly but resolving adaptation strategies such geographical relocation. Halliday (2006) provides evidence which might support this idea. Using data on a panel of rural household from El Salvador the author finds that while adverse agricultural shocks which lead to harvest and livestock losses increase migration toward the US, the damages caused by the 2001 earthquake are associated to a reduced probability of outmigration. The transitory nature of the latter shock might be a possible explanation for such heterogeneous reactions.[4]

In order to analyse the effects of climate anomalies on migration it is important to distinguish direct effects from indirect channels which produce their effects on migration flows via other push and pull factors. In *Figure 2.1*, we report a schematic representation. Changes in climatic conditions could have both *direct effects* as push factors of migration flows when the possibility of human survival in the "new" environment are reduced (for instance because of unsustainable water supplies) or *indirect effects* through market forces.[5] Migration might be induced by changes in quality of life[6], economic opportunities or a combination of both set of factors. Climate anomalies

[3] The authors finds that above a mean annual runoff of 900mm rainfall and human density are not correlated. Note that, as the authors point out, sixty percent of the population in Africa lives in zones with mean annual runoffs of less that 300mm.

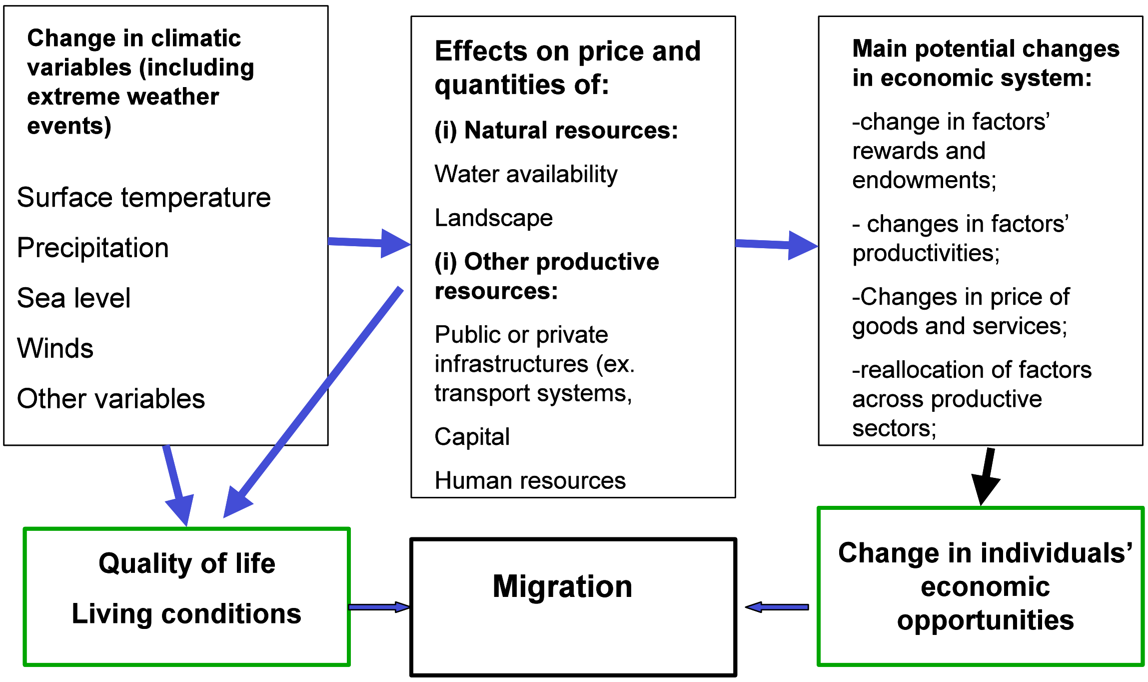
[4] The author suggests another possible explanation associated to the different labour market effects of these shocks. "One explanation is that the earthquakes created exigencies in El Salvador that increased the incentives for families to retain labour at home" (page 895, Halliday 2006). The two explanations need not be substitute but they go in the same direction: in fact if the destructive event is perceived to be permanent then the incentive for families to retain labour at home would be weak.

[5] Indirect changes can also occur through non market forces. Environmental degradation has often been one important factor behind social conflicts (see the interesting work by Reuveny 2007). Also in these cases, it is often possible to track back the occurrence of social conflicts and wars to the economic and re-distributive consequences of climate shocks.

[6] There is a rich literature on the role of climatic amenities on migration decisions (or demographic changes in general). Cebula (2005) finds that gross state in-migration in the US over the period 1999-2002 is an increasing function of

might significantly impact on factors' endowments (or on their productivities) and, in turn, these changes will be reflected in the price of factors of production and of final goods and services that employ them.

Figure 2.1. *Climate changes and migration: a map of direct and indirect links*



Economic systems might be highly resilient to climate-related shocks, in particular in urban areas where agglomeration forces are strong and exert a centripetal force on productive factors (including labour). The strength of agglomeration externalities can be appreciated for instance by looking at the study of Vigdor (2008) on population trend pre- and post-shocks related to natural or man-made disasters of high magnitude experienced in seven cities in different times (*Figure 2.2*). Cities that were growing before the event in all cases considered by Vigdor continued their positive trend also in the aftermath of disasters (even in the case of the extremely strong earthquake of San Francisco which left homeless more than half of the city population). The same pattern of resilience is observed in the case of shocks with more long lasting effects on environmental conditions (such as radiations from the atomic bombs of Hiroshima and Nagasaki) or in the study of Davies and Weinstein (2002) which use the "exogenous" events of bombing of Japanese cities during WWI in order to assess competing theory of urban growth. The authors find a highly persistent relative structure of the urban system with an almost complete rebound to pre-bombing equilibrium by 1960s.

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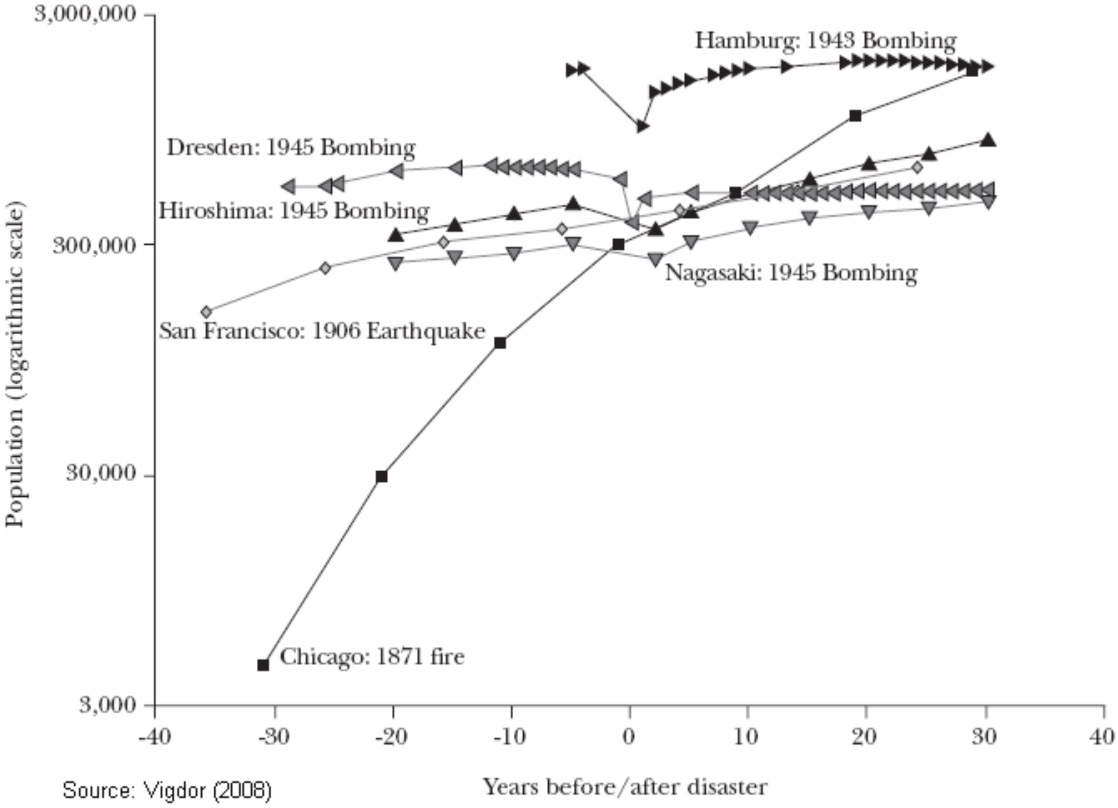
warmer temperatures, sunshine and recreation possibilities. Cheshire and Magrini (2005) show that urban population growth in EU countries is positively related to good climate but spatial variations seems to matter only within national borders: individuals do not respond to differences in weather conditions by relocating across borders.

__Figure 2.2__ Disasters and the persistence of City Population trends



These examples suggest that urban externalities might imply high resilience to (climatic or other) shocks. A key role in determining the population pattern is played by the degree of factors' mobility. Only when factors (capital and / or labour) are geographically mobile, also small changes in prices can drive large shifts in the geography of production.[7]

Different levels of resilience – for instance between urban and rural areas – imply that the ability to undertake different adaptation strategies is highly heterogeneous across communities. Qualitative analysis undertaken using ethnographic methods suggests that the degree of resilience – and hence the choice of migration as an adaptation strategy – is highly heterogeneous also across individuals. Reuveny (2007) argues that "people can adapt to environmental problem in three ways: stay in place and do nothing, accepting the costs; stay in place and mitigate the changes; or leave affected areas" (page 657). The cost and benefits of each option will largely depend on resources available to individuals (which might be affected or not by environmental changes), future expectations and the (partly-exogenous) institutional framework within which the environmental shock takes place. Individuals and households with a larger endowment of resources (financial assets, land and other

[7] Further insights can be gained by analysing the potential effects of climatic shocks within the so-called New Economic Geography (NEG) literature. For a survey see Baldwin R., Forslid R., Martin P., Ottaviano G. and F. Robert-Nicoud (2003), Economic Geography and Public Policy. Princeton University Press, Princeton NJ.

capital goods, human capital, social capital or "relationship capital"[8]) are more likely to undertake adaptation strategies rather than 'do nothing' but it is not necessarily the migration strategy the one that will be selected by them. For instance, individuals with large endowments of immobile capital (such as land or real estates) are probably less mobile than individuals with only a limited amount of capital or who derive their income only from labour. Individuals with high level of human capital might have a relative low access cost to technologies or productive processes which overcome the negative consequences of climate change/shocks.

One particular form of "relationship capital" is the possibility for the individual to rely on a network of family and friends who reside in other locations (migration networks). The effect of this form of capital on migration propensities might be ambiguous. On one hand, the network might exercise a strong pull effects by reducing migration costs. On the other hand, external support (for instance in the form of remittances) might facilitate the adoption of other coping strategies. Yang and Choi (2007) using household level data from the Philippines find that remittance flows increase as a consequence of rainfall shocks (replacing up to 60% of the decline in household income). Findley (1994) in a study on migration from rural Mali after the severe 1983-85 drought finds no evidence of increased international migration and Findley and Sow (1998) find that food deficit in rural households in Mali were compensated by remittances from migrants in France. These findings confirm the role of remittances (a consequence of established networks of migrants) as an insurance mechanism against income shocks. On the opposite side, the studies by McLeman on the drought in Oklahoma during the 1930s suggest that networks played a role of "bridge" and favoured the adoption of migration as a coping strategy strategy (McLeman 2006; McLeman and Smit 2006).

Another important element that might play a significant role in the nexus between climate change and migration is public policy response both before - such as pre-emptive measures and insurance mechanisms that limit the vulnerability to or the consequences of shocks – and after the environmental damages occur (emergency help, financial subsidies and aid, recovery plans etc.). Good governance will generally limit the extent of damages and reduce the number of individuals who will adopt migration strategies. An important role is often played by international support. According to a recent paper by Collier and Goderis (2009) the level of international aid mitigates the effects of negative shocks. The authors also find that donors do not re-distribute aid overtime toward shock-prone countries. By looking at the consequences of a specific climatic shock in developing countries, ie hurricanes, Yang (2008)[9] finds greater exposure to these events leads to a large increase in foreign aid. In his study, the author considers different types of international financial flows to developing countries in the aftermath of hurricanes: official development assistance (ODA), foreign direct investments, remittances, lending from multilateral institutions, portfolio investment and bank and trade-related lending. For the poorer countries within his sample, total financial inflows in the 3-years following the extreme climatic event represent approximately three-fourths of estimated damages. As mentioned above an important role in poorer country is played also by remittances.

The quality of Institutions affect the efficiency of shock-absorption mechanisms both before and after the occurrence of climatic changes. According to Reuveny (2007), the role of the US federal government was fundamental in limiting out-migration from the US Great Plains in the 1930s after

[8] Here we define relationship capital as the potential economic value derived from individuals' (weak and strong) ties with other individuals who reside in the same location or in other locations not affected by climatic changes.

[9] An interesting innovation of Yang (2008) is the use of a time-varying storm index which allows to take into account the magnitude of the shocks (proxied by the fraction of the country population affected by the event).

a series of very severe drought. In fact, the policymakers gave substantial financial and technological assistance to the farmers who decided to stay in the affected areas.

2.1 Migration: where?

The list of factors outlined above gives an idea on the complexity of the nexus between climate anomalies and migration. Another issue that should be considered is the following: *if changes in climatic conditions are strong enough to trigger human mobility, which types of mobility patterns are we likely to observe?* Relocation strategies might be highly different according to which individual is affected and by which kind of climatic shock. For those individuals who lack the financial resources to finance a costly international move, or for those communities who have a weak or inexistent network of established migrants in foreign locations, migration is likely to be of short distances and within the country. Cross-border migration will take place if this option, compared to other adaptation strategies, is not too costly. This might happen when the country affected by adverse climatic shocks is geographically, culturally or socially close to potential receiving countries.[10]

The dominance in terms of magnitude of internal over international flows is a stylised fact in migration literature on which there is unanimous consensus. Whatever is the determinant of migration, individuals are more sensitive to differentials in socio-economic conditions within countries than to differences between them. The existing evidence confirms that this holds true also for climatic changes. In *Table 2.1* we report information on 38 environmental episodes which have caused, according to Reuveny (2007), out-migration flows (as a primary factor or with other concomitant push factors). In most cases only internal relocation (see column 4) takes place and often from rural agricultural areas to urban areas. International migration flows of certain relevance are observed less frequently and are almost always in border countries (short-distance or toward countries with pre-existing political, ethno linguistic or cultural ties).

Barrios et al (2006) investigate the role of climate change on rural – urban migration in a panel of 78 countries over the period 1960-90. Their results outline a positive and statistically significant relationship between urbanization and climate change for Sub-Saharan Africa. No significant results are found for other developing countries suggesting that the strength of the link between climate change and migration is larger for those communities where agriculture is more vulnerable to shortage in rainfall.

The non-exhaustive list of factors outlined above which mediate the links between climatic changes and migration as an adaptation strategy implies that social scientists need to use multiple and complementary research strategies to broaden our knowledge on this important issue: from case studies on individuals and households in communities affected by adverse climatic events to econometric analysis on international migration flows (such as the present study).

[10] Migration might also differ in terms of duration. The move might be temporary (if, for instance the climatic shock does not produce long-lasting effects) or permanent. Analysing a sample of irregular migrants crossing Italian borders in 2003, Coniglio et al (2009) finds that individuals experiencing adverse climatic shocks or natural disaster in the village of origin are more likely to return home that individuals experiencing social conflicts.

In his survey of recent empirical analysis on the links between climate change and migration Piguet (2010) discusses relative strengths and limits of alternative methodological approaches[11]. In discussing the limits of empirical approaches similar to our study which employ multivariate methods using geographical areas as unit of analysis (ecological inference based on area characteristics) the author mentions two critical aspects. Firstly, the paucity and quality of environmental indicators used. In fact most studies employ rather rough and unsophisticated indicators of environmental change (such as past level or anomalies in rainfall). The second limit emphasized by Piguet (20010) is the so-called 'ecological fallacy' due to the fact that "correlations measured at the aggregate level might not hold true at individual level" (page 518, Piguet 2010). To overcome the first critique, in what follows we consider more refined environmental variables which aim at separating climate anomalies of different size and nature (for example positive versus negative precipitation anomalies or non linear effects of anomalies). With respect to the second shortcoming pointed out by Piguet, while we acknowledge the fact that the impact of climate shocks might differ substantially across subgroups (and also the fact that those who migrate might be different from those directly affected by climate shocks) we are specifically interested in aggregate net effects and not on individuals' and communities behaviour.[12]

Bearing in mind the complex links outlined in this section, we present in the following part the results of an empirical analysis on the role of (observed) climatic anomalies on international migration flows.

[11] The author classifies the existing empirical evidence in 7 different types: ecological inference based on area characteristics (to which the present study belongs), individual sample surveys, time series, multilevel analysis, agent based modelling and qualitative/ethnographic methods.

[12] In fact, one might turn Piguet's critique on its head and argue that the main limit of a case study approach is to be unable to take into account important general equilibrium effects and hence have a too narrow focus that might miss relevant indirect effects.

Table 2.1 *– Environmental migration episodes reported in Reuveny (2007)*

Period	Origin	Destination	Cross border flows	Environmental push factors	Other push factors	Number of migrants*
1970s - 1990s	1. Bangladesh (rural areas, coastal areas, islands)	Bangladesh (Chittagong Hill Tracts)		Droughts, water scarcity, floods, storms, erosion, desertification	Overpopulation, underdevelopment, government migration incentives	600,000
1984 - 1985	2. Ethiopia: (a) central/northern; (b) Awash river basin-Afar,	Ethiopia: (a) southwest, west; (b) Wollo region		Drought, famine, forest fires, locust invasion	Underdevelopment, overpopulation, government promotes cotton/sugar, overgrazing	600,000
early 1990s	3. Rwanda (rural south, center)	Rwanda (north), Zaire	yes	Arable land/water scarcity, land degradation, deforestation	Overpopulation, food scarcity, civil war, underdevelopment, government aid in north	1.7 Million
1960s - 1990s	4. Mexico and Southern Guatemala	Mexico (eastern, Chiapas)	yes	Land degradation, deforestation, land pressure	Persecution, civil war in Guatemala, Mexican government resettlement policy, unequal land distribution, overpopulation	280,000
1950s - current	5. Bangladesh (various regions)	India, West Bengal, Assam, Tripura	yes	Droughts, water/land/ food scarcity, land erosion, storms, salt intrusion	India's diversion of Ganges River, failure to share river water, overpopulation	12-17 Million
1950s - 1980s	6. El Salvador	Honduras up to the late 1960s, then US	yes	Deforestation, land degradation, arable land/water scarcity	Wealth disparity, skewed land-tenure, poverty, overpopulation, repression	300,000 to Honduras, 500,000 to US
1960s - 1980s	7. Ethiopia/ Eritrea	Southern Sudan	yes	Droughts, famines	Underdevelopment, Eritrean secession, war	1.1 Million
1980s - 1990s	8. Mauritania,	Senegal, Senegal River Valley	yes	Drought, soil erosion, desertification, deforestation, water scarcity	Moors-African enmity, interstate war, Senegal river dam raises land values and stakes, population growth	69,000
late 1970s	9. Somalia	Somalia - Ethiopia border region (Ogaden)	yes	Arable/grazing land degradation, water scarcity	Underdevelopment, population growth, interstate war	400,000
1970s - 1990s	10. Haiti (north)	Rural hillsides, l'Artibonite region, cities, Dominican Republic, US	yes	Deforestation, land scarcity/degradation, erosion	Poverty, inequality, high density, repression	1.3 Million
1970s - 1990s	11. Philippines (lowlands)	Philippines (center, uplands)		Arable land/water scarcity, deforestation, floods, slides, drought, land degradation	Overpopulation, land/wealth disparity, vague property rights, unemployment, underdevelopment	4.3 Million
1970s - 1980s	12. South Africa (black areas)	South Africa (urban centers)		Land degradation, deforestation, subsistence crisis, water scarcity	Repression, poverty, poor infrastructure, African unemployment, overpopulation	Up to 750,000 per year
late 1960s - 1980s	13. Sahel (rural areas)	Sahel (urban regions, neighboring coastal states)	yes	Droughts, famines, land scarcity	Inflation, underdevelopment, overgrazing	10 Million
1960s - current	14. Brazil (northeast)	Brazil (central and southern Amazon region)		Droughts, land degradation, water scarcity, deforestation	Overpopulation, poverty, land disparity, government subsidizes settlers, vague property rights	8 Million
1970s - 1980s	15. Sudan (north, south, west)	Sudan (Khartoum, Central, Kordofan, east)		Droughts, famine, desertification, deforestation, erosion	Civil war, underdevelopment, policies against small farms and pastoralism, population growth	3.5 - 4 Million by early 1990
1930s	16. US (Great Plains)	US (other regions)		Droughts, sand storms, land degradation	Great Depression, over-plowing/grazing	2.5 Million
late 1970s	17. Ethiopia	Ethiopia - Somalia border region, Ogaden	yes	Grazing/arable land degradation, deforestation	Overpopulation, Ogaden War, land disparity, underdevelopment	450,000
1970s - 1990s	18. Nigeria (Jos Plateau)	Nigeria (urban areas, intra-regional)		Soil/water/air pollution, silted rivers, land scarcity/degradation	Tin-mining, poverty, unemployment, high population density/growth	n/a
1980s - 1990s	19. Pakistan	Pakistan (urban areas, especially Karachi and Islamabad)		Water scarcity, deforestation, pollution, floods, land degradation	Population growth, unequal access to resources, poverty, unemployment, unclear land-tenure	n/a
1970s -	20. Bangladesh	Bangladesh, urban		Droughts, storms, floods, water	Overpopulation, rural poverty	n/a

1990s	(rural areas)	centers		scarcity		
1980s - 1990s	21. China (primarily Gansu and Ningxia)	China (urban centers)		Floods, land degradation, desertification, water scarcity	Mountainous terrain, poverty, malnutrition, government incentives	20 - 30 Million
1970s - 1990s	22. Ecuador (highlands, southern region)	Ecuador (northern Amazon)		Droughts, deforestation, land degradation, water scarcity	Underdevelopment, constructing oil pipelines in Amazon region	n/a
1995 - 2000	23. North Korea	China (urban centers)	yes	Floods, tidal waves, droughts, land degradation, deforestation	Failure of collective farming policy, lack of infrastructure, poverty	300,000 - 400,000
late 1980s - mid 1990s	24. Somalia	Somalia-Ogaden, Kenya, Ethiopia, Djibouti	yes	Drought, erosion, deforestation	Civil war in Somalia, population growth, overgrazing	2.8 Million
1950 - 1980s	25. Guatemala (rural areas)	Guatemala (north Peten region, urban centers, eastern lowlands, Pacific Coast), US	yes	Land degradation, deforestation, floods, river sedimentation, water scarcity	Overpopulation, land inequality, underdevelopment, government promoting export crops, insurgency	100,000
1940s - 1980s	26. Dominican Republic (Las Ayumas)	Dominican Republic (Santiago's urban center)		Deforestation, land degradation	Coffee price rise stimulates deforestation to grow coffee, poverty	Several tens of thousands
1931 - 1939	27. Canada (Great Plains)	Canada (other regions, urban areas)		Droughts, sand storms, land degradation	Great Depression, over-plowing/grazing	300,000
	28. Mexico (rural areas, Oaxaca)	Mexico (urban centers), US	yes	Drought, land degradation, water scarcity, deforestation	Underdevelopment, inequality, population growth	600,000 - 900,000 annually
1960s - 1990s	29. Kenya (Western, Northern)	Kenya (Rift Valley,some remain in West, urban centers)		Drought, land degradation, land scarcity, famine	Overpopulation, ethnic strife, inequality, unemployment	150,000 - 200,000
1970s - 2000	30. Uzbekistan, Kazakhstan, Aral Sea,	Within region or adjacent regions	yes	Pollution, salinization, dust storms, water scarcity, sea desertification	Unemployment, underdevelopment, ethnic factor, water scarcity	65,000 - 100,000 annually
1990s	31. Caspian Sea region, Kalmykia	Russia, neighboring regions	yes	Inundation, floods, land scarcity	Ethnic pull factor, unemployment, underdevelopment	2200 - 8100 annually
	32. Russia (Kola Peninsula)	Russia (various regions)		Air pollution	Poor healthcare, social problems	5% of Population
1960s - 2000s	33. Burkina Faso (Mossi Plateau)	Burkina Faso (south, east)		Drought	Underdevelopment, population pressures	n/a
1978 - 1983	34. India (west Rajasthan, East India)	India (Haryana, Madhya Pradesh, Madras)		Drought	Underdevelopment	n/a
1980s - current	35. Zimbabwe (Southern lowlands)	Zimbabwe (highlands)		Drought	Unclear property rights, overgrazing, poverty, seasonal movement	n/a
1980s - 1990s	36. Thailand (northeast)	Thailand (other rural, areas, urban centers)		Deforestation, land scarcity/degradation	Underdevelopment	n/a
1990s	37. Russia (Arctic region)	Russia (urban centers), other CIS countries	yes	Extreme weather	Socioeconomic decline	70,000
1950s - 1990s	38. Tanzania (Southern and northeast regions)	Tanzania (Usangu Plains)		Land scarcity/ degradation	Overpopulation, poverty, government promotes commercial agriculture	84,000

Source: Reuveny (2007), please refer to Table 1 in the original article for further details and sources on each of the episodes listed above.

* Note that the reported number of immigrants in most cases cannot be attributed only and directly to environmental causes.

3. ***Empirical analysis***

3.1 Empirical strategy and data

In this section we investigate the determinants of international bilateral migration flows from a sample of 155 origin countries toward 25 OECD countries in the period 1990-2001[13]. Our main aim is to test the relevance of climate variability in the origin countries as a push factor of bilateral migration flows. We follow a methodological approach similar to Ortega and Peri (2009)[14] and use a pseudo-gravity empirical specification. Like in their model the dependent variable is the total size of bilateral migration flows. In particular, we estimate the following specification:

$$ln(M_{ijt}) = \beta_0 + \beta_1 \boldsymbol{X}_{i,t-1} + \beta_2 \boldsymbol{Z}_{ij,t-1} + \beta_3\,(\boldsymbol{ClimateShocks}_{i,t-n}) + D_i + D_j + D_{jt} + e_{ijt} \qquad (1)$$

where M_{ijt} is migration flows from origin country *i* to destination country *j* at time *t*[15]. We introduce a set of push factors operating in the country of origin $\boldsymbol{X}_i$ (such as *GDP per capita, change in employment rate* and the *change in the surface of irrigated land* occurred in the year before) and our main covariates of interest, $ClimateShocks_{j(t-n)}$ which represent a vector of *indicators of climatic anomalies* in origin country *i.* In addition we control for a set of bilateral variables $\boldsymbol{Z}_{ij,t-1}$ which greatly affect bilateral migration flows such as *geographical distance* between country *i* and *j*, the log of the (past) *bilateral stock of migrants* from origin country *i* in destination country *j*, a dummy equals one if the pair of countries share a *common language*. In order to control for time-varying pull factors related to economic, social and policy changes in destination countries we introduce in the empirical specification a set of country-of-destination-by-time fixed effects (D_{jt}). These set of dummies will hence absorb any effects specific to the OECD destination countries. The specification includes also country of origin and destination fixed effects in order to control for time-unvarying characteristics.

The non-climatic covariates used in the regression analysis are described in the *Appendix 2* while climatic variable are described in the next Section and in *Appendix 3*. With respect to the former, we expect a negative effect of GDP per capita and employment rate change on bilateral migration; both variables proxies for economic opportunities in the origin country. Our a priori expectation on the effect of a *change in the surface of irrigated land* is to observe a negative relationship with outmigration. We also expect, as in existing studies, that *geographical distance* is negatively related with bilateral flows between origin and destination countries. On the contrary, we expect that a common language and a dense network of already established migrants, by reducing the cost of migration and increasing the number and value of opportunities in the destination country, are positively associated with bilateral flows.

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[13] We use unbalanced data for the sending/origin countries reported in *Appendix A*. To the best of our knowledge comprehensive dataset on bilateral migration flows which include also South-South migration (ie migration between and within less developed and emerging countries) are not available.

[14] Differently from their work, our main focus is on push factors (in particular past climate anomalies) rather that pull factors such as immigration policy changes.

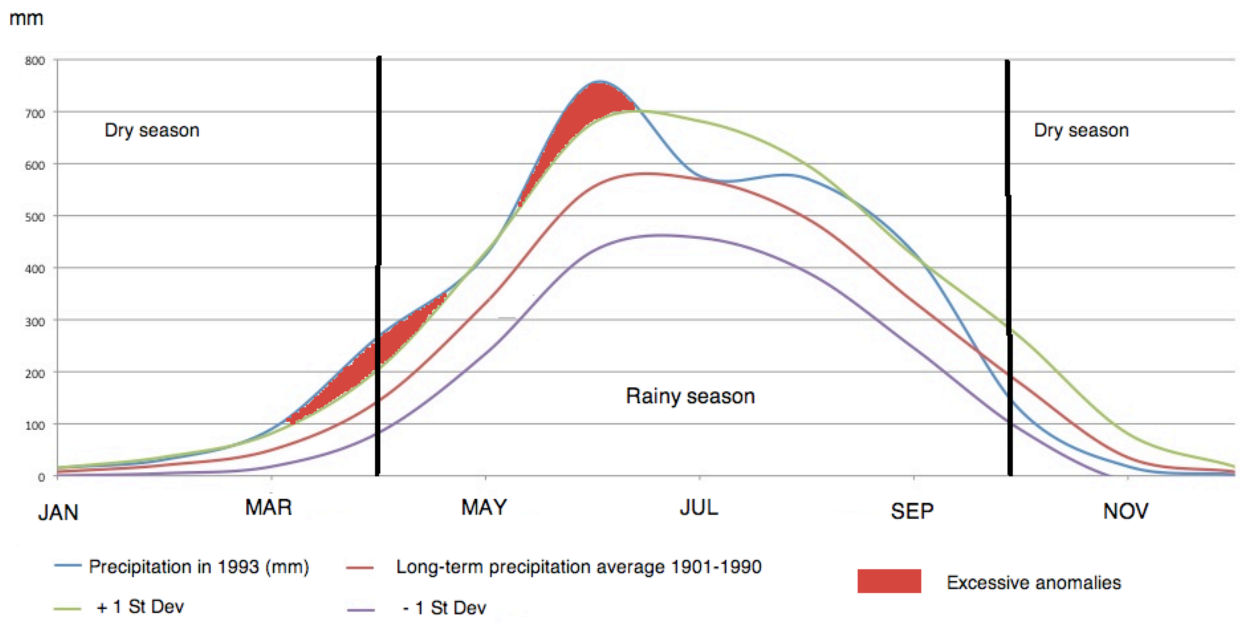
[15] When the bilateral flow is zero we add 1 to it before taking the log.

3.2. Climate data and identification of climate anomalies

The existing evidence outlined above emphasize the highly heterogeneous effects on local communities of climate shocks/anomalies of different nature. Simple measures of changes in precipitation - like for instance the use of yearly rainfall like in Barrios et al (2006) – might represent an unsatisfactory way for identify climatic shocks. An important novelty in our approach is the explicit consideration in the empirical analysis of the heterogeneous nature of climate anomalies.[16]

Our climatic variables are based on data from Mitchell et al (2003) who provide detailed information on monthly precipitation and average temperature at country-level for the period 1901-2000[17]. Our starting point, using Mitchell et al (2003) data, is the computation for each of the 155 origin country of the long-term monthly mean values (and standard deviations) of precipitation and temperature in the period 1901-1990.

Figure 3.1. *Monthly precipitation in Bangladesh: 1901-1990 averages and rainfall in 1993*



Source: authors' elaboration

[16] Some data limitations are unavoidable, in particular we are aware that using yearly data aggregated at the country-level might mask high intra-borders variations (an issues which characterize any cross-country empirical study irrespectively of the research question). As a robustness check we have performed our estimation taking explicitly into account two important dimension which might amplify the country-level aggregation problem: (i) the absolute dimension of the country (surface); (ii) climatic zone homogeneity of the country (% of the country falling within the main climate zone). Estimates have been carried out by progressively removing the larges and more climate-diverse migrant origin countries. Results are available upon request and confirm the qualitative results highlighted in the paper.

[17] TYN CY 1.1 database, Mitchell et al. (2003). Available at: www.cru.uea.ac.uk/~timm/cty/obs/TYN_CY_1_1.html

In *Figure 3*, monthly precipitations in 1993 are reported together with the long-term average monthly rainfall and the relative standard deviations during the period 1901-1990 for Bangladesh.

On the basis of these distributions we compute a rich set of variables which measure climate anomalies – in temperature and precipitation - with respect to the country long-term mean occurred in three different time horizons before bilateral migration between country *i* and *j* occurs[18]: (i) 1 year before; (ii) 3 years before; (iii) 5 years before. In particular, we test for the relevance of the following climatic variables as push factors of international migration flows:

(i) *absolute levels* of precipitation and temperature;

(ii) *surplus* or *deficit* of rainfall and temperature with respect to countries' long-term values (both absolute value - in millimeters and Celsius degree respectively - and percentage value).

(iii) *excess anomalies* above or below 1 Standard Deviation with respect to long-term values (absolute value - in millimeters and Celsius degree respectively; percentage value). We also consider separately the effects of positive – ie above 1 St Dev – and negative excess anomalies – below 1 St Dev;

(iv) *index of intra-annual rainfall variability*, which is calculated as the mean absolute devietion (MAD) during the considered time span over the long term MAD. The standardization of the index allows us to explicitly consider the country specific natural level of variability which is tipically different on the basis of the prevailing climate features. An index larger than 1 would hence imply that during the considered period precipitation have been more volatile than usual;

The climatic anomalies specified above have been separately computed for the *rainy and dry season*. In this way it is possible to investigate if a climate shocks – for instance excessive precipitation in the past 3 years - have heterogeneous effects depending on the season when they occur.

3.3. Econometric issues

Two main issues need to be addressed in the estimation of equation (1) above on the determinants of bilateral immigration flows. The first issue is the presence of "zeros" in bilateral migration flows, a problem which leads to bias when using OLS estimations. Although in our sample the relative size of zeros is less pronounced compared to other empirical works on migration determinants like Beine et al (2011) or Pedersen et al (2008) we address the issue using three solutions commonly employed in trade/migration literature. The first – but probably less desirable - solution often employed is that or re-specify the dependent variable as $ln(M_{ijt}+1)$. Other studies employ as an alternative solution a Heckman two-step selection model where the first step equation is a probit estimate on the probability of observing a value equal to zero for the dependent variable. The main difficulty with this second strategy is the ability to find an appropriate exclusion restriction. Beine et

[18] Since we have no information on the monthly distribution of migration flows and since several existing studies emphasize the not immediate reaction to climatic events we do not consider in the study contemporaneous anomalies.

al (2010) use to this purpose pre-existing diplomatic links with the idea that these affects the probability of observing bilateral flows but not their size. The third strategy – our preferred option - is that of employing a Poisson regression, a form of generalized linear model where the response variable is modeled has having a Poisson distribution.
The second issue is related to the endogeneity of bilateral migration stocks (diaspora) – one of the regressors - and our dependent variable, bilateral migration flows. In fact, unobservable bilateral characteristics might affect both the size of diasporas and the subsequent migration flows. Beine et al (2011) follow Munshi (2003) and employ an instrumental variable estimation approach instead of using the current size of diasporas (ie the bilateral stock between country *i* and *j*). In particular they use as instruments – supposedly correlated with the size of bilateral diaspora but not with current flows – a dummy variable capturing the existence of guest workers scheme between the country of destination and origin in the '60s and '70s and a variable which proxies the bilateral diaspora in the '60s (see Beine et al 2011 for details). In this paper, we use lagged values of bilateral diaspora (in year 1960) which were recently made available by the World Bank (Global Bilateral Migration Database). We argue that this variable is a good proxy for the intensity of network effects and is very unlikely to be affected by the same estimation issue given the consistent time lag between the stocks and the flows.

3.4. Estimates and main results

The starting point of our analysis is the parsimonious baseline model of bilateral migration flows reported in the first column of *Table 3.1*.[19] Estimation results for the non-climatic covariates are in line with expectations. The size of bilateral migration flows is decreasing in the GDP per capita of origin countries which captures the relative level of development. The employment rate in the origin country present a negative coefficient but is weakly significative[20]. As highlighted in previous studies (see Beine et al 2011 and Pedersen et al 2008), migration networks play a crucial role in channelling immigration flows; in our baseline model the bilateral stock of already established migrants in 1960 is a strong determinant of subsequent bilateral flows. Distance is negatively associated with the size of the flows, while a common language between origin and destination countries has a positive effects on immigration flows.
We firstly proceed with the inclusion in the baseline model of the *index of (excess) rainfall variability* computed at different time spans (averages of 1,3 and 5 years lags), columns (1) to (3). The coefficients related to the index are positive and significant; an increase in variability with respect to the long-term values of precipitation is associated with an increase in outmigration. For instance if we consider column (2), a back-of-the-envelope calculation reveals that, ceteris paribus, an increase in the index of rainfall variability from mean value to 2 standard deviation above mean is associated with a 30% increase in bilateral migration. It is interesting to notice that the magnitude is increasing in the time span considered which implies that a persistent excess variability amplifies the migration push. Note from the remaining columns in *Table 3.1* that, as expected, the inclusion of simple and highly aggregated measures of climate anomalies does not produce significant effects. These results are robust to different time specifications of climatic variables.

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[19] In what follows we present only a limited number of estimates in order to keep the paper of a reasonable size. Additional estimations are available upon request from the authors.
[20] In alternative specifications we employ the difference in GDP per capita and employment rates between country *i* and *j*. Results are available upon request from the authors.

As argued in section 2, the nexus between climate shocks and migration is mediated by many factors; in particular the vulnerability of communities affected greatly depend on available resources. In *Table 3.2* we interact the *index of (excess) rainfall variability* with per capita GDP of the origin country – a proxy for the level of development – and with a measure of the relative importance of the agricultural sector (share of agriculture over total GDP). We find a negative and statistically significant interaction effect with per capita GDP; an excess in rainfall variability is associated with outmigration flows only in relatively poor countries (column 1 and 2). This result seems to confirm the hypothesis that population of less developed areas are more likely to cope with climatic shocks by adopting relocation strategies. In our analysis the threshold of GDP per capita below which anomalies are positively associated with migration outflows is approximately 1700 current US dollars (which includes most African countries and large countries such as China, Philippines).
The degree of vulnerability in terms of outmigration is clearly increasing in countries where the agriculture sector is large[21]. Agriculture is the sector which is more vulnerable to shocks, the outmigration-impact of large precipitation anomalies is – as one should intuitively expect – larger for countries which mostly rely on rain-fed agriculture

In *Table 3.3*, we present regression results where we test for the relevance of precipitation anomalies of large magnitude of different sign (above or below 1 standard deviation with respect long-term mean). The finding point out to the importance of considering the type of shocks. While exceptionally abundant rainfall are associated to increasing bilateral migration flows the effect of exceptionally low rainfall is not statistically significant.[22] Climate shocks might have different effects depending not only on the magnitude and sign but also on the timing of the events. In fact, given that one of the main transmission channel, as argued above, is the agricultural sector, whether the shocks falls before, after or during the main crop season might be important. Given the impossibility to conduct a highly disaggregated analysis which considers the differences in agricultural systems of all the countries in the sample, we distinguish for each country climate shocks occurring in the rain and dry seasons.

The estimation results reported in *Table 3.4* seems to confirm the relevance of the timing of precipitation and temperature anomalies. In the first column we include in the baseline model a variable which measures the magnitude of temperature anomalies (above or below 1 st deviation from the long-term mean) occurred during the rainy season. The sign of the coefficient is negative which implies that a strong decrease (increase) in temperature during this season is associated with more (less) outmigration. In column (2) we interact the climatic variable with per capita GDP, the interaction effect has a negative and significant coefficient implying a positive association between temperature anomalies and outmigration. The effects of temperature anomalies during the dry season produces have the same pattern but are substantially different in magnitude (columns 3 and 4). The last two columns in *Table 3.4* show the different seasonal effects of precipitation surplus and excess anomalies. Note from the last column that an excessive rainfall is associated with outmigration only in the dry season.

The possibility for individuals affected by changes in climatic conditions to rely on a network of family and friends who reside in other locations (migration networks) might greatly affect their

[21] Similar results are obtained using data on employment in agriculture over total employment.
[22] Note that the aggregate measure of excessive precipitation anomalies is reported in Table 3.1 column 5 and is not statistically significant.

choices in terms of adaptation strategies. The results reported in *Table 3.5 (a)* suggests that abundant precipitation (surplus wrt the mean values) occurred in the past 5 years are significantly associated with higher migration flows but the existence of dense bilateral network of already established migrants seems to mitigate the effect. We obtain a similar result when we focus only on more extreme precipitation events (anomalies above or below the mean values). This results might be due to the "insurance" effects played by migrant networks through remittances (as in Yang and Choi 2007). In column (3) we test for an heterogeneous impact of draughts (negative precipitation anomalies) and floods (positive precipitation anomalies) and find evidence that while network seems to mitigate outflows in case of floods the opposite happens in case of severe lack of rainfall. Interestingly, negative precipitation anomalies induce more international migration in origin countries that have larger networks of established migrants – *ie* international migration is "channelled" through existing bilateral migration corridors. This result is in line with case studies (for instance McLeman et al 2008) that show that migration is a feasible and affordable adaptation strategy almost exclusively when individual have already established ties – family and friends ready to assist them - in other locations. The important corollary of this empirical evidence is the fact that it is likely that future climate-induced migration flows will follow "beaten paths" rather than create new ones.

In the second part of *Table 3.5 (b)* we distinguish between precipitation shocks on the basis of the season.[23] During the rainy season, precipitation shocks (including shocks of abnormal entity, column 6) are associated an increase in bilateral migration flows in case of excessive rainfall (like floods in Bangladesh in 1998 or the recent floods in Thailand during the monsoon season which have compromised the production of rice). During the dry season, on the contrary, outmigration is generally triggered by unusually scarce rainfalls. In these cases, migrant diasporas seem to "bridge" new international migration flows. This complex role of diasporas emerges also from studies based on individual sample surveys (see Piguet 2010 for a recent survey).[24]

4. *Conclusive remarks*

In the past few years, we have often been exposed to apocalyptic figures on migration flows that will be soon induced by changes in climatic conditions. Some of these figures were taken, often uncritically, from important reports such as the Stern review (where between 150 to 200 million environmental refugees are forecasted in the next 30 years, a conservative assumption according to the authors) or other studies such as Christian Aid (2007). These estimates are often based on simplistic assumptions and what they actually measure is 'population at risk' (for instance number of people living in coastal foodlplains at less than 1 meter of elevation) rather than actual migrants. In fact, these estimates do not consider other forms of adaptation strategies and in particular do not consider how eventually relocation of population affected by climatic changes will take place.

[23] We present only results based on the specification of the climate variable as 1 year lag. Results on different time lags are available upon request.

[24] A recent case study on Bangladesh (Paul 2004) based on household surveys in tornado-affected communities finds evidence against climate induced outmigration. Evidence based on a sample of 739 rural household in El Salvador (Halliday 2006), a country with large international migrant's network, finds a positive relationship between climate shocks and migration. Analogous results are found by Munshi (2003) for outmigration from Mexican provinces to the US.

The complexity of the links implies that our knowledge on the nexus between these important phenomena relies on the ability to pool results and information using different lenses (ie from different methodological approaches).

In this paper, we contribute to the existing literature employing a "macro" approach and looking at international bilateral migration flows. We explicitly test the importance of past climate shocks of different type, magnitude, sign and timing as a determinant of bilateral flows. The study presents some limits due to data or methodological constraints – such as the lack of data on south-south migration flows or the aggregate nature of the analysis. Notwithstanding these limits, we contribute to the existing literature and find evidence of a significant association between past climate patterns and migration. The effects are highly heterogeneous and shaped by important co-factors such as the level of development, the relative importance of agriculture and the role of existing migrant diaspora. With respect to the last factor, we find that networks of already established migrant might have a complex role: in case of events such as drought – or in general scarce rainfall – might "bridge" individuals out of the affected countries hence boosting and channelling new migration flows. In other cases, for instance abundant rainfall (in particular during the rainy season), networks mitigate the adverse effects and reduce outmigration (very likely, as emphasized by other studies, through increased remittance flows).

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Table 3.1 Climate anomalies and international migration: baseline estimations

Dependent variable:	**Baseline**		**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(1)**	**(2)**
Bilateral migration flows ij (in log for OLS, in absolute for Poisson)	OLS	Poisson	PREC	PREC	PREC	PREC	PREC	PREC	TEMP	TEMP
GDP per capita i (lag 1; ln)	-0.40***	-0.36***	-0.33***	-0.29***	-0.31***	-0.407***	-0.297***	-0.418***	-0.41***	-0.41***
	(0.127)	(0.105)	(0.0861)	(0.0705)	(0.0796)	(0.0929)	(0.0850)	(0.0914)	(0.102)	(0.0994)
Employment rate i (lag 1; ln)	-0.0280*	-0.00904	-0.0163	-0.0192	-0.0174	-0.0116	-0.0179	-0.0139	-0.00857	-0.00853
	(0.0145)	(0.0160)	(0.0142)	(0.0141)	(0.0154)	(0.0134)	(0.0138)	(0.0129)	(0.0179)	(0.0183)
Distance ij (ln)	-0.81***	-0.57***	-0.57***	-0.58***	-0.57***	-0.570***	-0.577***	-0.573***	-0.56***	-0.56***
	(0.144)	(0.189)	(0.198)	(0.197)	(0.193)	(0.197)	(0.198)	(0.199)	(0.197)	(0.198)
Common language (dummy)	1.387***	0.990***	0.895***	0.893***	0.898***	0.895***	0.906***	0.886***	0.905***	0.905***
	(0.309)	(0.294)	(0.297)	(0.295)	(0.301)	(0.301)	(0.298)	(0.297)	(0.305)	(0.306)
Network migrants ij (1960s; ln)	0.310***	0.257***	0.265***	0.265***	0.264***	0.265***	0.265***	0.265***	0.266***	0.266***
	(0.0401)	(0.0374)	(0.0402)	(0.0402)	(0.0406)	(0.0405)	(0.0403)	(0.0405)	(0.0410)	(0.0407)
intra-annual rainfall variability i (lag 1)			**0.236****							
			(0.109)							
intra-annual rainfall variability i (lag 3)				**0.600****						
				(0.259)						
intra-annual rainfall variability i (lag 5)					**0.990*****					
					(0.325)					
Precipitation surplus (wrt long-term mean, lag 3)						0.000570				
						(0.000667)				
Precipitation excess anomalies (sum of absolute values, lag 3)							0.00107			
							(0.000668)			
Precipitation excess anomalies (compensated values, lag 3)								0.000984		
								(0.000693)		
Temperature surplus (wrt long-term mean, lag 3)									0.0595	
									(0.154)	
Temperature excess anomalies (wrt long-term mean, lag 3)										0.0512
										(0.394)
Constant	16.27***	6.179***	6.014***	5.571**	5.199**	6.299***	6.055***	6.499***	5.915**	6.059**
	(2.009)	(2.170)	(2.327)	(2.300)	(2.363)	(2.244)	(2.314)	(2.273)	(2.372)	(2.361)
Observations	7,495	7,495	6,313	6,313	6,313	6,313	6,313	6,313	6,313	6,314
R-squared	0.756	-	-	-	-					

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. In OLS estimation the dependent variable is ln(migration flows ij +1)t. Robust standard errors clustered by country of destination in parentheses.

Table 3.2 Rainfall variability and level of development

Dependent variable: Bilateral migration flows ij (Poisson regression)	**(1)** PREC	**(2)** PREC	**(3)** PREC	**(4)** PREC
GDP per capita i (lag 1; ln)	-0.237**	0.128	-0.333***	-0.296***
	(0.0934)	(0.266)	(0.114)	(0.101)
Employment rate i (lag 1; ln)	-0.0165	-0.0177	-0.0235	-0.0253
	(0.0142)	(0.0153)	(0.0156)	(0.0164)
Distance ij (ln)	-0.573***	-0.568***	-0.598***	-0.596***
	(0.198)	(0.196)	(0.213)	(0.213)
Common language (dummy)	0.898***	0.902***	0.790**	0.793**
	(0.297)	(0.299)	(0.312)	(0.312)
Network migrants ij (1960s; ln)	0.265***	0.264***	0.258***	0.257***
	(0.0402)	(0.0405)	(0.0390)	(0.0389)
Agricultural GDP i (lag 1; ln)			-0.0435	-0.357
			(0.261)	(0.319)
Index of rainfall variability i (lag 1)	**0.840*** **		**-0.292** **	
	(0.227)		(0.142)	
Index of rainfall variability i (lag 1) * GDP pc i	**-0.0853*** **			
	(0.0279)			
Index of rainfall variability i (lag 1) * Agric GDP i			**0.132*** **	
			(0.0468)	
Index of rainfall variability i (lag 3)				**-0.971*** **
				(0.374)
Index of rainfall variability i (lag 3) * Agric GDP i				**0.441*** **
				(0.125)
Index of rainfall variability i (lag 5)		**3.905*** **		
		(1.442)		
Index of rainfall variability i (lag 5) * GDP pc i		**-0.422** **		
		(0.214)		
Constant	5.349**	2.168	6.009*	5.483*
	(2.353)	(3.589)	(3.077)	(2.938)
Observations	6,313	6,314	5.728	5.728

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. In OLS estimation the dependent variable is ln(migration flows ij +1)t. Robust standard errors clustered by country of destination in parentheses.

Table 3.3 Precipitation anomalies and international migration: draughts versus floods

Dependent variable: Bilateral migration flows ij (Poisson regression)	**(1)** PREC	**(2)** PREC	**(3)** PREC
GDP per capita i (lag 1; ln)	-0.350***	-0.293***	-0.311***
	(0.0904)	(0.0874)	(0.0868)
Employment rate i (lag 1; ln)	-0.0161	-0.0185	-0.0175
	(0.0144)	(0.0145)	(0.0152)
Distance ij (ln)	-0.576***	-0.577***	-0.568***
	(0.198)	(0.197)	(0.195)
Common language (dummy)	0.894***	0.895***	0.905***
	(0.296)	(0.296)	(0.304)
Network migrants ij (1960s; ln)	0.265***	0.264***	0.264***
	(0.0397)	(0.0400)	(0.0407)
Positive precipitation anomalies (% values; **lag 1**)	**0.00930****		
	(0.00432)		
Negative precipitation anomalies (% values; **lag 1**)	0.00690		
	(0.00422)		
Positive precipitation anomalies (% values; **lag 3**)		**0.0234*****	
		(0.00901)	
Negative precipitation anomalies (% values; **lag 3**)		0.0133	
		(0.0116)	
Positive precipitation anomalies (% values; **lag 5**)			**0.0427****
			(0.0166)
Negative precipitation anomalies (% values; **lag 5**)			0.0214
			(0.0170)
Constant	6.131***	5.656**	5.282**
	(2.283)	(2.219)	(2.309)
Observations	6,313	6,313	6,313

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. Robust standard errors clustered by country of destination in parentheses.

Table 3.4 Climate anomalies and international migration: dry and rainy seasons

Dependent variable: Bilateral migration flows ij (Poisson regression)	**(1)** TEMP	**(2)** TEMP	**(3)** TEMP	**(4)** TEMP	**(5)** PREC	**(6)** PREC
GDP per capita i (lag 1; ln)	-0.399***	-0.374***	-0.452***	-0.494***	-0.422***	-0.273***
	(0.100)	(0.0963)	(0.0928)	(0.0961)	(0.0973)	(0.0821)
Employment rate i (lag 1; ln)	-0.00408	0.00629	-0.00539	-0.00281	-0.00901	-0.0178
	(0.0180)	(0.0183)	(0.0179)	(0.0178)	(0.0158)	(0.0148)
Network migrants ij (1960s; ln)	-0.572***	-0.574***	-0.565***	-0.563***	-0.572***	-0.572***
	(0.201)	(0.200)	(0.198)	(0.198)	(0.199)	(0.195)
Distance ij (ln)	0.895***	0.892***	0.901***	0.897***	0.895***	0.905***
	(0.300)	(0.300)	(0.305)	(0.305)	(0.300)	(0.296)
Common language (dummy)	0.267***	0.266***	0.266***	0.266***	0.266***	0.264***
	(0.0408)	(0.0408)	(0.0413)	(0.0417)	(0.0409)	(0.0403)
Temperature anomalies - **Rainy season** (**lag 5**)	**-0.332***					
	(0.126)					
Temperature anomalies - **Rainy season** (**lag 5**)		**2.637**				
		(1.038)				
Temperature anomalies - **Rainy season** (**lag 5**) * **GDP pc i**		**-0.427***				
		(0.144)				
Temperature anomalies - **Dry season** (% of mean value; **lag 3**)			-0.000457			
			(0.000300)			
Temperature anomalies - **Dry season** (% of mean value; **lag 3**)				**0.00871**		
				(0.00403)		
Temperature anomalies - **Dry season** (% of mean value; **lag 3**) * **GDP pc country i**				**-0.00132**		
				(0.000606)		
Precipitation surplus - **Rainy season** (% of mean value; lag 3)					**0.00838***	
					(0.00508)	
Precipitation surplus - **Dry season** (% of mean value; lag 3)					0.00106	
					(0.00211)	
Precipitation anomaly - **Rainy season** (% of mean value; lag 3)						0.0103
						(0.00711)
Precipitation anomaly - **Dry season** (% of mean value; lag 3)						**0.00988***
						(0.00242)
Constant	5.987**	5.160**	6.136***	6.190***	6.205***	5.438**
	(2.343)	(2.328)	(2.329)	(2.317)	(2.374)	(2.294)
Observations	6,313	6,313	6,313	6,313	6,313	6,313

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. Robust standard errors clustered by country of destination in parentheses.

Table 3.5 (a) Precipitation shocks and the role of diaspora

Dependent variable: Bilateral migration flows ij (Poisson regression)	**(1)** PREC	**(2)** PREC	**(3)** PREC
GDP per capita i (lag 1; ln)	-0.404***	-0.415***	-0.290***
	(0.103)	(0.0952)	(0.0790)
Employment rate i (lag 1; ln)	-0.00622	-0.0106	-0.0212*
	(0.0183)	(0.0151)	(0.0122)
Distance ij (ln)	-0.569***	-0.582***	-0.596***
	(0.196)	(0.189)	(0.193)
Common language (dummy)	0.898***	0.863***	0.876***
	(0.308)	(0.311)	(0.296)
Network migrants ij (1960s; ln)	0.265***	0.262***	0.277***
	(0.0416)	(0.0440)	(0.0581)
Precipitation surplus (% of long-term mean; lag 5)	**0.0376*****		
	(0.0144)		
Precipitation surplus (% of long-term mean; lag 5) *** Network**	**-0.00407****		
	(0.00190)		
Precipitation anomalies (in mm; lag 5)		**0.00641*****	
		(0.00207)	
Precipitation anomalies (in mm; lag 5) *** Network**		**-0.000604*****	
		(0.000235)	
Precipitation anomalies - **positive values** (in mm; lag 5)			**0.00903*****
			(0.00230)
Precipitation anomalies **positive values** (in mm; lag 5) *** Network**			**-0.000742*****
			(0.000274)
Precipitation excess anomalies - **negative values** (in mm; lag 5)			-0.00364
			(0.00232)
Precipitation excess anomalies negative values (in mm; lag 5) *** Network**			**0.000545***
			(0.000292)
Constant	6.173***	6.303***	6.131***
	(2.238)	(2.259)	(2.266)
Observations	6,313	6,313	6,313

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. Robust standard errors clustered by country of destination in parentheses.

Table 3.5 (b) Precipitation shocks and the role of diaspora

Dependent variable: Bilateral migration flows ij (Poisson regression)	**(5)** PREC	**(6)** PREC
GDP per capita i (lag 1; ln)	-0.393***	-0.394***
	(0.0826)	(0.0816)
Employment rate i (lag 1; ln)	-0.0136	-0.0146
	(0.0134)	(0.0131)
Distance ij (ln)	-0.576***	-0.581***
	(0.199)	(0.200)
Common language (dummy)	0.905***	0.895***
	(0.292)	(0.294)
Network migrants ij (1960s; ln)	0.266***	0.264***
	(0.0406)	(0.0406)
Precipitation surplus - **Rainy season** (in mm; lag 1)	**0.00163****	
	(0.000667)	
Precipitation surplus - **Rainy season** (in mm; lag 1) * **Network**	**-0.000151****	
	(6.42e-05)	
Precipitation surplus - **Dry season** (in mm; lag 1)	**-0.00151****	
	(0.000651)	
Precipitation surplus - **Dry season** (in mm; lag 1) * **Network**	**0.000163***	
	(8.36e-05)	
Precipitation excess surplus - **Rainy season** (in mm; lag 1)		**0.00193****
		(0.000929)
Precipitation excess surplus - **Rainy season** (in mm; lag 1) * **Network**		**-0.000182***
		(0.000101)
Precipitation excess surplus - **Dry season** (in mm; lag 1)		**-0.00192****
		(0.000893)
Precipitation excess surplus - **Dry season** (in mm; lag 1) * **Network**		**0.000258****
		(0.000104)
Constant	6.390***	6.497***
	(2.290)	(2.291)
Observations	6,313	6,313

Note: ***, **, * denote statistical significance at 1, 5 and 10% respectively; estimates include origin and destination country fixed effects, destination country by time fixed effects (275 = 25x11); robust standard error in parenthesis. Robust standard errors clustered by country of destination in parentheses.

Appendix 1 – *List of countries included in the empirical analysis*

Origin countries (155)

Afghanistan, Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belize, Benin, Bermuda, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Cote d'Ivoire, Croatia, Cuba, Democratic Republic of the Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Laos, Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Macedonia, Madagascar, Malawi, Malaysia, Maldives, Mali, Marshall Islands, Mauritania, Mauritius, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Nicaragua, Niger, Nigeria, Niue, North Korea, Oman, Pakistan, Palau, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Puerto Rico, Qatar, Romania, Russian Federation, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, Slovenia, Solomon Islands, Somalia, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Syria, Tajikistan, Tanzania, Thailand, Togo, Tokelau, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Tuvalu, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Vanuatu, Venezuela, Viet Nam, Yemen, Zambia, Zimbabwe.

OECD destination countries (25)

Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, South Korea, Spain, Sweden, Turkey, United Kingdom, United States.

Appendix 2 *–Covariates included in the empirical analysis*

Variable	Source	Number of obs.	Mean	Std. Dev.	Min	Max
Bilateral migration flows ij	OECD	10681	1,591	6,084	0	109,816
GDP pc i (lag1; ln)	World Bank – World Development Indicators /UN population division data	10545	7,02	1,235	4,141	10,920
Employment rate i (lag1)	World Bank – World Development Indicators	9449	58,5	11,47	34,5	87,7
Distance in km (ln)	CEPII Distances databases	10625	8,7	0,73	4,39	9,79
Common language	CEPII Distances databases	10625	0,175	0,38	0	1
Network migrants ij (1960s; ln)	Wold Bank – Global Bilateral Migration database	8246	5,18	3,002	0	13,979
Agriculture GDP share i (lag1; ln)	World Bank – World Development Indicators	9471	20,88	14,98	0,109	93,977

General description of climate shocks (source: elaboration on Mitchell et al. 2003)

Variable	Description
Intra-annual rainfall variability i	Mean Absolute Deviation (MAD) of monthly precipitation in the considered period / long-term MAD (period 1901-1990). An index > 1 implies higher variability in rainfall compared to the usual level of variability.
Precipitation (or temperature) surplus	Sum of monthly differences between precipitation (or temperature) in the considered period (1, 3 or 5 years lag) and monthly long-term averages. Positive values implies higher precipitation (or temperature) than the long-term mean. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in % of the long-term mean.
Precipitation (or temperature) anomalies	Sum of monthly precipitation (or temperature) shocks in the considered period (1, 3 or 5 years lag) that **are <u>at least 1 standard deviation above or below the long-term averages</u>**. Positive values implies excess precipitation (or temperature). The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in % of the long-term mean.
Positive precipitation anomalies (% values; lag1)	Sum of monthly precipitation (or temperature) shocks in the considered period (1, 3 or 5 years lag) that are **<u>equal or larger than 1 standard deviation above the long-term averages</u>**. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in % of the long-term mean.
Negative precipitation anomalies (% values; lag1)	Sum of monthly precipitation (or temperature) shocks in the considered period (1, 3 or 5 years lag) that are <u>equal or larger than</u> **<u>1 standard deviation below the long-term averages</u>**. The variable is calculate both in absolute values – respectively in mm or Celsius degrees – and in % of the long-term mean.

Descriptive statistics of climate shocks

Variable	N. of obs.	Mean	Std. Dev.	Min	Max
Intra-annual rainfall variability i (lag1)	8956	1,030	0,311	0,077	3,605
Intra-annual rainfall variability i (lag3)	23573	1,036	0,213	0,176	2,245
Intra-annual rainfall variability i (lag5)	8956	1,036	0,178	0,209	2,011
Precipitation surplus (wrt long-trem mean; lag3)	8956	-25,248	108,799	-587,685	658,481
Precipitation excess anomalies (sum of absolute values; lag3)	8956	194,105	168,739	0	1.109,301
Precipitation excess anomalies (compensated values; lag3)	8956	1,430	93,905	-467,742	699,672
Temperature surplus (wrt long-term mean; lag3)	8956	0,373	0,321	-0,515	1,835
Temperature excess anomalies (wrt long-term mean; lag3)	8956	0,725	0,416	0,098	2,169
Positive precipitation anomalies (% values; lag1)	8956	9,397	11,483	0	132,326
Negative precipitation anomalies (% values; lag1)	8956	8,040	7,702	0	47,779
Positive precipitation anomalies (% values; lag3)	8956	9,661	8,639	0	112,017
Negative precipitation anomalies (% values; lag3)	8956	8,042	4,987	0	27,597
Positive precipitation anomalies (% values; lag5)	8956	9,617	7,580	0	85,828
Negative precipitation anomalies (% values; lag5)	8956	8,121	4,251	0	24,780

Variable	N. of obs	Mean	Std. Dev.	Min	Max
Temperature excess anomalies in rainy season (lag5)	8956	0,197	0,235	-0,600	1,360
Temperature excess anomalies in dry season (lag3)	8956	-6,565	85,232	-1.372,672	484,446
Precipitation excess surplus in rainy season (% of mean value; lag3)	8956	1,517	10,187	-30,723	87,120
Precipitation excess surplus in dry season (% of mean value; lag3)	8956	2,727	13,801	-43,369	91,483
Precipitation excess anomalies in rainy season (% of mean value; lag3)	8956	16,941	12,145	0	146,032
Precipitation excess anomalies in dry season (% of mean value; lag3)	8956	20,948	12,403	0	91,483
Precipitation surplus (% of long-term mean; lag5)	8956	-1,209	8,045	-33,188	56,719
Precipitation excess anomalies (in mm; lag5)	8956	2,408	77,182	-347,588	666,025
Precipitation excess anomalies - positive values (in mm; lag5)	8956	98,599	94,171	0	829,448
Precipitation excess anomalies - negative values (in mm; lag5)	8956	96,191	85,028	0	550,570
Precipitation surplus in rainy season (in mm; lag1)	8956	-19,654	147,936	-1.151,610	1.256,093
Precipitation surplus in dry season (in mm; lag1)	8956	-7,257	90,894	-582,034	539,922
Precipitation excess surplus in rainy season (in mm; lag1)	8956	-2,575	120,429	-1.010,652	1.147,803
Precipitation excess surplus in dry season (in mm; lag1)	8956	2,815	74,352	-568,886	525,682