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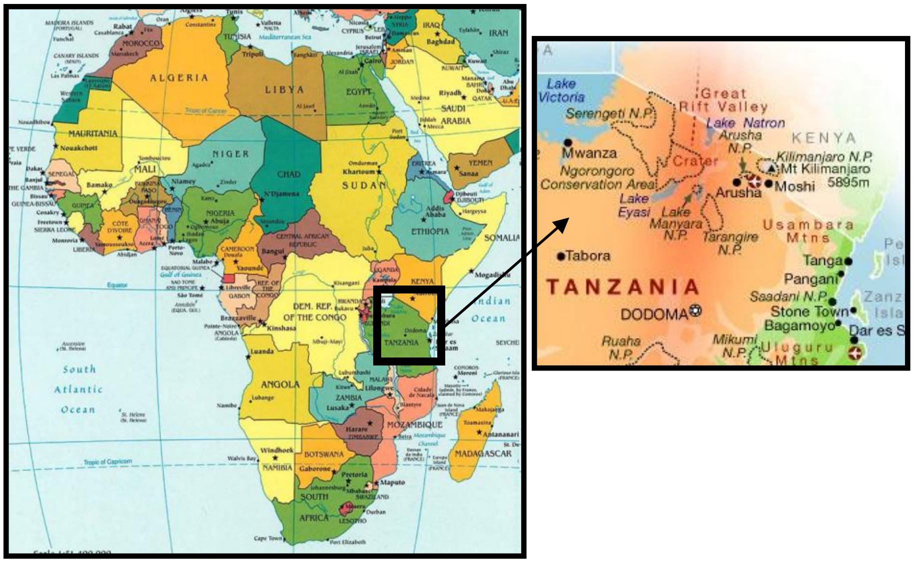
The Causes Behind, and Characteristics of the Northern Tanzanian Climate

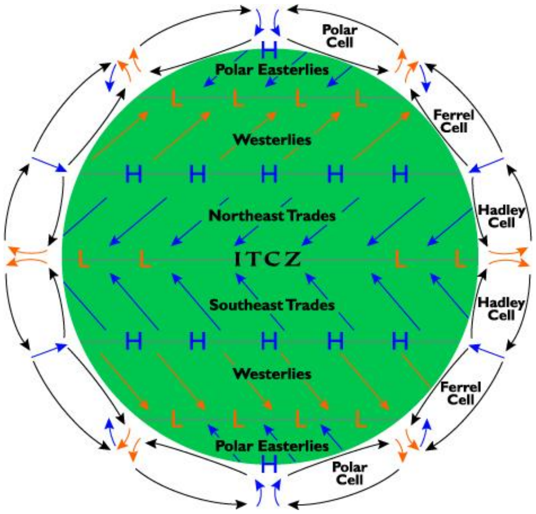
There are many inter related factors that together determine the climatic qualities of a region. Of these many factors, there are two general elements which, when analyzed together, help to piece together an understanding of what makes up the characteristics of a climate. The correlation of the elements is examining the interaction between the global pressure belts, winds, and weather patterns, with the topography of the land. When looking at what makes up the climate of Northern Tanzania, it can be shown that these are the two dominant factors. Strait up, the climate of Northern Tanzania is a tropical equatorial climate modified by altitude. This means that the region is characterized by the equatorial trade winds and the weather patterns, along with the variety of topography which exists in Northern Tanzania. With the in depth analysis of these key elements, an insight into the causes behind and characteristics of Northern Tanzania's climate will be provided.



The provinces of Northern Tanzania are located a just a few degrees south of the equator on the

African continent. Africa is unique to other continents in that it is the only continent to have significantly sized land masses on both sides of the equator. It is also distinctive by its asymmetrical shape and distinctive topography. The absence of any extensive, linear mountain chains allows a free circulation of air over the continent, so that, in general climatic changes from one place to another occur gradually. Because of this, most of Africa's climate is almost solely determined by the interaction of the global pressure belts and winds and the weather patterns associated with them. These global pressure belts and winds are caused by the uneven heating of the Earth's surface due to different sun zenith angles and the differential heating between land and ocean. The rotation of the Earth causes some additional forces to act on air including the centrifugal and centripetal forces. All of these together create what we know as the global pressure and wind circulations.

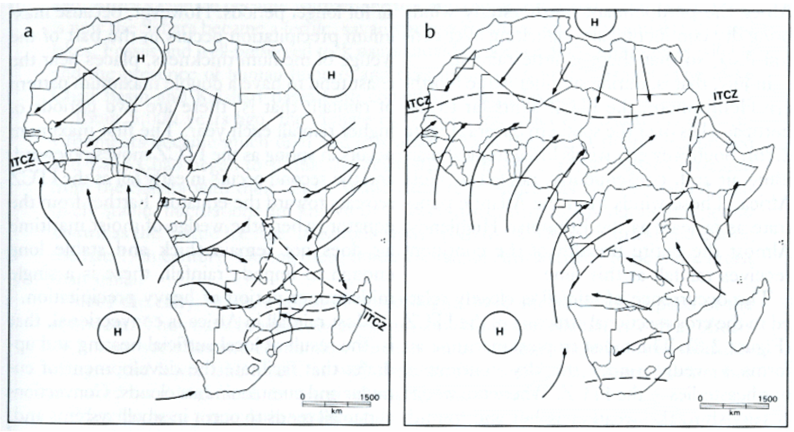
In equatorial regions, the sun's radiation is nearly perpendicular to the earth's surface causing temperatures in these regions to be the highest. This warm, moist air mass creates convective, unstable regions which produce large updrafts. These updrafts cause air to converge and rise at the surface, creating a region of relatively low pressure. They rise and subsequently cool until reaching the tropopause, the boundary between the troposphere and stratosphere. The cooler air cannot continue through the warmer stratospheric layer and thus are forced to diverge causing the air to head towards the poles. Due to the Coriolis force though, the air gets deflected and does not make it to the poles. By the time the air flow reaches about 30 degrees North and South, the deflection is so much, that the flow is latitudinal. The cool, dry air begins to sink thereby causing areas of surface high pressure. Due to the high pressure and dry conditions, it is at these latitudes that many of the Earth's deserts exist. The air then continues along the surface towards the equator, a journey in which it warms and gathers moisture. The now warm, humid air arrives back at the equator and the cycle begins once again. This circulation is called the Hadley Cell.

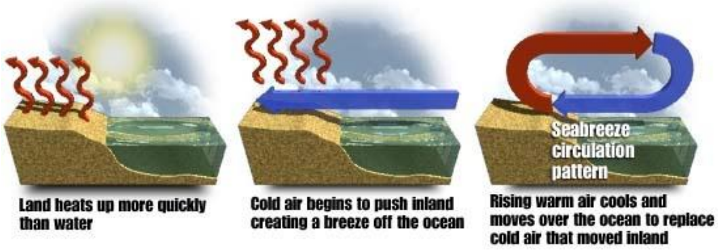


There are actually three cells in each hemisphere: the Hadley Cell, Ferrel Cell, and Polar Cell. But the Hadley Cell is of key importance because it influences the weather and climate of equatorial Africa. Figure one shows these cells as well as the deflection caused by the Coriolis Effect. In the Northern Hemisphere there is a deflection to the right while in the southern hemisphere it is to the left. In tropical and sub tropical regions, these Coriolis deflections result in the Northeast and Southeast trade winds. It is at the equator where these winds and the two Hadley cells meet causing areas of large instability from convergence and thus large convective clouds. (1) This region is called the Inter-tropical Convergence Zone, in short, the ITCZ.

The ITCZ often not located at the equator a resultant of the tilted axis of the Earth. Since the earth is tilted 23.5 degrees, the latitude of maximum differential heating changes as the Earth travels around the sun. This annual migration of the ITCZ follows the 90 degree sunlight angle latitude but at a 6-8 week delay for reasons similar to why high temperatures often occur late in the afternoon, many hours after solar noon. There are other variations in the ITCZ that are not known as commonly including its diurnal motion in which it shifts South in the morning, and North in the afternoon. (1) Since the ITCZ is in essence the meeting of two air masses, the position of it varies considerably from year to year depending on how strong these air masses are in comparison to each other. Its irregular movement is of critical importance, since it plays a large role in determining the amounts of precipitation that a region will see (7).

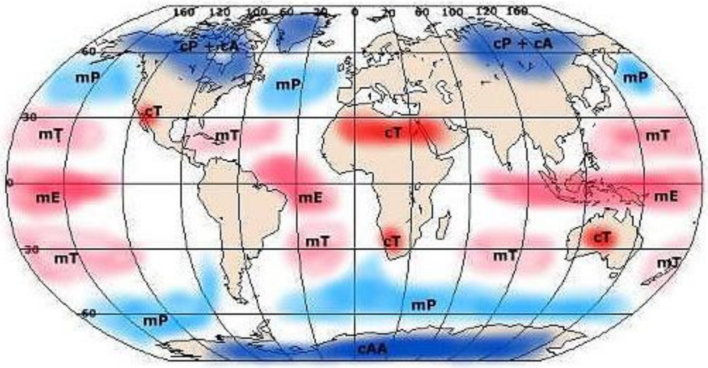
The location of the ITCZ in reference to Northern Tanzania decides which of the trade winds dominate and thus determines the average timings of wet and dry seasons there. Northern Tanzania experiences two rainy seasons and one extended dry season. The 'short rains' occur from November to December as the ITCZ pushes south of the region. The 'longs rains' occur on its northerly track back up towards the equator from about February through April. (4) From May through October it is generally dry. Figure 3 shows us the ITCZ's average location in Africa during January and July. When looking at the figure, one might one wonder why the ITCZ does not extend further south in Western Africa. In fact, it rarely goes below the equator. The reason is due to the differential heating of land and ocean. The land warms much faster than the oceans because it is much shallower and has a lower heat capacity. In the times of peak insolation (incoming solar radiation), the land is much warmer than the surround oceans causing a pressure gradient to build between the two air masses. Air over the land rises and is replaced by the maritime air. (Figure 4) This causes regions of relatively low pressure over the land and high pressure over the ocean. This explains why there are highs or anticyclones located over both the South Atlantic and Indian Oceans.   The



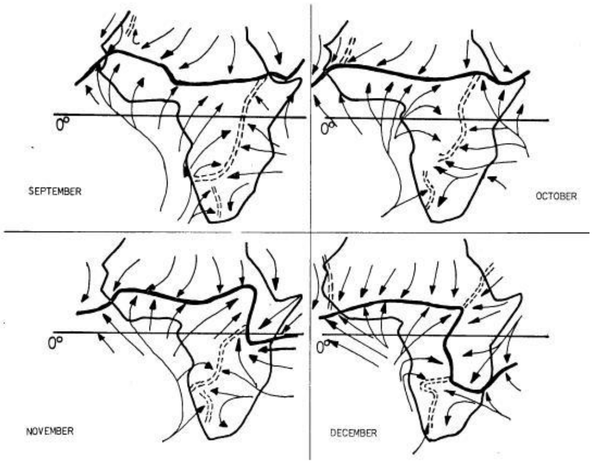


pressure gradients that result from these differentials drive air circulation and the air masses which meet at the ITCZ. They also cause other frontal boundaries to form.

Before we can look at the monthly progression of the ITCZ and how it affects northern Tanzania, it is imperative to discuss the different types of air masses that influence the climate of Africa. The three predominant air masses that influence Africa are the continental tropical (cT), maritime tropical (mT) and maritime equatorial (mE) air masses. A continental tropical air mass is generally stable with dominant high pressure. Because of the continuously subsiding air, these areas experience very hot and dry conditions. The Sahara and Kalahari deserts are the two largest sources of cT in Africa. Maritime tropical air masses also compose of subsiding air but are humid, coming from over the oceans. They are warm, humid air masses which are fairly stable but can cause some instability on the western sides of oceans. The South Atlantic Anticyclone and Indian Anticyclone are sources of the mT air mass. Maritime equatorial air masses do not have a distinct source but develop when mT air passes over oceans, gathering considerable amounts of moisture. The warm temperatures and high water contents that characterize this air mass make it very unstable. Figure 5 shows the location of these air masses in relation to Africa. The mE on the map does not show any parts of it affecting Africa but often times it can affect areas near the equator on the coast.



Now that the different types of air masses that meet at the ITCZ have been classified, we can observe the monthly progression of the ITCZ, and how its location affects the weather and different seasons that are seen in Northern Tanzania. Figure 6 shows this monthly progression of. The ITCZ is notated by the dark line and the dash lines show other frontal boundaries. The graphics start in September, the middle of the dry season, because it makes the analysis easier to see. In September and October, the ITCZ has already reached its maximum reach into North Africa and begins to move southward because the maximum insolation is occurring around the equator. Temperatures warm as the sun is directly overhead, but conditions are relatively dry due to the stable mT air mass that the south east trade winds bring in from the Indian Ocean. In November & December drastic changes can start to be seen in the ITCZ. Western portions stay well above the equator due to land-ocean differential heating and the strength of the South Atlantic Anticyclone. In East Africa there is a large dip in the ITCZ due to the local low pressure that develops over Southern Africa from 90 degree angled sunlight that the Southern Hemisphere receives during these months. If the western Africa landmass crossed the equator too, the ITCZ would follow. These months bring the 'short rains' to Northern Tanzania. The ITCZ passes through the region changing the prevailing wind from the south-east trade wind, to the northeast trade wind. These trade winds are called the Harmattan winds. They are very dry and very warm winds which originate in the Arabian and Sahara deserts. While they do not usually push the ITCZ far enough south for the rainy season to completely cease in Northern Tanzania, they correlate to the decrease in rainfall and rise in temperatures between December and February (as seen in Figure 7).



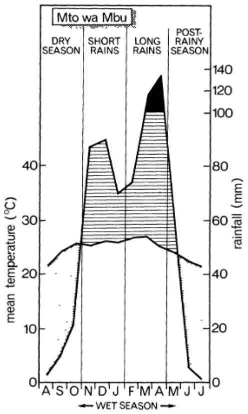
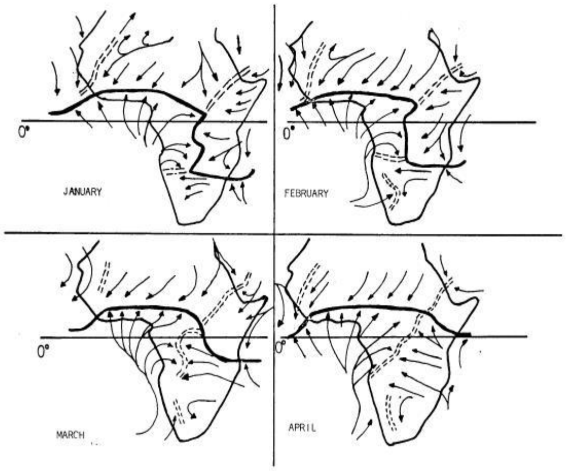
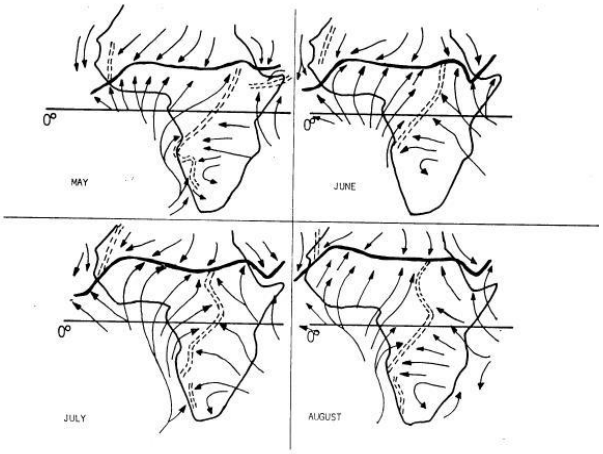


FIG. 2. Climate diagram for the village of Mto-wa-Mbu (station 6 in Fig. 1) Black indicates a per-humid period, hatched a humid period, and stippled an arid one. The biomodal curve represents rainfall, the other one the mean temperature.

In January and February the sun's location of direct sunlight has hit is furthest point into the Southern Hemisphere and is heading northward back towards the equator. Due to the 6 to 8 week lag of the ITCZ though, it doesn't start to head back towards the equator in East Africa until early February. As the center of the ITCZ begins to press northward again, towns in northern Tanzania (like Mto wa Mbu – Figure 7) begin to see a rapid increase in rainfall. March and April are by far the wettest months in Northern Tanzania. The ITCZ is overhead at this point causing copious amounts of precipitation to fall from large, convective cumulonimbus clouds. [due to the convergence of the warm, moist air from the south, and the hot, dry air from the north.] The sun zenith angle of 90 degrees is also overhead at this time of the year only adding to the instability and convection.



By May, the ITCZ has pulled well north of the equator and Northern Tanzania allowing for the Southeast trade wind flow to return to the region. The air becomes stable as the cooler mT air mass off of the Indian Ocean matriculates into the region once again. Rainfall amounts drop off substantially by the end of May, bringing in June, July, and August which see little if any rain.



During these months, the ITCZ is deep into North Africa in correspondence to the Northern Hemisphere summer. As was displayed by the paragraphs and figures above, the trade winds that affect Northern Tanzania determine what air mass is in place. Figure 8 displays a closer look of the mean monthly wind vectors over Tanzania for the months of (a) January, (b) April, (c) July, and (d) November. The region of Tanzania in which we are focusing on is the white rectangle.

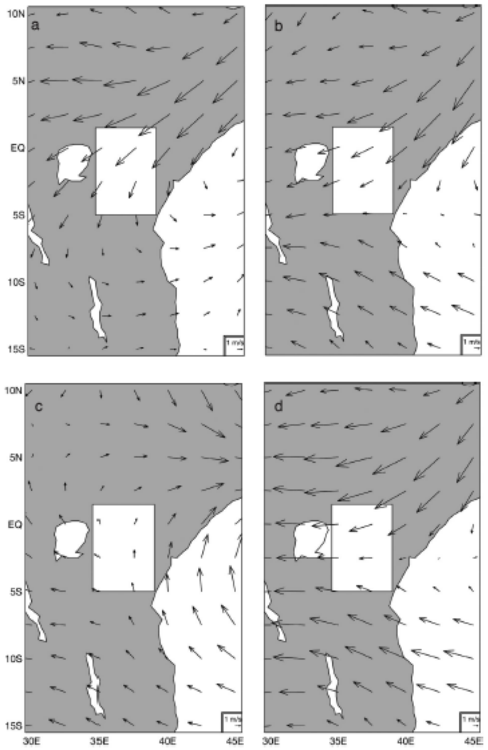
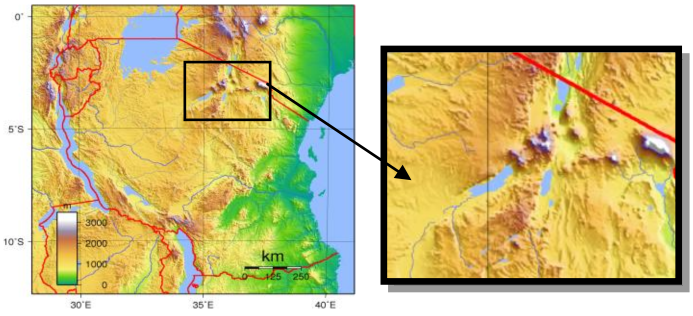


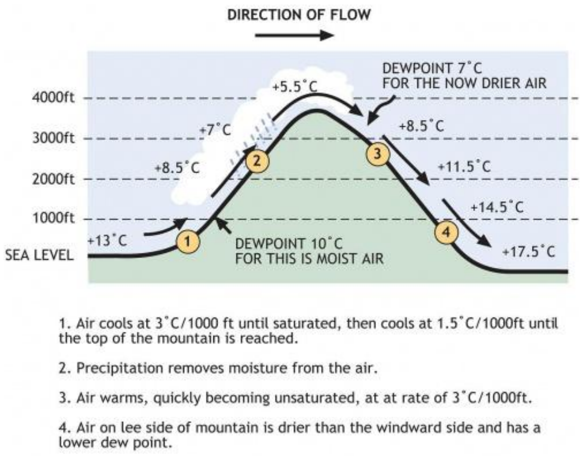
Fig. 8. Mean monthly vector winds at 700 hPa (NCEP/NCAR reanalysis data averaged over 1950 to 1990) for (a) January, (b) April, (c) July and (d) November

The ITCZ is a major factor in determining the climate and seasons of Northern Tanzania. Another factor that is just as substantial is the topography of the region. The topography of Northern Tanzania is quite contrasting and can be examined by looking at Figure 9 below. In the east, by the Indian Ocean, is the coastal plain in which altitudes range from sea level to 200 meters. Heading inland elevations increase drastically with altitudes in the central and western parts of the region ranging between 1000 and 3000m. Some of these include Ol Doinyo Lengai at 2879m, Olmoti at 3073m, the Ngorongoro Crater Rim at 2375m and the Empakaai crater rim at 3218m. There are some isolated mountains which surpass 3000m in elevation most notably, Mount Kilimanjaro at 5895m and Mount Meru at 4566m! In this area is also the Great Rift Valley which forms an elongated north-south



depression surrounded by many mountains higher than 2000m. At some points in the valley elevations are down around 500m. When looking at the close up inset in Figure 9, the rift valley can be seen by the lighter yellow shading along with the locations of most of the lakes on the map. Part of the Serengeti plains are on the western portions of this insert. The wide range of elevations in this region cause many different microclimates to exist within the climate and also contribute to the varied precipitation and temperatures which are seen in various locations of the region.

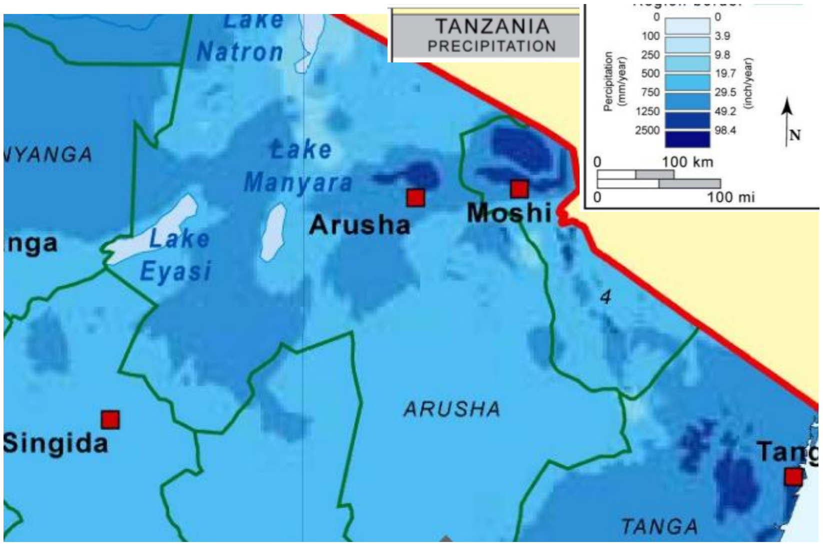
Temperature trends are the most obvious climatic characteristics that are affected by the varied topography. The temperatures at high altitude locales correlate to those at flat levels but are decreased as a function of their altitude above the flat lands. As you head up a mountain, the temperature decreases at the environmental lapse rate of 6.5 degrees Celsius per 1000m. For example if temperatures in Arusha (alt. 1400m) are 25 degrees C, then you could expect temperatures at the nearby Mt. Meru (~4600m) to be 4 degrees C. These mountains also change the amounts of precipitation that are seen in and around them. These trends are much harder to examine. As is expected, the mountains cause roadblocks moving air masses. To move, the air mass must rise over the mountains, often causing orographic precipitation to occur. Orographic precipitation occurs when large portions of the atmosphere rise in order to pass over a land barrier such a mountain or escarpment. As they rise, the air cools, expands and then often condenses to form clouds. This side of a mountain is called the windward side and often large amounts of rain can fall solely due to the uplift mechanism that the land barrier acts on the moving air mass. After the air



1. Air cools at 3°C/1000 ft until saturated, then cools at 1.5°C/1000ft until the top of the mountain is reached.
2. Precipitation removes moisture from the air.
3. Air warms, quickly becoming unsaturated, at at rate of 3°C/1000ft.
4. Air on lee side of mountain is drier than the windward side and has a lower dew point.

mass surpasses the top of the mountain, it begins to descend and condensation ceases. Photo1 shows the air mass topping the Ngorongoro crater rim and shortly there after becoming unsaturated. The unsaturated air descends this side of the mountain, called the leeward side, warming at the dry adiabatic lapse rate causing the air to be warmer than on the other side's bottom of the mountain. The reasons for this can be easily explained. As the air ascends the windward side, it spends a great deal of time cooling at the wet adiabatic lapse rate (clouds), which is a rate of 5 degrees C per 1000m as apposed to the dry adiabatic lapse rate which is 10 degrees C per 1000m. The leeward side of mountains are also much dryer and are said to be in the rain shadow. "Moldavia Gorge lies just beyond the Rift Valley in the rain shadow of the Ngorongoro highlands, making it the driest part of the whole region" (8). This is also the reason why the Serengeti plains and Great Rift Valley are relatively dry; they are in a rain shadow. Photo 2 displays the plains to the west of the Ngorongoro highlands, near Olduvai Gorge.

After examining orographic precipitation and where it tends to occur we can deduce that when we look at a map of average rainfall in Northern Tanzania that there will be generally higher amounts, around, and east of the mountains tops, and lower amounts on the western sides. When we look at figure 10 we realize that our deductions are indeed correct. The two large blobs of blue north of Moshi and Arusha show the increased rainfall on Mount Kilimanjaro and Mount Meru respectively, due to orographic effects.



When heading west from Mount Meru we encounter an area of quite low annual precipitation. This is the Great Rift Valley. Continuing west we had a darker blue area which are the mountains in and around the Ngorongoro highlands. Further to the west are the rain shadowed Olduvai Gorge and Serengeti plains.

The ITCZ and Orographic precipitation are the two key sources of rainfall in Northern Tanzania. Three smaller climatic processes produce rainfall there including continental heat lows (thermal lows), convergence rainfall, and local convective rainfall. Heat lows develop over land when strong solar radiation produces extensive warm, buoyant air masses which rise and then are replaced by moist airstreams from the oceans, bringing rain. These mainly occur within a few hundred kilometers from the ocean (sea-breezes) but can also occur near the shores of Lake Victoria (a lake-breeze). See figure 4 and the paragraphs around it for a more in depth look at how these form. Convergence precipitation occurs when moist air masses are forced to converge due to the shape of the land, thus converging, rising and then causing precipitation. The Great Rift Valley is a good example of a potential location for this to occur. Whenever the winds are blowing out of the due north or south, the air gets funneled into the valley and is forced to condense and rise. Local convective precipitation, otherwise known as thunderstorms, occur when conditions are right for convection to occur developing large cumulonimbus clouds. This type of precipitation can cause large amounts of precipitation over short time periods, effecting small areas. Much of the precipitation in the tropics are convective in nature. In fact, most of the precipitation that is associated with the ITCZ is convective. All three of these processes that create precipitation in Northern Tanzania (heat lows, local convective, and convergence) along with orographic precipitation are interrelated, and are, "…interacting with the air masses of the ITCZ, resulting in highly unpredictable amounts of rainfall" (4) Even still, the precipitation in correlation to the ITCZ and precipitation as a result of the topography, namely orographic precipitation, are the two most influential on the climate of Northern Tanzania.

It is only after researching and analyzing the Meteorological factors that are prominent in a region, that we can begin to piece together the actual climate that is given to a region.

Key Sources / Works Cited:

Cole, Roy and De Blij, H.J.. SURVEY OF SUBSAHARAN AFRICA A Regional Geography 2007 Oxford University Press, New York

Pavitt, Nigel Africas Great Rift Valley 2001

Gabler, Robert et al. (James Petersen & L.Michael Trapasso) Essentials of Physical Geography Eighth Edition 2007 Thomson Brooks/Cole United States

Maddox, Gregory G. Sub-Saharan Africa AN ENVIRONMENTAL HISTORY 2006 ABC CLIO Denver

Low, Pak Sum Climate Change and Africa 2005 Cambridge University Press New York

Anderson, Michael et al (Jan Dempewolf, Kristine Metzger, Denne Reed, Suzanne Serneels) Gereation and Maintenance of Hereogeneity in the Serengeti Ecosystem 2007

Ogutu, J. O et al. (H.-P Piepho, H.T Dublin, N. Bhola and R. S. Reid) El Nino-Southern Oscillation, rainfall, temperature and Normalized Difference Vegetation Index fluctuations in the Mara-Serengeti ecosysytem. 2007 Blackwell Publishing, Afr. J. Ecol., 46, 132-143

Oettli, P, and Camberlin, P. Influence of topography on monthly rainfall distribution over East Africa May 24, 2005 Climate Research Universite de Bourgogne

Wolanski, Eric et al. (Gereata, Emmanuel) Water quantity and quality as the factors driving the Serengeti ecosystem, Tanzania *Hydrobiologia* 458: 169-180, 2001 Kluwer Academic Publishers, Netherlands

Prins, H. H. T, (Loth, P. E.), Rainfall patterns as background to plant phenology in northern Tanzania Journal of Biography (1988) 15, 451-463

Sechambo, Fanuel, Land Use By People Living Around Protected Areas: The Case of Lake Manyara National Park 2001 UTAFITI Special Issue, Volume 4: 105-116

McGauley, Mike Introduction to the West African Monsoon 2000 <http://orca.rsmas.miami.edu/classes/mpo551/mike//index.html>

Other Sources- Mainly Graphics

http://www.defenseindustrydaily.com/images/GEO_Africa_Map_lg.jpg

http://rst.gsfc.nasa.gov/Sect14/air_masses_2.jpg

http://www.icess.ucsb.edu/esrg/IOM2/Differential_Heating.html

https://www.courses.psu.edu/test/test100_hkr/AFIM/Body_HTML/ITCZ.html

http://www.skybrary.aero/images/thumb/Fohn.jpg/500px-Fohn.jpg http://www.stockmapagency.com/media/Country/Modern/T_Tanzan_Precip.jpg

http://www.addictedtotravel.com/travel-guides/countries/tanzania-travel-guide

http://upload.wikimedia.org/wikipedia/commons/8/87/Tanzania_Topography.png