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Coastal Deserts and Their Aridities

A Study of the Comparison of Coastal Deserts

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I. ABSTRACT

This paper will focus on the comparison of coastal deserts in terms of their unique climate components, including precipitation, relative humidity, and temperature, to determine which desert is considered to be the "driest" in nature. Our two test subjects for this analysis include the Atacama Desert in western South America and the Namib Desert in southwestern Africa. Through looking at various datasets with the scope of defining the qualities of a dry climate (i.e. low precipitation, lower relative humidity, and high temperature), and taking into account traditional atmospheric processes relevant to the two regions during different El Nino-Southern Oscillation cycles, we have come to the conclusion that the Atacama Desert is in fact comparatively the drier of the two deserts.

INTRODUCTION

Coastal deserts are some of the most rare natural phenomena, with only a handful of them being found on the planet. These unique geographical features are the precipice between the vast ocean and the dry, desert dunes, creating a stunning visual juxtaposition between the extremes of wet and dry. While the deserts themselves are rather picturesque visually, they are also quite hostile towards the development and sustainability of life, and thus are rather isolated from human interaction (see Figure 1). Nonetheless, they are an interesting case study in terms of their unique, atmospheric setup, as well as their relationship with their nearby bodies of water. Coastal deserts are most prominently found on the western coasts of continents, with the Atacama being

Figure 1: A Remote Corner of the Namib Desert (Courtesy of Emperor Traveline)

on the western edge of Chile in South America, and the Namib being on the southwestern corner of Africa, in the country of Namibia. Both deserts are in the vicinity of large high-pressure systems over their respective, bordering oceans, and are one of the main contributors to their very strong temperature gradient. Breaking this concept down, both the Atacama and the Namib are located in a region colloquially known as the Subtropical High-Pressure Belt, which is located roughly 30 degrees to the north and south of the Equator. This region's main atmospheric circulation is known as a Hadley cell, which is a main contributor to trade winds, monsoonal moisture, and heat transport for the sub-Equatorial regions across the globe. Due to the placement and circulation of the Hadley cell, this region of the globe in particular is characterized to have stronger downward vertical motion, and thus convergence of air aloft and divergence of air towards the surface (see Figure 2). These atmospheric conditions provide for more clear, sunny weather patterns, as any water vapor in the atmosphere is being pushed down towards the surface. This process is preventive of any cloud formation, and thus very minimal precipitation. These conditions are favorable for a more arid or desert-like climate, especially when this weather pattern is dominant over the region for extended periods of time.

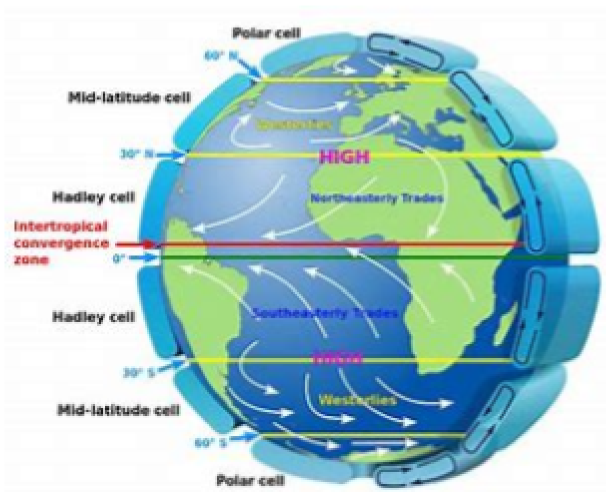

Figure 2: A Model of the Different Cells of the Atmosphere. Demonstrates the Presence of Hadley Cells Over the Subtropical Regions

The ocean currents also play an important role in the formation and sustaining of the coastal desert. Because of the high-pressure systems in control over the neighboring oceans, there is an anticyclonic rotation in play, which in turn creates northward currents along the coasts. In our case, the Humboldt and the Benguela Currents are the notable examples of currents formed along the coasts of Chile and Namibia. These currents are responsible for pulling up cooler waters from the Southern Ocean, the ocean surrounding the nearby continent of Antarctica, which is very cold in nature due to the ice that melts from the continent itself. Thus, this creates that strong temperature inversion that was mentioned earlier, between the cold ocean and the comparatively hot, desert climate.

There is some variability in this inversion for both deserts, however, which is dependent on a few different factors: the current seasonal state, and the smaller atmospheric and topographic features unique to each continent. We will explore these variabilities below.

II. ATACAMA DESERT: DATA AND ANALYSIS

One might have heard about the Atacama Desert being one of the driest places on the planet from word of mouth, and it is certainly true. The geographical setup of the Atacama is quite intriguing, as it lies on the forefront of the famous Andes mountain range. Just on the other side of the mountain peaks lies the lush, very saturated and biodiverse Amazon rainforest, which is the largest rainforest biome both in South America and the world (see Figure 3). How could such a diverse gap of rainfall occur in such a short proximity? If we refer back to Figure 2, we notice that in the subtropical regions south of the Equator, there are southeasterly trade winds

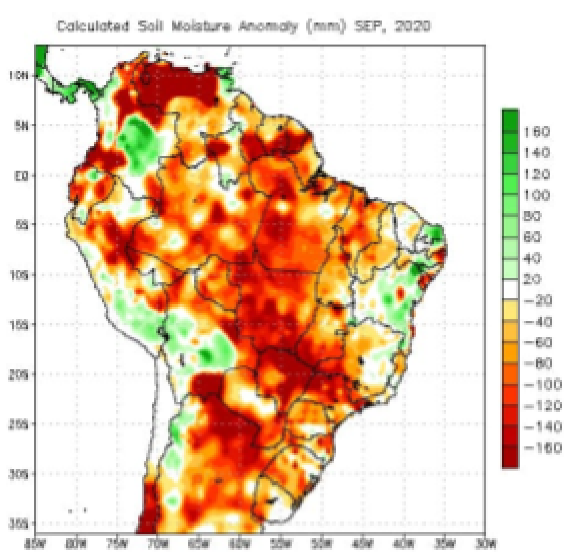

Figure 3: Calculated Soil Moisture Content for South America, Courtesy of Rain Makes Grain

that blow through the Amazon westwardly towards the Atacama Desert, due to the anticyclonic flow of the high pressure system situated over the southern Atlantic Ocean. In doing so, these winds have to encounter some of the tallest and most densely congregated peaks in the Andes chain, and thus the process of airlifting is very prominent in this region. In turn, this airlifting mechanism up the windward side of the mountains condenses moisture, and thus more precipitation can form before coasting over the mountains (this can be seen by the very saturated regions east of the Andes). After this process occurs, the now-less-saturated air races down the leeward side of the mountain, leaving little moisture to precipitate in regions such as the Atacama Desert and the Bolivian Salt Flats.

Precipitation in the Atacama is very low due to the cold ocean currents previously mentioned, topographical features of windward precipitation blocking the leeward region of the Atacama desert from experiencing rain, and the constant inversion from the cold Humboldt ocean current. That being said, saturation at the surface can create dew that is responsible for the cyanobacteria microorganisms that make up the only life in the Atacama Desert, which live under porous, translucent rock. These moments of dew formation typically occur at night due to radiational cooling of the surface (McKay et. at, 2003).

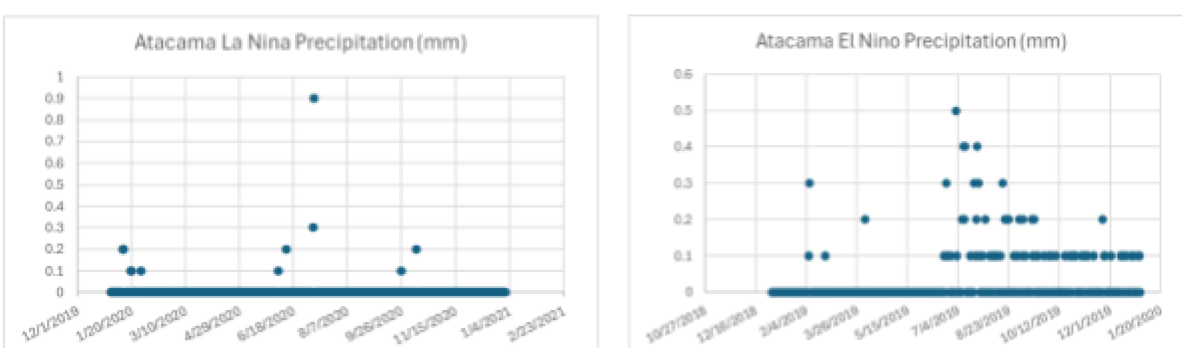

Figure 4: Graphs Describing Precipitation Amounts in the Atacama Desert During El Nino and La Nina Conditions

The low levels of precipitation in the Atacama can be seen very clearly within our data set, which is collected by the Weather and Climate database for daily temperatures under both La

Nina and El Nino conditions (see Figure 4) (Chile Climate, n.d.). South America's rainfall is primarily impacted by El Nino events, which aligns with paleoclimate data showing increased precipitation during El Nino events dating back 10,000-16,000 years ago, according to proxy temperature records (McKay et. at, 2003). From our data set, we can see that while there is an anomalous 0.9mm rainfall during the La Nina, small-scale precipitation of 0.1-0.5mm occurs much more frequently during the 2019 El Nino year.

During La Nina, only 11 days of the year had precipitation of 0.1 mm or greater (with a resolution inaccuracy of ± 0.05mm) as opposed to a staggering 74 precipitation events during El Nino. This amounts to 2.5mm of total precipitation in 2020 and 11mm in 2019. Granted, all of these readings are not considered as significant precipitation due to how low the precipitation amounts are. The Atacama typically only has a major rain event every decade. These precipitation events likely originated from condensation at the surface from fog, rather than from a typical precipitating cloud above the surface. The majority of precipitable water may have also evaporated before reaching the surface, but this is unlikely since the surface temperatures for the Atacama are not anomalously high.

Figure 5: Graphs Describing Temperature and Dewpoint Values in the Atacama During El Nino and La Nina

This may be surprising, but based on our two annual data sets for the years 2019 and 2020, temperatures in the Atacama typically fall between 10-20°C, whereas other famously arid areas like Death Valley experience 40°C maximum temperatures that can last multiple days (see

Figure 5). This supports the notion that Atacama is a temperate desert, a Köppen climate classification of a region with mean temperatures above -3°C and below 18°C. From our data, we find that both temperature and dew point follow a sinusoidal fit in accordance with the changing of the seasons in the Southern Hemisphere. The highest temperatures take place from February to March, whereas the coldest temperatures occur during July and August. During La Nina, the temperature should theoretically be lower, which matches our data set with an average annual temperature of 17.26°C in 2019 (El Nino) and an average temperature of 16.73°C in 2020 (La Nina).

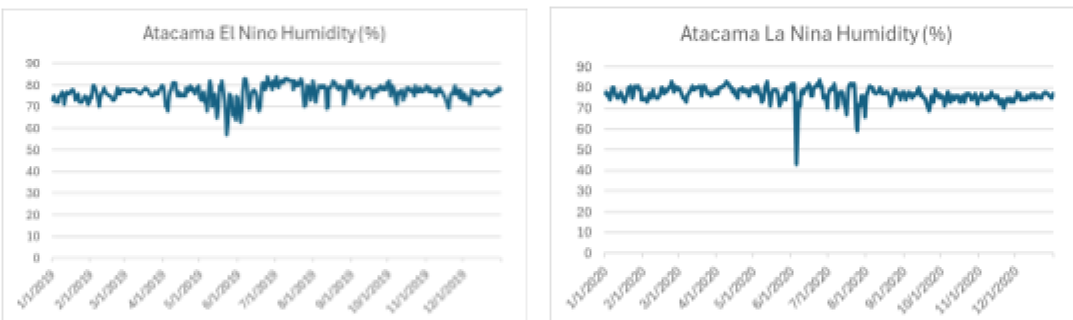

Figure 6: Graphs Describing Humidity Levels in the Atacama During El Nino and La Nina

This brings us to a puzzling part of our data set: the relative humidity (RH%). Relative humidity is determined by the ratio of vapor pressure to saturation vapor pressure. As we understand from the Clausius-Clapeyron Equation, vapor pressure and saturation vapor pressure can be calculated from the temperature and the dew point to find the RH%. At an RH% of 100%, we have saturation, and the RH% of our data set shows a consistent 70-80% range between where the relative humidity typically lies (see Figure 6). We would expect for the relative humidity to be lower because there is too little precipitable water to create precipitation, so the vapor pressure should not be so close to the saturation vapor pressure.

Additionally, since the Atacama has topographical features that leave it on the leeward side of a mountain range, we should see decreased relative humidity. This is because as an air parcel rises up a mountain, it reaches a lifting condensation level, then rises moist adiabatically to the peak of the mountain while precipitating out water. Then, on the descent to the leeward side of the mountain, it will lower dry adiabatically while maintaining the mixing ratio at the peak of the mountain. This relationship leaves a more steep gap between the temperature and dewpoint than the windward side while decreasing the mixing ratio and increasing saturation mixing ratio. On a thermodynamic diagram, you can see this interaction (see Figure 7).

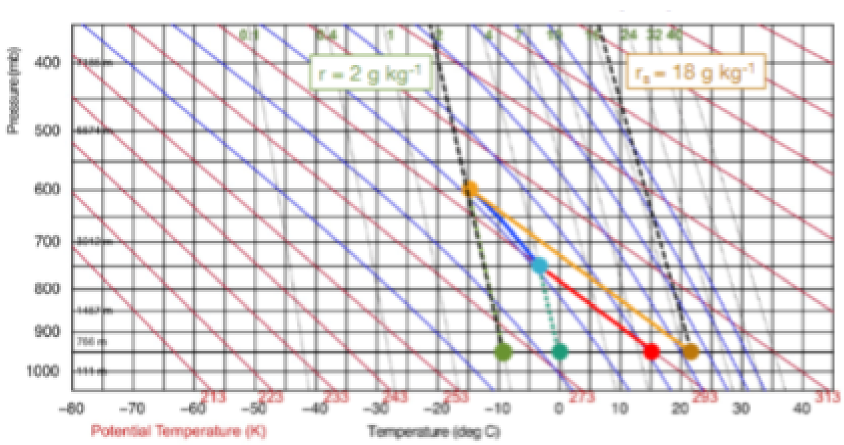

Figure 7: A Thermodynamic Diagram of the Atacama, Demonstrating the Steep Gap Between Temperature and Dewpoint

The Atacama is known to have moisture that varies heavily with the time of day, which could explain the high RH% values that seem unintuitive. We know from our temperature and dew point data that the temperature and dewpoint are relatively close to each other, and this relationship is directly responsible for the vapor pressure and saturation vapor pressure ratio that create the RH%. This high RH% could be responsible for the fog that collects in the Atacama Desert. This fog is responsible for the small amounts of water in the desert, including under the rocks where cyanobacteria live as well as fog “oases” and some precipitation events when the fog is heavy (McKay et. at, 2003). Fog frequency increases during the night due to the temperature decreasing to a point of saturation as the temperature becomes close enough to dewpoint, which in turn forms water droplets which is one of the only sources of moisture for the Atacama.

III. NAMIB DESERT: DATA AND ANALYSIS

The continent of Africa in general is known for having some of the biggest contrasts in biodiversity, from dense jungles to scorching deserts (The Sahara being a notable example) to incredible mountainous terrains to sprawling savannas. This leaves a very large spectrum of moisture content throughout the entirety of the continent. Interestingly, when looking at data from the current calculated soil moisture ranking for Africa, when looking at the region where the Namib Desert is located, there is not as strong a contrast of dry soil when compared to regions in western Africa (see Figure 8). One might think as well, similarly to the Atacama Desert, there would be a driving atmospheric force that would bring moisture from the more wet regions of Africa (i.e. Kenya, Tanzania, etc.). In this case, most of the circulation (and thus precipitation) that affects Southern Africa includes the Angola Low and the Kalahari Heat Low.

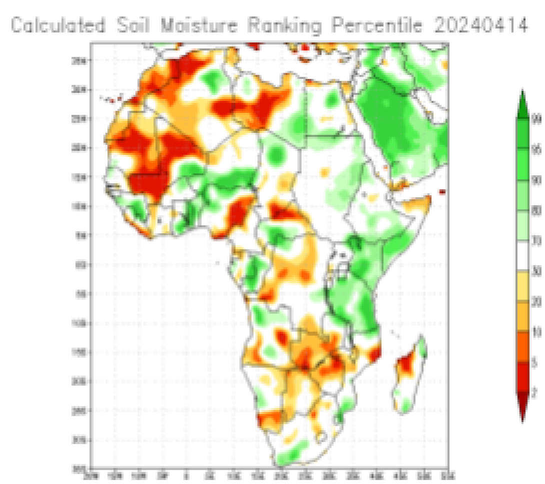

Figure 8: Calculated Soil Moisture Content for Africa, Courtesy of Rain Makes Grain

As a coastal desert, similar to the Atacama, anticyclonic motion drives southwesterly winds that cause cold ocean currents. Additionally, upwelling of deep, cold ocean waters results in the temperature of waters along the coast being too cool to vaporize. A resultant cold, moist marine atmospheric boundary layer is formed which creates a strong temperature inversion from its capping inversion separating the free atmosphere. This inversion is further reinforced by the turbulence of stratocumulus clouds that cap the marine boundary layer. The marine boundary layer height as well as La Nina events are what influence the varying moisture of Namib (Vicencio Veloso et. al, 2024).

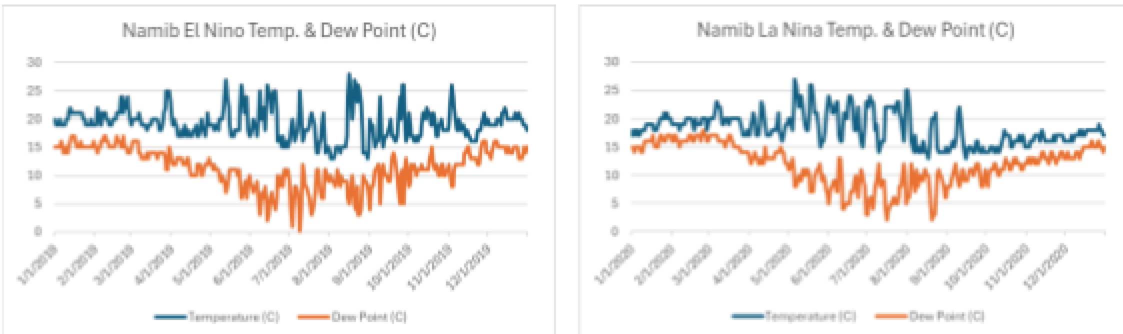

Figure 9: Graphs Describing the Temperature and Dewpoint Values in the Namib During El Nino and La Nina Cycles

For our data, we generalized Erango's weather data (a region of Namibia) for the conditions of the Namib Desert, since the Namib Desert spans across 2,000 kilometers encompassing the countries of Namibia, Angola, and South Africa. (Namibia Climate, n.d.) The temperature is much less sinusoidal than the temperature data for the Atacama; however, you can still see seasonal variance in temperature (see Figure 9). For El Nino conditions in 2019, the average temperature is 19.2°C, while the La Nina conditions of 2020 are 18.2°C— a 1°C celsius difference across years. We can also observe that the dew point temperatures in the Namib are much lower than the dew points in the Atacama. This is interesting because theoretically, it should make fog harder to form due to the difference between the dewpoint and temperature when radiational cooling occurs at night.

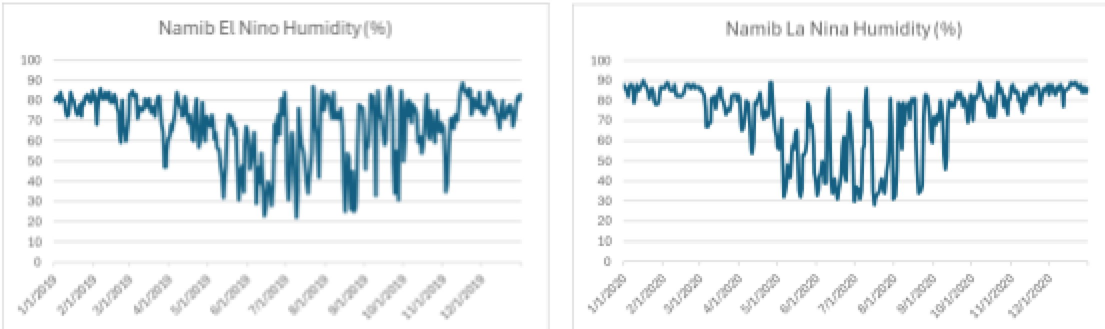

Figure 10: Graphs Describing the Humidity Levels in the Namib During El Nino and La Nina Cycles

Namib has more variance in humidity as opposed to Atacama based on our data set, reaching consistent minimums of 30% RH (see Figure 10). The data shows that daily relative humidity also drastically changes independently of monthly and seasonal trends. The humidity variance during the La Nina could have to do with the marine boundary layer variance during the fall and winter (March – August) which coincides with the minimums we see in humidity. The seasonal cycle of the marine boundary layer shows that there is a thinner marine boundary layer during the fall and winter, resulting in a lower capping inversion and a decoupling of sea surface temperature from the water vapor content offshore of the Namib. This creates synoptic variability which may explain this increased variance in humidity and temperature.

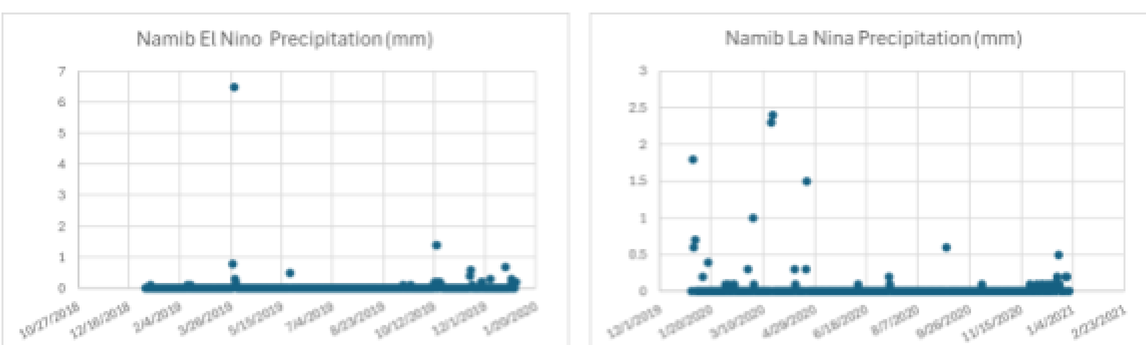

Figure 11: Graphs Describing the Precipitation Levels in the Namib During El Nino and La Nina Cycles

El Nino events are speculated to cause increased precipitated rain in coastal deserts as upwelling stops, which causes coastal waters to warm, freeing more water for vaporization. This upwelling occurs due to Ekman transport of surface water to the left of the wind. When this

Ekman transport moves water away from the coast, this water is replaced with cold water from the deep ocean (Nicholson, 2011). We can see that there is an anomalously large rain (6.5mm) during the El Nino which makes up for nearly half the year's total precipitation. However, in terms of total precipitation, the data does not reflect the pattern of El Nino having greater amounts of precipitation, since the increased frequency of rain events causes a total precipitation of 15.5 mm during La Nina compared to the 14.2mm during El Nino (see Figure 11).

IV. THE RESULTS

As expected, our data shows higher precipitation in the Namib by comparison to the Atacama. This is due to the lack of topographical features to exaggerate the lack of precipitation than the cool ocean-water circulation. The relative humidity in the Atacama across El Nino is much less varied than in the Namib with a high average annual RH% of 77% during La Nina and 76% during El Nino, as opposed to Namib with an RH% of 72% during La Nina and 67% during El Nino. While Atacama hardly dipped below the 70%–80% range for relative humidity, Namib consistently dropped to RH% values of as low as 22% over the course of the two years.

Despite the difference in RH% values, precipitation data as a variable in the deserts' aridities shows the Atacama to be more arid. With an accumulated precipitation in the Atacama of 11.0mm during El Nino and 2.5mm during La Nina and accumulated precipitation in the Namib of 14.2mm during El Nino and 15.5mm during La Nina, the Namib precipitates much more water. El Nino conditions seem to have increased average yearly temperature as expected, but precipitation data was not directly in line with predictions by patterns of coastal desert precipitation in the Atlantic. The Namib experienced more precipitation during La Nina by a small amount due to more accumulated small precipitation events, however this could have been an issue in accumulated resolution error from the instruments collecting precipitation data.

Atacama did follow the trend of experiencing more precipitation during El Nino; however, the anomalous 0.9mm rain event on July 7th, 2020 was expected to be during El Nino conditions was puzzling since it contradicts our knowledge of significant rain events being more likely to occur during El Nino Conditions.

V. CONCLUSION

As we have explored in this paper, coastal deserts are uniquely characterized in regards to their juxtaposition of desert and ocean, and are a fascinating case study to dissect. We have explored these unique environments to determine how their precipitation, relative humidity and temperature values differentiate these deserts from one another. As we constructed an analysis of comparing these components between the Atacama and the Namib Deserts, we were able to come to the conclusion of which desert qualifies as the “driest” in nature, which reveals the Atacama Desert as the more arid of the two.

We revealed that while the Atacama has the capability of producing dew during the nighttime and fog due to condensation at the surface, the desert experiences very minimal precipitation overall. While the temperatures of the Atacama are not typically as warm as a typical desert, the lack of water content in the desert leaves a barren, desolate landscape that upholds its reputation as one of the driest places on the planet. And as we’ve looked at data in regards to the El Nino-Southern Oscillation, we have come to determine that this aridity is more severe during La Nina cycles, but is still rather minute regardless of which cycle is in control.

On the contrary, we have discovered that the Atacama in comparison to the Namib Desert is the more arid of the two. The Namib in general has a greater variability in humidity levels due to the marine boundary layer, which helps to support water vapor in the atmosphere. In general, conditions in the Namib have much more variation versus the Atacama, and thus provide for more variation in terms of favorable conditions for precipitation.

While both the Atacama and Namib Deserts create a visually yet excruciating environment, challenging the boundaries of survival of most flora and fauna, our research has investigated that the Atacama's aridity is more apparent and more intense. As we continue to analyze our climate, it will certainly be of interest to monitor these coastal deserts, and see how they will transform as we enter our modern and future climate.

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