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STOCHASTIC APPROACH TO DESCRIBE RAINFALL CLIMATOLOGY AND PHENOMENOLOGY OVER ANGOLA.

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INTRODUCTION.

Probably, there is a relationship between warm and cold events in the tropical eastern South Atlantic and summer rainfall over Angola and Namibia. These events appear to originate as equatorial Kelvin waves in response to modulations of the trade winds over the tropical South Atlantic. It is well-known that the Southeast Atlantic warm events influence not only the coastal rainfall of tropical Southwestern Africa, but also there is a significant relationship between winter frontal rainfall in Southwestern South Africa and mid-latitude SST patterns, involving shifts in the jet stream and storm-tracks over the mid-latitudes.

The tropical circulation is characterized by a number of non-seasonal variations which vary in their frequency. Belonging to the group of high frequency variations are semi-diurnal pressure oscillations and diurnal local circulations changes. The former, often referred to as atmospheric tides, have their greatest amplitudes at the equator and appear to be related to direct solar heating of the upper atmosphere. Diurnal changes in local circulation systems manifest themselves in the form of sea/lake and land breezes and mountains and valley winds.

It should be noted that both atmospheric tides and local circulation systems do display seasonal variations in their intensity with more often then not the greatest intensities being displayed during the month of maximum solar heating.

The objectives of this research work are: (1) Analyse the climate and the phenomena that influence precipitation in different regions of Angola. (2) Provide better understanding of regional rainfall climatology. (3) Make rainfall regime prognostic and future climate, which are important to managing the natural and hydrological resources and planning human activities.

TARGET AREA: ANGOLA.

Angola is a country located in the coast west of Africa positioned inside of the latitudes of tropical influence and its rainfall exhibits quasi-regular low-frequency variability on both interannual and intraseasonal time scales. However, many aspects of the interrelationship between intraseasonal and interannual modes, especially the linkage between Madden-Julian Oscillation (MJO) and the El Niño South Oscillation (ENSO) phenomenon have not been described yet, i.e. whether ENSO and MJO modulate or alter each other. Considering the latitude, Angola should have a typically tropical climate.

The mean NDJFMA rainfall and rain variance during 1951-1980 indicated largest variability to the south of Angola as well as in the Indian Ocean ITCZ corresponding to the large mean rainfall in the studied-region. The rain variance in summer is dominated by the SST of Benguela Current and the African ITCZ. The Southwestern Africa is influenced by the Subtropical High Centre Pressures of the Southern Atlantic Anticyclon, which controls the seasonal oscillation of the trade winds of marine influence the marine trade winds and their continental adaptation the continental trade winds. In the dry regime, the NE trade winds are more intense. During the rainy season, they flow parallel to the coast usually, becoming marine trade winds. The results revealed that the precipitation regime in the analysed stations has a well marked annual cycle, with rainfall concentrated in the South Hemisphere summer, which is the period of intense convection, September-April. The annual cycle is related to the waxing and waning of the ITCZ, that migrates northward to approximately 12°N, in August-September; and southward, to approximately 4°S, in March-April. The annual cycle of the series corresponding to those stations, were similar, despite the differences of intensity registered. The rainfall presented long-term variability that seems to be related with the PDO (20-30 years) and high frequency variability apparently related with ENSO events (3-7 years). It was clear that African Southwestern climate variability is related to global climate variability.

Further work is required to test the dynamical hypotheses on ENSO's impact on Southern Hemisphere summer climate. During the studied period, strong influence of the Benguela's Niño was noticed, originating an increasing precipitation drift. Future work includes data analysis of neighbouring countries, submitted to robust statistical tests in order to improve their consistency, investigating, among others, the interdecadal variability of the ITCZ, and its relationship with the Benguela Current and planetary structures, such as ENSO, NAO, and PDO. Longer-term changes in the ITCZ displacement have high social and economic impacts through severe droughts or flooding over areas of its influence. However, four factors are crucial over the local weather definition, determining the climate of Angola based on (1) the migration of the Intertropical Front (ITF) and/or the Intertropical Convergence Zone (ITCZ), (2) the displacement of the South Atlantic anticyclone associated to the cold phase of the Benguela Current, (3) the Namibia Desert and (4) the altitude of the central region. The rain variance in summer is dominated by the Benguela Current and the East Pacific ITCZ.

The South Western African area is influenced by the Subtropical High Centre Pressures of the Southern Anticyclone, which control the seasonal oscillation of the trade winds of marine influence – the marine trade winds, and continental characteristic - the continental trade winds. In the dry regime, the trade winds of northeast are more intense. During the rainy regime, they are more parallel to the coast, becoming marine trade winds. The precipitation regime in all the analysed stations has very marked annual cycles, with the precipitation concentrated on the months of the South Hemisphere summer, that is the period of larger convection, being the rainiest months September-April.

The annual cycle is related with the ITCZ position, which seasonally migrates to the North, approximately 12°N, in August-September; to the South, approximately 4°S, in March-April. The annual cycles of the series corresponding to those stations, are similar, nevertheless the differences of intensity registered. The precipitation presented long period variability that seems to be related with the PDO (20 - 30 years) and apparently related with variability of shorter periods with events ENSO (3 - 7 years). It is clear that African South-Western climate variability is related to global climate variability.

ITCZ AND ITF.

The ITCZ, or Intertropical Convergence Zone, is a belt of low pressure girdling the globe at the equator (near the equator, from about 5°N and 5°S, the northeast trade winds and southeast trade winds converge in a low pressure zone). It is formed, as its name indicates, by the convergence of warm, moist air from the latitudes above and below the equator. This region is also known as Intertropical Front or the Equatorial Convergence Zone.

Solar heating in the region forces air to rise through convection which results in a plethora of precipitation. The ITCZ is a key component of the global circulation system. The location of the ITCZ varies throughout the year and while it remains near the equator, the ITCZ over land ventures farther north or south than the

ITCZ over the oceans due to the variation in land temperatures. In Africa, the ITCZ is located just south of the Sahel at about 10°S, dumping rain on the region to the south of the Sahara Desert.

The Intertropical Front (ITF) - The Equatorial Front; also called tropical front. A front presumed to exist within the equatorial trough separating the air of the Northern and Southern Hemispheres. It has been generally agreed that this front, if one exists, cannot be explained in the same terms as the fronts of higher latitudes. However, the extent to which frontal theory is to be modified and the nature of the modifications are as yet very controversial questions.

Similar to the ITCZ, the ITF zone over the oceans can be well marked; over land, sensible heating usually leads to 'breaks' or other anomalies, and the regional-scale monsoon circulation also distort, or swamp the idealized structure of the ITF and the ITCZ as well. Cloudiness (hence precipitation activity) can vary sharply over a period of 24hr. Day-to-day change of position is often small, but the zone migrates north & south through the course of a year, roughly in sympathy with the changing position of the sun.

PDO AND NAO.

The Southern Oscillation Index (SOI) is a pronounced disturbance of the atmospheric circulation over lower latitudes of the Pacific sector associated with a redistribution of mass during the course of the El Niño warming (negative value of the SOI) and La Niña cooling (positive value of the SOI) of the equatorial Pacific. The SOI is based on the standardized pressure difference between Tahiti and Darwin.

The El Niño Southern Oscillation (ENSO) phenomenon is the major cause of year-to-year variations in climate over lower latitudes and one of the most significant causes of global climate change on this time-scale. The ENSO is associated with disruption to tropical climates in many regions. The Pacific Decadal Oscillation (PDO) is a leading index associated to the ENSO phenomenon by taking into account the monthly Sea Surface Temperature (SST) anomalies in the North Pacific Ocean. In effect, to characterize the nature of the ENSO, SST anomalies in different regions of the Pacific is used.

The North Atlantic Oscillation (NAO) is a major disturbance of the atmospheric circulation and climate of the North Atlantic region, linked to a waxing and waning of the dominant middle-latitude westerly wind flow during winter. The NAO index is based on the pressure difference between the Iceland (north) and Azores (south) of the mid-latitude westerly flow. It is, therefore, a measure of the strength of these winds. Strictly, it should only be used for the north hemisphere winter period (from December to March). The NAO exerts a strong influence on year-to-year climate variability and there is evidence of longer-term trends in this phenomenon. It is related to the shorter-term shift between zonal and meridional circulation types that occurs on a day-to-day time scale and is know as the index-cycle.

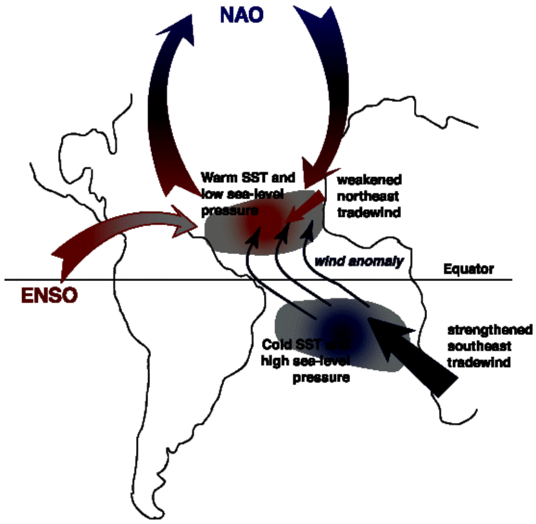


Fig.1: Revision on Planetary Circulation Configurations, which can Exert Influences in the Angola Rainfall. Source: Giannini et al., Analysis of Tropical Atlantic Variability / Preconditioning role of Tropical Atlantic Variability.

BENGUELA AND ANGOLA CURRENTS.

The Benguela Current is the eastern boundary current of the South Atlantic subtropical gyre. It begins as a northward flow off the Cape of Good Hope, where it skirts the western African coast equatorward until around 24°S-30°S. Here most of it separates from the coast as it bends toward the northwest. However, two branches of the current do continue along the coast, and one of them joins the Angola Current at the Angola-Benguela front near 16°S. There is seasonal variability in the velocity of the current.

The Angola Current forms the eastern section of a large, cyclonic gyre in the Gulf of Guinea. In the upper layer (0-100m), it seems to be formed mainly by the southeast branch of the South Equatorial Countercurrent and the southward-turning waters from the north branch of the Benguela Current. There is temporal (seasonal) variability in the velocity of the current. Another feature that can be found near the Angola Current is the Angola Dome, a cyclonic eddy doming of the thermocline centred near 10°S and 9°E. It is a cold water dome. The Angola Dome does not exist during the winter!

African Geographical Contrasts:

North Equator - it is a great desert-like or half-barren continental surface dominated by high pressure, being the coast east exposed to the dry trade winds. The climate distribution is more regular;

South Equator - contains 1/3 of the surface and the eastern coast is exposed to the humid trade winds. There is a very important climate variation from West to East. There is no "important" mountain chains that can influence the climate.

Angola Climate Characterization:

Inland – The Northern Region: warm and rainy; Central Region: formed by plateaus. This is characterized by annual average temperature of about 19°C, with a winter dry season and summer wet season; The Southwest Region - semiarid region due to proximity of the Kalahari Desert, with dry winter season and slight wet summer season. The region suffers from influences of great tropical air masses;

Littoral – The Region is characterized by annual average rainfall less than 600mm, relative humidity above 30% and mean temperature greater than 23°.

The rainfall exhibits quasi-regular low-frequency variability on both interannual and intraseasonal time scales. However, many aspects of the interrelationship between intraseasonal and interannual modes especially the linkage between Madden-Julian Oscillation (MJO) and the El Niño South Oscillation (ENSO) phenomenon have not yet been described, i.e. whether ENSO and MJO modulate or alter each other.

Fig.2: Angola is located on the south part of the Occidental Africa.. Experimental Data Set: 12 rain-gauges from Angola meteorological stations. Common Period of Reference: 1951-1980.

Experimental Design:

1. 12 rain-gauges from Angola meteorological stations. Common Period of Reference: 1951-1980;
2. 4 meteorological stations from 1951 to 2004 (detecting coastal factor);
3. 1 special Phenomenon Case Study: 1951-2004 ⇒ 1984. Comparison between observed data set and NCEP Reanalyses.

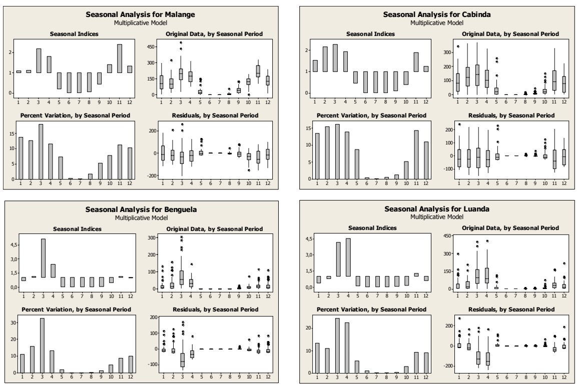


Fig.3: The monthly rainfall (1951-1980) assembling some meteorological stations. The evidence of seasonality defining the important contribution of March (3) for the rainy periods.

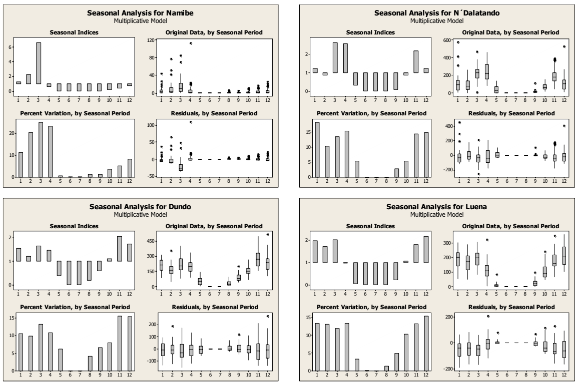


Fig.4: The monthly rainfall (1951-1980) assembling some meteorological stations. The evidence of seasonality defining the important contribution of March (3) for the rainy periods.

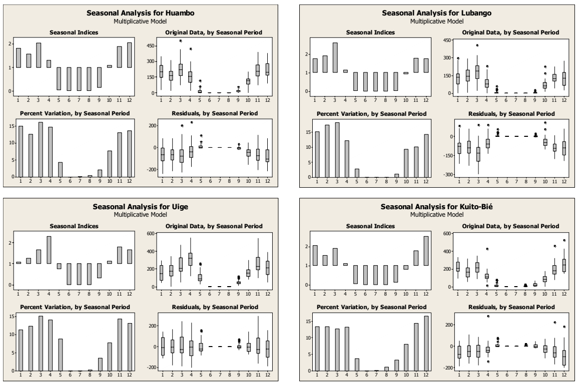
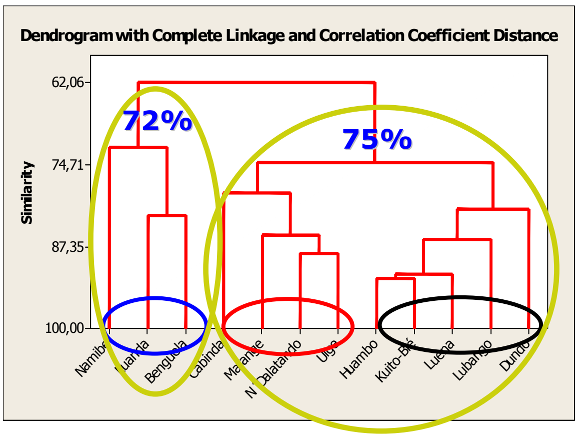


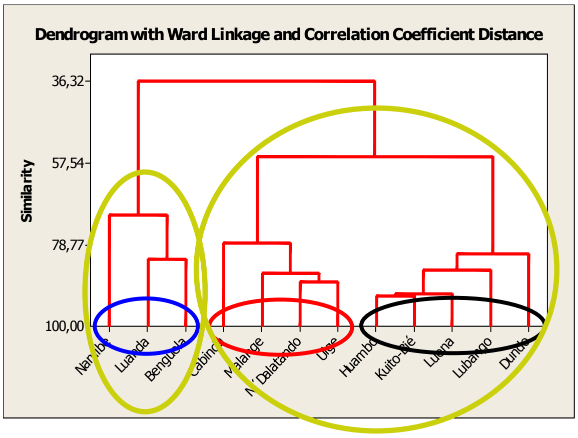
Fig.5: The monthly rainfall (1951-1980) assembling some meteorological stations. The evidence of seasonality defining the important contribution of March (3) for the rainy periods.

CLUSTER ANALYSIS.

Angola (rainfall based) is stochastically subdivided into three (eastern, central and western) separate areas, in which monthly rainfall fluctuation time series are very similar to one another



Cluster 1 (Similarity = 81.55%)
HUAMBO; KUITO-BIÉ; LUENA; LUBANGO; DUNDO.
Cluster 2 (Similarity = 79.12%)
UIGE; N'DALATANDO; MALANGE; CABINDA.
Cluster 3 (Similarity = 72.05%)
BENGUELA; LUANDA; NAMIBE.



Cluster 1 (Similarity = 81.20%)
HUAMBO; KUITO-BIÉ; LUENA; LUBANGO; DUNDO.
Cluster 2 (Similarity = 78.28%)
UIGE; N'DALATANDO; MALANGE; CABINDA.
Cluster 3 (Similarity = 71.02%)
BENGUELA; LUANDA; NAMIBE.

TARGET-STUDY METEOROLOGICAL STATION: NAMIBIE.

Desert; hot, dry; rainfall sparse and erratic The cold Benguela current keeps the *coast* of the Namibia desert cool, damp and free of rain for most of the year, with a thick coastal fog. Inland, all the rain falls in summer (November to April). Summer temperatures are high while the altitude means that nights are cool. Winter nights can be fairly cold, but days are generally warm. The mean NDJFMA rainfall and rain variance during 1951-1980 indicated largest variability to the south of Angola as well as in the Indian Ocean ITCZ corresponding to the large mean rainfall in the target-region. The rain variance in summer is dominated by the Benguela Current and the East Pacific ITCZ. The South Western African area is influenced by the Subtropical High Centre Pressures of the Southern Anticyclone, which control the seasonal oscillation of the trade winds of marine influence – the marine trade winds, and continental characteristic – the continental trade winds. In the dry regime, the trade north-eastern winds are more intense. During the rainy regime, they are more parallel to the coast, becoming marine trade winds.

TREND AND DRIFT ANALYSES.

The annual rainfall (1951-1980) assembling some meteorological stations. The evidence of a statistically significant ($\leq\alpha$=0.05) negative trend and strong interannual variability define the rainfall deficit phenomenology.

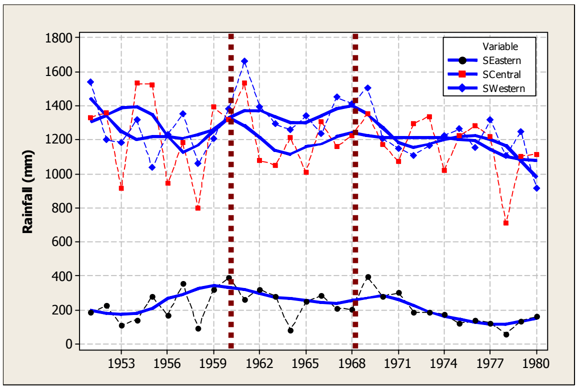


Fig.6: No structural change-point is detected for each discriminated region. The continuous line fits a LOWESS curve to the data. The Chow procedure for segmentation and the Pettitt test show no changes in rainfall behaviour over Angola.

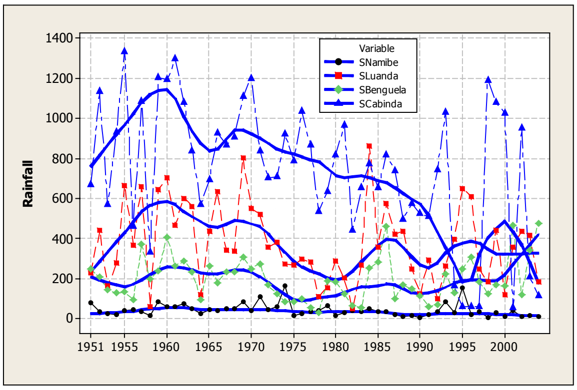


Fig.7: Coastal Precipitation Trends: 1951-2004. The annual rainfall (1951-1980) assembling some meteorological stations. The evidence of a statistically significant ($\alpha \leq 0.05$) negative trend and strong interannual variability define the rainfall deficit phenomenology.

Large Scale Circulation - Decadal Variability Diagnostic:

1. Vertical Movement Section - average along the meridian 15°E (1948-2003), between latitudes 10°N-40°S: It is observed that, in January, the latitude band 5°S-25°S presents ascending movements (ω < 0) in all target-area troposphere with maximum of about -0.8 hPa/s centred at 22°S. July presents descending movements (ω > 0) between 10°S-30°S with maximum in the order of 0.3 hPa/s, indicating predominance of the dry station in this latitudinal band. The more intense variability of ascending movements are centred in 5°S, which corresponds to the latitude of Cabinda.

2. Vertical Movement Section - average along the meridian 15°E (1948-76 & 1977-03, cold PDO phase & warm PDO phase, respectively), between latitudes 10°N-40°S: The ascending movements are predominating, practically, in overall territory of Angola (ω < -0.4 hPa/s) from the south of 10°S. Strong ascending movements from the northern of 15°S, with a kernel less than -0,8 hPa/s between 950-700 hPa. This is a possible explanation for the high rainfall intensity captured by the majority of the meteorological stations, except for Cabinda.

3. Vertical Movement Section - average along the meridian 15°E (1948-76 & 1977-03, cold PDO phase & warm PDO phase, respectively), between latitudes 10°N-40°S: There was a predominance of ascending movements between the equator (0°) and 20°S. This analysis suggests that the July's of the period 1977-03 (e.g., Luanda (8°49'S) and Cabinda (5°33´S)) were wettest when compared with the period of 1948-76.

4. Vertical Movement Section - January (summer) - average along the meridian 15°E and average along the meridian 20°E 1948-76, cold PDO phase), between latitudes 10°N-40°S: 15°E, strong subsidence between 25°S and 35°S. However, intense ascending movements up to 500 hPa at the same latitudes over the 20°E section. It is possible that the inland part of Angola has suffered some droughts (low rainfall intensity) in this period, with decreasing trends. 20°E, ascending movements in low troposphere (5°S) have weakened, however they became more intense between 12°S-20°S.

5. Vertical Movement Section - July (winter) - average along the meridian 15°E and average along the meridian 20°E 1948-76, cold PDO phase), between latitudes 10°N-40°S: It is possible that the differences between the two longitudes are resultant of the displacement of the centre of the Subtropical Highs throughout the northwest during the PDO cold phase. This may have contributed for the increase of rains in the interior in this month (July).

6. Vertical Movement Section - January (summer) - average along the meridian

15°E and average along the meridian 20°E 1977-03, warm PDO phase), between latitudes 10°N-40°S: The configurations are coherent with the positive precipitation trend observed in Benguela and Luanda, and the negative observed in Cabinda. 15ºE, subsidence is more active in the south of 20ºS however in 20ºE ascending movements until 26°S.

7. Vertical Movement Section - July (winter) average along the meridian 15°E and average along the meridian 20°E 1977-03, warm PDO phase, respectively), between latitudes 10°N-40°S: The configurations are coherent with the positive precipitation trend observed in Benguela and Luanda, and the negative observed in Cabinda. The centre of Subtropical High is displaced throughout east, what may have intensified the gradient of horizontal pressure. Consequently, there is a softly rainfall increase during the month of July in the interior.

SUMMARY.

The results reveal that the precipitation regime in all the analysed stations has very marked annual cycles, with the precipitation concentrated on the months of the South Hemisphere summer, that is the period of larger convection, being the rainiest months September-April. The annual cycle is related with the position of the ITCZ, which seasonally migrates to the North, approximately 12°N, in August-September; to the South, approximately 4ºS, in March-April. The annual cycles of the series corresponding to those stations, are similar, nevertheless the differences of intensity registered. The precipitation presented long period variability that seems to be related with the PDO (20 - 30 years) and apparently related with variability of shorter periods with events ENSO (3 - 7 years).

It is clear that African South-Western climate variability is related to global climate variability. Further work is required to test the dynamical hypotheses on ENSO's impact on Southern Hemisphere summer climate. During the period in study, strong influence of the Benguela's Niño was noticed originating an increasing precipitation drift.

PERSPECTIVES.

The very near future work includes data analysis of neighbouring countries, submitted to robust statistical tests in order to improve their consistency, investigating, among others, the interannual variability of the ITCZ, the main mechanism that "produces" rain in Tropical Africa (variation in the location of the ITCZ drastically affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes. Longer term changes in the ITCZ can result in severe droughts or flooding in nearby areas), and its interactions with the Benguela Current and Large Scale phenomena like ENSO, NAO, and PDO.

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