Atmospheric/Oceanic Influences on Climate in the Southern Appalachians

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Abstract--Despite a wealth of research, scientists still disagree about the existence, magnitude, duration and potential causes of global warming and climate change. For example, only recently have we recognized that, given historical global climate patterns, much of the global warming trend we are experiencing appears to be natural. We analyzed long-term climatologic records from Coweeta Hydrologic Laboratory (1934 to present). There is strong annular and decadal cycling in temperatures and rainfall patterns. These are confounded by a significant amount of natural climatic variability in the southern Appalachians. The natural variability is closely linked to fluctuations in the North Atlantic Oscillation (NAO). For example, the record drought in the southeastern United States, while extreme, was not unusual given historical patterns of alternating wet and dry cycles. These cycles are characteristically precluded by phase shifts in the NAO. The breaking of the drought by Hurricane Isidore and Tropical Storm Kyle (Sept. 2002) was also consistent with past drought cessation in this region. Apparent trends toward cooler and wetter conditions for this region are consistent with observed behavior in the NAO. While the highly variable nature of climate in this region makes it difficult to identify climate trends, nighttime temperatures (minimum daily) have increased over the past fifty years.

INTRODUCTION

Coweeta Hydrologic Laboratory (Coweeta), est. 1934, is one of the oldest operating experimental watersheds of the USDA Forest Service (Figure 1). Coweeta is a forested, 2185 ha watershed near the southern end of the Appalachian Mountains in western North Carolina. The precipitation and stream gauging network of Coweeta provides one of the oldest and most complete watershed scale hydrologic records in the world. The research mission is to evaluate, explain, and predict how water, soil, and forest resources respond to ecosystem management practices, natural disturbances, and the atmospheric environment; and to identify practices that mitigate impacts on these watershed resources. Coweeta, an Experimental Ecological Reserve and Long-Term Ecological Research site (http://coweeta.ecology.uga.edu), shares climatic and meteorological data and research with the National Climatic Data Center (Asheville, NC), the National Weather Service (Greenville-Spartanburg, SC) and the National Atmospheric Deposition Program.

BACKGROUND

This manuscript summarizes historical patterns in precipitation, temperature, and streamflow observed at Coweeta in the context of the primary regional climatic driver known as the North Atlantic Oscillation (NAO). Reported data are from the main climatic station, CS01, and the main weir on Ball Creek, WS08 (Figure 1). Data are available from the USDA Forest Service experimental watershed climate and hydrology databases, CLIMDB and HYDRODB (http://www.fsl.orst.edu/hydrodb/). Raw NAO data were obtained from the database of Dr. James Hurrell, National Center for Atmospheric Research, Boulder, CO (http://www.cgd.ucar.edu/cas/jhurrell/indices.html).

NAO

The North Atlantic Oscillation (NAO) is an atmospheric pressure gradient flux between a persistent equatorial high pressure system and an Icelandic low pressure system that drives climatic variability in the southeastern and coastal Atlantic United States (Hurrell, et al, 2003). The NAO is caused by, and interacts with, sea surface temperatures and wind patterns over the North Atlantic. It is similar to the Pacific Oscillation that drives the El Nino/La Nina cycle. Relative changes in strength between these systems cause large scale changes in atmospheric mass and subsequently exhibit control of general wind and weather patterns over the maritime climatic regions of the Atlantic Ocean. As such, it plays a dominant role in influencing climatic trends and variability from central North America to Europe. The winter NAO index, computed as the difference between the polar low and the subtropical high during the winter season (December through March), strongly influences climate and while varying from year to year, exhibits a tendency to remain in positive or negative "phases" for several years. The Positive NAO phase features a relatively larger pressure gradient with a stronger high and stronger low pressure centers. Winter conditions are generally mild and wet in the Atlantic coastal areas (Figure 2). Conversely, the negative phase has a weaker high and a weak Icelandic low. This allows deeper penetration of polar air masses to the United States and generally produces lower temperatures and more snow. See Hurrel, et. al. (2003) for a comprehensive NAO review.

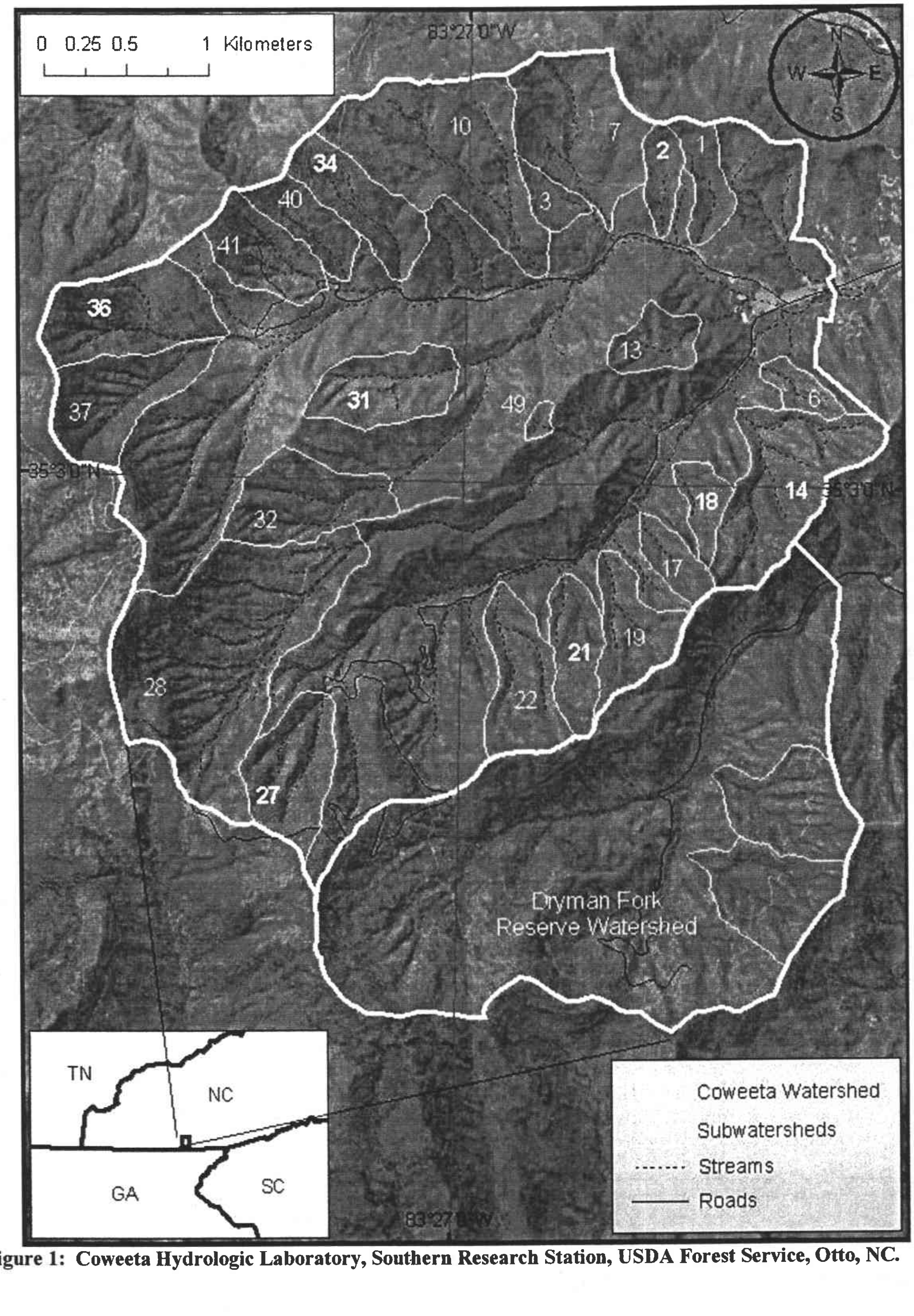


Figure 1: Coweeta Hydrologic Laboratory, Southern Research Station, USDA Forest Service, Otto, NC.

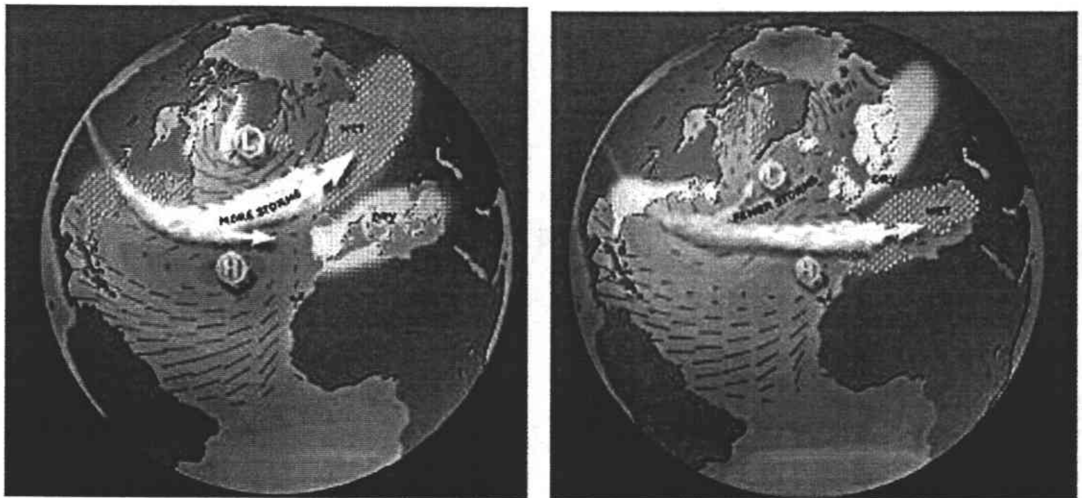


Figure 2: Generalized weather conditions during the positive (left) and negative (right) phases of the North Atlantic Oscillation (images courtesy of NOAA & Lamont-Doherty Earth Observatory, 2001).

<u>Site Description</u>

The Blue Ridge Mountains extend from southern Pennsylvania to northern Georgia, and feature narrow ridges, hilly plateaus, mountains, and high peaks. Bedrock is generally igneous and metamorphic and soils are typically of quartz-rich gneiss, mica-shist, and granitic origin. Elevations at Coweeta range from 675 m near the eastern outlet to 1592 m along the western ridge of the watershed. Slopes range from 30 to over 200 percent. Average rainfall is 230 cm/yr at upper elevations (1600 m) and 180 cm/yr at CS01 (685 m) (Swift, et al, 1988). Mean annual temperature is 12.6 C and ranges from an average of 11.7 C in winter to 21.6 C in the summer. Frequent rain, over 130 storms distributed throughout the year, sustain streamflow (127 cm/yr) and high evapotranspiration rates. The region is categorized as having a maritime, humid, temperate climate (Swift, et al, 1988).

METHODS

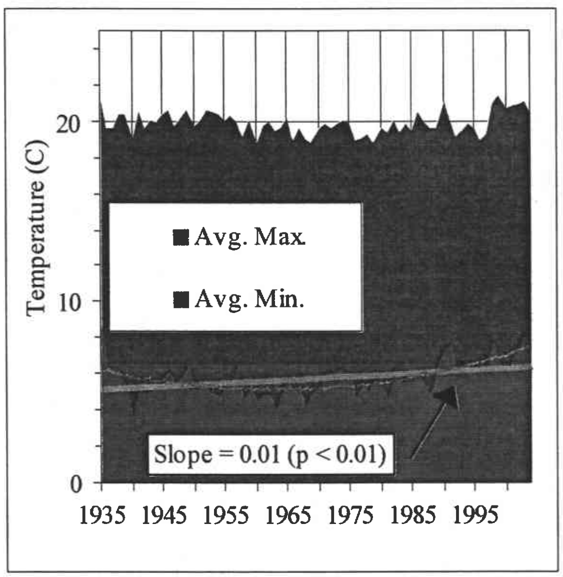
Data processing methods follow federal standards and were previously reported (Swift and Cunningham, 1986; Hibbert and Cunningham, 1966). Instrumentation, operation, and maintenance at CS01 (along with all climate stations at Coweeta) were consistent with National Weather Service standard methods. While all meteorological variables were measured at CS01, descriptions here are limited to precipitation and temperature instruments. All readings were taken at 0900 United States Standard Time, eastern time zone. Total precipitation was collected in a standard precipitation gauge and measured to the nearest 1/100th of an inch. Precipitation intensity was recorded using a Belfort Gravimetric recording precipitation gauge. Temperature was measured inside a standard shelter with maximum/minimum thermometers and a hygrothermograph. Streamflow at WS08 was measured by recording the water surface elevation (stage) on 5 minute intervals in the ponding basin of a calibrated, twelve foot Cipolleti weir (Figure 3). Time series and trend analyses of the data were conducted with standardized departure (anomaly) approach (McCabe and Wolock, 2002) by comparing individual standardized values over the period of record.

RESULTS

<u>Temperature</u>

Annual minimum and maximum record temperatures exhibited no trends over the period of record (Figure 4a). Average maximum (daily) temperatures showed no trend while minimum (nighttime) temperatures increased (Figure 4b). Curvature in the data suggested a polynomial trend however, the record was too short to test the statistical significance of this apparent trend. Average daily temperatures, (minimum + maximum)/2, exhibited a periodicity consistent with Winter NAO data (Figure 5); NAO and temperatures were unbiased through the 1950's, below average during the 1960's and early 1970's, and positively biased since.

Figure 3: Twelve foot Cipolleti weir at WS08 (760 ha) during Tropical Storm Isidore, September, 2002.



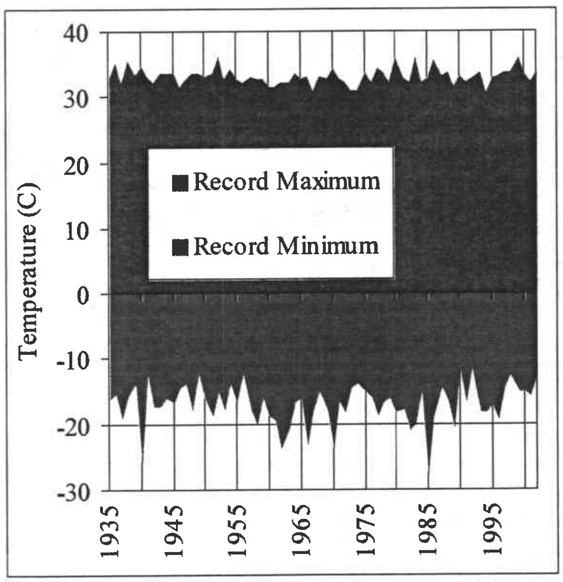


Figure 4a: Record temperatures at Coweeta exhibited no trend.
Figure 4b: Long term average minimum temperatures (nighttime) were increasing. Curvature in data suggested a polynomial or wave function however, the period was too long to identify with existing data.

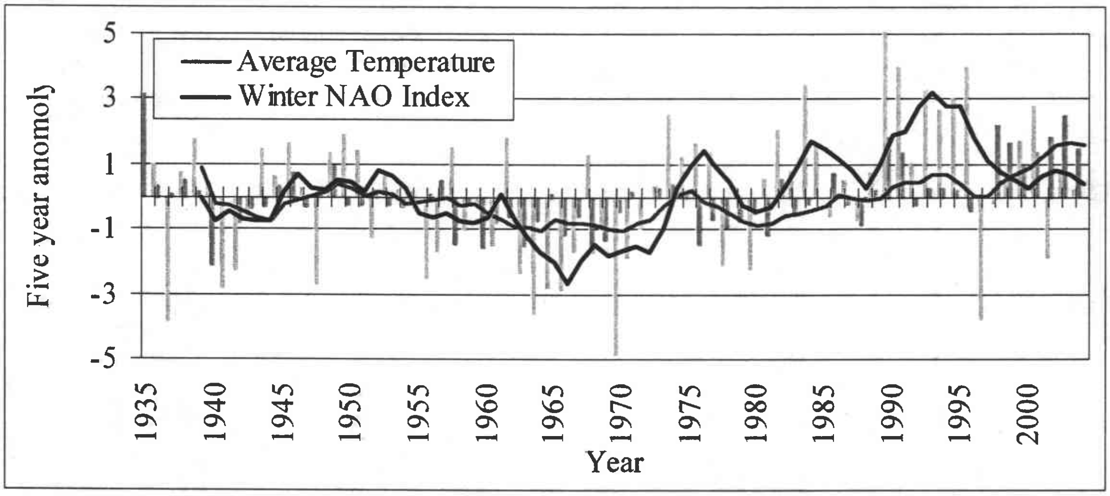


Figure 5: Average annual temperature and winter NAO anomaly (bars) and five year average trend lines.

Precipitation and Stream flow

Annual precipitation (Figure 6a) and stream flow (as water yield, Figure 6b) exhibited no trends over the period of record. Conversely, when precipitation and stream flow were compared with the winter NAO, dry and wet trends were evident (Figure 7). Wet and dry periods, indicated by 5 year moving average, were preceded by positive and negative phases of the NAO.

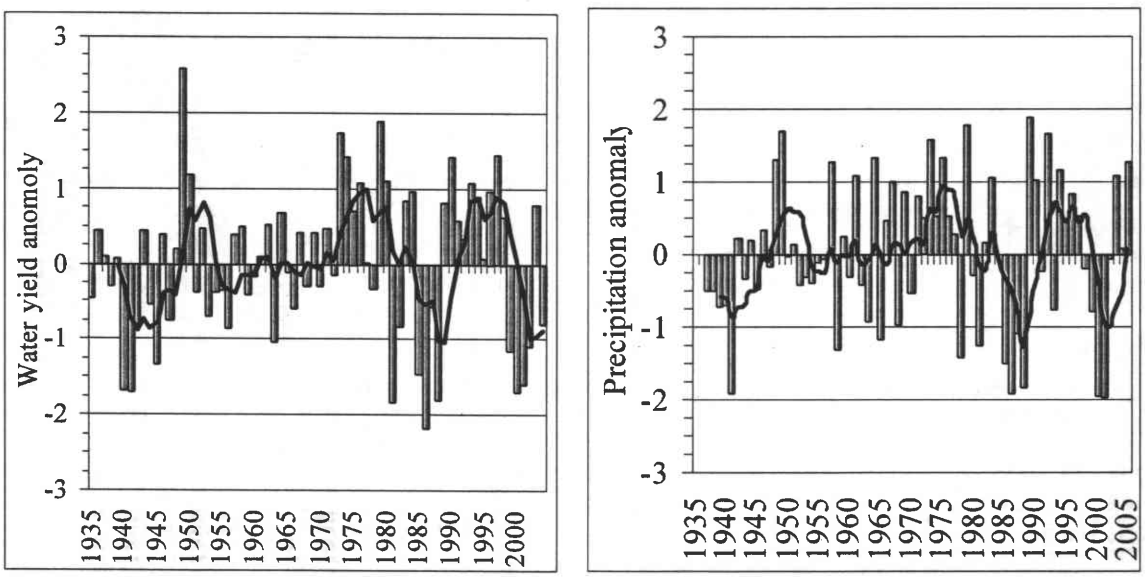


Figure 6a: Annual precipitation anomaly and five year trend at Coweeta.
Figure 6b: Annual stream flow (water yield) anomaly and five year trend at Coweeta.

DISCUSSION AND CONCLUSIONS

Analyses of core climatic data from the Coweeta Hydrologic Laboratory indicated long-term positive increase in minimum, nighttime temperatures and periodicity in average annual temperature and total annual precipitation and streamflow. This periodicity was consistent with phase shifts in the winter NAO. The winter NAO plays an important role in controlling the track of air masses across the region hence, it may steer general tendencies in regional climate (Portis, et al., 2001; Hurrell, 2000). Boyles and Raman (2003) reported recent trends in temperature and precipitation; however, these were generalized and did not address linkages with the NAO. While similar patterns and linkages exist for other maritime climatic regions in closer proximity to the Atlantic Ocean, (Karabörk, et al., 2005; Hayden and Hayden, 2003; Higgins, et al., 2000), Coweeta data indicated the influence of the NAO extend far inland. Previous research found no relation between El Nino/La Nina (ENSO) oscillation in the Pacific and Coweeta data (Grenland and Kittel, 2002; Greenland, 2001). This is likely because the southern Appalachians are too far away from the southern Pacific to be affected by its climatic influences.

Long-term climatic monitoring is very important because it helps explain current weather in terms of what has happened in the past and what may happen in the future. There is a significant amount of natural climatic variability in the southern Appalachians. The natural variability is closely linked to variability in the NAO. For example, the record drought in the southeastern United States (1999 - 2002), while extreme, was not unusual when considered in the context of historical patterns of alternating wet and dry cycles. These cycles were linked to shifts in the NAO. Similarly, the breaking of the drought by Hurricane Isidore and Tropical Storm Kyle (Sept. 2002) was typical for this region as past droughts have been broken by hurricanes or tropical storms. While recent trends toward warmer and wetter conditions for this region were consistent with observed behavior in the NAO, the warming trend was stronger than expected, given historical patterns; the NAO has had a positive bias from the early 1970's through present. These trends in core climatic data were consistent observed NAO behavior however, predicting future behavior is difficult due to interdependency between global climate trends, the NAO and sea surface temperatures (Eden and Jung, 2001).

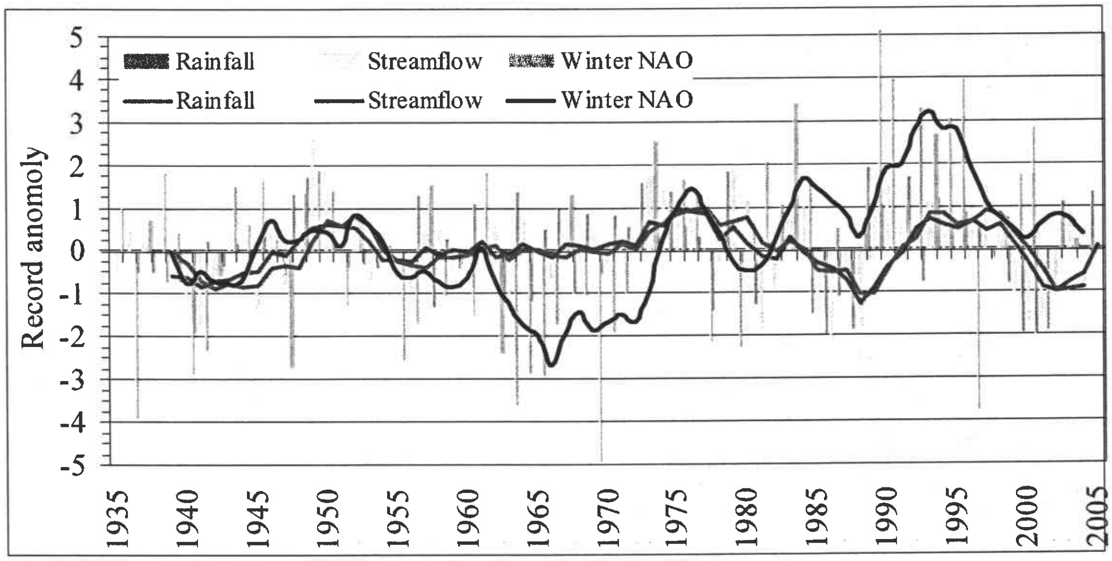


Figure 7: Average annual precipitation, streamflow, and winter NAO index anomaly (bars) and five year moving average trend lines.

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