

El Niño / Southern Oscillation and North American Land Birds

by Steven B. Feldstein

2217 Earth-Engineering Science Building

EMS Environment Institute

Pennsylvania State University

University Park PA 16802

sbf@essc.psu.edu

Introduction

From the end of 1982 through the first few months of 1983, in the Galápagos Islands of the eastern tropical Pacific Ocean, there was a huge mortality of nesting seabirds. For example, populations of the Galápagos Penguin (*Spheniscus mendiculus*) and Flightless Cormorant (*Phalacrocorax harrisi*) declined by 49% and 77%, respectively (Valle and Coulter 1987). Other species, such as Blue-footed Booby, Lesser Frigatebird, Magnificent Frigatebird, and Brown Pelican, also experienced high mortalities. Many individuals of these and other species managed to survive by migrating away from the Galápagos Islands, abandoning their young birds to starve to death.

At first, this dramatic incident puzzled ornithologists. However, it quickly became evident that this massive mortality and migration of seabirds was due to the occurrence of an exceptionally strong warming of the waters in the eastern tropical Pacific Ocean. Such a pattern of oceanic warming was a clear signal of the occurrence of an El Niño. Measurements of the sea surface temperature (hereafter, SST) subsequently revealed that the 1982–1983 El Niño was the strongest El Niño up to that time during the 20th century. The ocean water in this region is normally cold due to the up-

welling of deep water from far below the ocean surface. Accompanying this cold water is an abundance of nutrients that supports a diverse ecosystem. During an El Niño, this cold water upwelling is suppressed. As a result, there is a large reduction in available nutrients, leading to a collapse in the populations of the fish and other marine species that seabirds normally prey upon.

Twenty years ago, El Niño was not only unknown to the public; even most atmospheric scientists were unaware of this phenomenon. The apparent intensity and dramatic impact of the 1982–1983 El Niño on worldwide weather, causing destructive floods and devastating droughts on a global scale, brought this phenomenon to the attention of atmospheric scientists and the general population alike throughout the world. In North America, perhaps the most striking influence of this El Niño was the rash of severe storms that battered the coast of California.

Over the past two decades, since the 1982–1983 event, there have been many interesting scientific studies on the impact of El Niño on North American birds. Most of these studies have focused on seabirds. Presumably this emphasis on seabirds stems from the observation that during El Niño the SST in a narrow strip along much of the west

coast of North America increases by several degrees centigrade. This SST increase not only leads to a reduction in the nesting success of several West Coast seabird species (e.g., Wilson 1991, Harding *et al.* 2003), but also coincides with numerous sightings of warm-water species, such as Black-vented Shearwater, Red-billed Tropicbird, Elegant Tern, Xantus's Murrelet, and Craveri's Murrelet, at latitudes well to the north of where they are normally seen. These El Niño / seabird relationships will not be further discussed in this article.

There has been much less research on the impact of El Niño on North American land birds—the focus of this article—presumably due to the more subtle and indirect links between El Niño and land birds. In this article, I summarize the results of several recent scientific studies on the impact of El Niño on North American land birds, and I briefly discuss a simple technique commonly used by atmospheric scientists that might help enhance our understanding of the relationship between El Niño



Galápagos Islands; November 2002. © Jan Nachlinger.

The effects of El Niño on marine bird species, such as the Galápagos Penguin (above, with marine iguana, *Amblyrhynchus cristatus*) and Flightless Cormorant (right), are well known. Comparatively little studied, however, is the question of El Niño's effects on land bird populations. This article addresses that question and proposes several investigations that could be carried out by birders in North America.



Galápagos Islands; November 2002. © Gwen Kittell.

and North American land birds. I also discuss the science that describes how El Niño affects the weather and climate over North America. (For our purposes, *weather* is defined as the day-to-day variation in temperature, precipitation, and wind, whereas *climate* is defined as the monthly or seasonal average of the weather.)

Studies of the Impact of ENSO on North American Land Birds

Here I summarize the findings of three recent papers that examined the relationship between ENSO and

North American land bird populations (Sillett *et al.* 2000, Morrison and Bolger 2002, Nott *et al.* 2002).

Sillett *et al.* (2000) examined demographic changes in Black-throated Blue Warbler populations over several ENSO events (1986–1998), both on their tropical winter quarters in Jamaica and on their mid-latitude breeding grounds in New Hampshire. Relationships between warbler survival and fecundity to ENSO were found. During El Niño events, when the rainfall is lower than average in Jamaica, fewer adults were found to survive the winter. The opposite was found during La Niña events. The authors attributed these differences in survival to the fluctuations in food availability, which they linked to the amount of rainfall. Further observations suggested that this impact of ENSO extends into the breeding season, as the fecundity (as measured by the number of fledglings per nest and

continued on page 610

El Niño Southern Oscillation

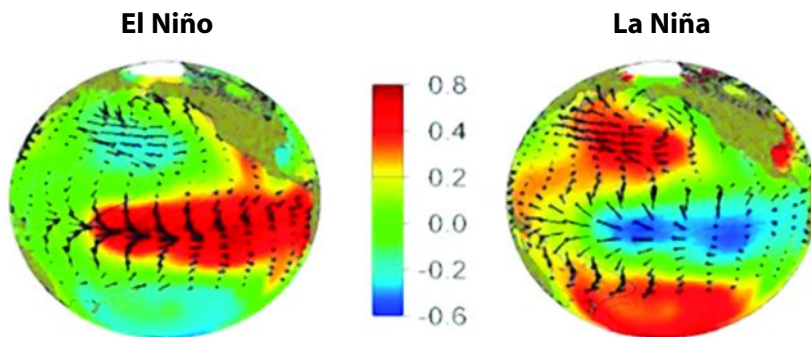


Fig. 1. SST and surface wind anomalies during typical El Niño and La Niña events. The SST anomaly values are normalized to give a maximum value of 1.0. Image courtesy of © the University of Washington.

Science of El Niño / Southern Oscillation (ENSO)

There is much confusion in the popular media as to what is meant by the term El Niño. The standard scientific definition is that El Niño represents a warming of the sea surface in the eastern and central tropical Pacific Ocean (between the Date Line and the South American coast). These characteristics are illustrated in Fig. 1, which shows typical SST anomaly values during an El Niño event. (Throughout this article, the term *anomaly* will refer to the difference between the value of a variable during a particular month and the value of that variable averaged over many years for that month.) For an average El Niño, the SST warms by one or two degrees centigrade, with a three- or four-degree warming during a more extreme event. In those years when an El Niño event takes place, a well-organized SST anomaly first appears between June and August. The SST anomaly gradually increases in strength, attaining its largest amplitude usually by October. By December, the SST anomaly is typically decaying, and by April it is usually only weakly present (Larkin and Harrison 2002).

The El Niño SST warming described above is part of an irregular cycle that repeats every three to seven years. During the opposite side of the cycle, known as La Niña, there is a cooling of the SST in the eastern and central tropical Pacific (Fig. 2 shows a listing of the most recent El Niño and La Niña events). The spatial pattern of this cold SST anomaly is similar to that for El Niño, except for the change in the sign (+ or -) of the anomaly (see Fig. 1). The growth and decay of the La Niña SST anomaly tends to occur over similar months as those for El Niño (Larkin and Harrison 2002).

In order to reflect the observation that changes to the atmosphere coincide with an El Niño or La Niña, scientists coined the name El Niño / Southern Oscillation (hereafter, ENSO) for this cycle. The El Niño part of this name represents the oceanic part of the cycle, *i.e.*, the warm and cold SST anomalies described above, and the Southern Oscillation refers to the atmospheric contribution, which takes the form of a seesaw fluctuation in the sea-level pressure between Tahiti and Darwin, Australia. As first observed more than 70 years ago by Walker and Bliss (1932), during an El Niño event the average sea-level pressure is reduced at Tahiti and is enhanced at Darwin, Australia. The opposite changes in sea-level pressure occur during a La Niña event. Although the name ENSO is firmly engrained within the scientific community, this name is unfortunately somewhat misleading. This is because this name may incorrectly suggest that El Niño is much more important than La Niña.

During an El Niño, because the water in the eastern

tropical Pacific is warmer, there is an increase in evaporation. This leads to an increase in the strength and frequency of thunderstorms (see Fig. 3). When many of these thunderstorms occur at the same time and extend over a fairly broad area, the air is compressed in the vertical direction. This causes the excitation of so-called **planetary-scale Rossby waves**, which propagate northeastward toward North America (Hoskins and Karoly 1981, Sardeshmukh and Hoskins 1988, Held and Kang 1987).

To put it in technical terms, Rossby waves occur in fluids on rapidly rotating spheres, such as the atmosphere and ocean; the adjective 'planetary scale' refers to the very large horizontal scale of the Rossby waves, typically being greater than several thousand kilometers. To put it in more familiar terms, consider the simple analogy of dropping a stone into a body of water. The behavior of the stone is analogous to that of the thunderstorm, since the stone depresses the surface of the water, which in turn excites surface-water waves. As we all have experienced, these waves take on the shape of concentric circles, which continue to propagate in an outward direction until they dissipate due to friction. The planetary-scale Rossby waves behave in a similar manner, as they propagate away from their source region in the eastern and central tropical Pacific toward North America. For further discussion, see <www.cdc.noaa.gov/ENSO/enso.description.html>.

Among the many differences between surface-water waves and Rossby waves, there are two that are crucial for our discussion: (1) Surface-water waves generated by the stone may travel tens of meters before being dissipated, whereas Rossby waves can easily travel half way around the globe; and (2) these surface-water waves usually have a wavelength of just a few centimeters, whereas the Rossby waves have a wavelength that is typically several thousand kilometers.

At almost all times there is some Rossby wave propagation from the eastern and central tropical Pacific toward North America. Both the El Niño and the La Niña SST anomalies alter the characteristics of this wave propagation. As described above, during an El Niño, there is an increase in the thunderstorm activity in the eastern and central tropical Pacific. This leads to the more frequent excitation by thunderstorms of large-amplitude Rossby waves that propagate to North America. The opposite characteristics occur during a La Niña event. Because of the colder SSTs in the eastern tropical Pacific during a La Niña, there is less evaporation and thus a reduction in the thunderstorm activity (see Fig. 3) and a corresponding decrease in the frequency and amplitude of the Rossby waves that propagate to North America. Returning to our analogy of dropping stones, we consider the scenario where stones are continuously being dropped into the

body of water. The analogy to El Niño would be to drop the stones more frequently and to use larger stones. This increases the frequency of excitation of the surface-water waves and also increases their amplitude. The corresponding analogy to La Niña would be to drop these stones less often and to use smaller stones. This analogy is based on the property that the changes in thunderstorm activity over the eastern and central tropical Pacific during El Niño and La Niña events have a stronger influence on North American climate than do the thunderstorm changes over the western tropical Pacific (see Fig. 3).

The planetary-scale Rossby waves that reach North America from the eastern tropical Pacific during an El Niño or La Niña have their greatest influence during the winter season. One may wonder why the impact of El Niño and La Niña is greatest during the winter, since the El Niño and La Niña SST anomalies typically reach their maximum amplitude during October. This question has been addressed in the atmospheric science literature. Without going into much detail, one factor is the presence of a jet, *i.e.*, a narrow belt of very strong winds, over the central subtropical Pacific Ocean. This jet provides an energy source which amplifies the Rossby waves that are propagating from the eastern tropical Pacific toward North America (Simmons *et al.* 1983, Branstator 1985a, Branstator 1985b). In addition, the mid-latitude storms associated with day-to-day weather interact with the planetary-scale Rossby waves in a manner that further increases their amplitude (Kok and Opsteegh 1985, Held and Kang 1987). Both of these processes have their strongest influences during the winter season. Therefore, these two processes more than compensate for the reduction in the amplitude of the SST anomaly during the winter.

Schematic diagrams (Fig. 4) illustrate the average North American climate during both El Niño and La Niña events, for the months of January through March. The differences between the El Niño and La Niña climates in Fig. 4 are due mostly to the influences of the planetary-scale Rossby waves excited by the El Niño and La Niña SST anomalies. Keeping in mind that during an average winter the observed winds are intermediate between those shown in the two schematic diagrams in Fig. 4, we see that one impact of these planetary-scale Rossby waves is to displace the Pacific jet stream southward during an El Niño and northward during a La Niña. Other features to note in Fig. 4 are that the jet stream takes on a west-to-east orientation across the southern states during El Niño and a more wavy structure across the northern states during La Niña. Another important difference is that the polar jet stream is stronger and more extensive during La Niña.

Distinct differences between the El Niño and La Niña anomalous temperature fields can also be seen in Fig. 4. For example, during El Niño, an extensive warming is

present across the northern U.S., southern and western Canada, and southern Alaska. A widespread cooling in more or less a similar region takes place during La Niña. Furthermore, there is cooling across the southern U.S. during El Niño, and a warming in the same region during La Niña. These temperature differences can be understood from the property that the narrow belt of winds that makes up the jet stream separates cold air to the north and warm air to the south. Thus, when the jet stream shifts southward, as during an El Niño, the southern U.S. becomes colder (Fig. 4). Similar arguments can account for all of the anomalous warm and cold regions shown in Fig. 4.

The relationship between the anomalous precipitation in North America and the El Niño and La Niña SST anomalies is rather subtle, because the planetary-scale Rossby waves *indirectly* influence the precipitation. Before I describe how this happens, it is first important to emphasize that these Rossby waves propagate very slowly and can persist for about one month (Feldstein 2000). Because these waves—or equivalently, the jet streams influenced by corresponding El Niño and La Niña events—evolve much more slowly than do mid-latitude storm systems, these jet streams behave as if they were not changing with time during the lifetime of the storm system. This perspective allows us to regard the storm systems as being steered by jet streams influenced by El Niño or La Niña. As a result, during El Niño, storm systems originating in the mid-latitude North Pacific are steered by the jet stream toward California and then farther eastward toward the Gulf states, bringing additional rain to this region. This contrasts with La Niña, in which the jet stream steers the storm systems toward the Pacific Northwest and across the northern states. This results in more rain and snow in those states, and in a much drier southern U.S.

It is important to emphasize that the Northern Hemisphere response to ENSO, shown in Fig. 4, represents an *average* over many separate El Niño and La Niña events. During an individual El Niño or La Niña event, the climate can be strikingly different from that shown in Fig. 4. The reason is that there are a whole host of other important physical processes that contribute to the variability of North American climate. The strong impact of these various phenomena implies that it is very difficult to make a linkage between the North American climate and ENSO during any individual El Niño or La Niña event. It is only when an average is made over many El Niño or La Niña events that an atmospheric pattern emerges which is both statistically significant to a reasonable degree and which is amenable to investigation.

continued from page 607

their mass at fledging) was higher following La Niña events and lower after El Niño events. These variations in fecundity were found to be related to fluctuations in the populations of their lepidopteran larvae prey, which were significantly correlated with ENSO.

Morrison and Bolger (2002) investigated the reproductive success of Rufous-crowned Sparrows in the coastal sage-scrub of southern California. Three consecutive breeding seasons were examined. These included 1997, when the rainfall total in southern California was close to its long-term average, and 1998 and 1999, which coincided with El Niño and La Niña events, periods during which the rainfall in southern California was well above and below average, respectively. A dramatic difference in the breeding success was observed between the El Niño and La Niña events. For example, during the 1998 El Niño event, there was an average of 5.1 fledglings per pair for the breeding season. This contrasted with a value of 0.8 fledglings per pair for the 1999 La Niña breeding season. Careful observations showed that these differences in fecundity were due to an increase (or decrease) in both the brood size and the number of fledged nests per pair during the El Niño (or La Niña)

events. The authors also examined the primary factors that may account for these fecundity differences. Their findings suggested that



Several recent studies have pointed to possible effects of El Niño / Southern Oscillation (ENSO) on population fluctuations in North American land birds. For example, breeding success in Rufous-crowned Sparrows that breed in coastal California may ultimately be determined by ENSO-influenced variation in precipitation. Anza-Borrego State Park, California; March 2003. © Bob Steele.

the poor reproduction during the La Niña event was due to low levels of available food, such as seeds and arthropods. For the El Niño event, the level of available food was close to that of the previous “average” year, suggesting that a factor other than food availability may be more important in accounting for the high fecundity. The observations of the authors indicated that there was a reduction in nest predation by

snakes early in the breeding season. They suggested that the cool, rainy weather during the El Niño event may have resulted in a lower level of activity for these snakes.

Nott *et al.* (2002) examined the relationship between ENSO and the reproductive success of 16 species of neotropical migrants that winter in western Mexico. Nine years (1992–2000) of data, which span two El Niño and one La Niña events, were used. To examine reproductive success, the authors used banding data from 33 Monitoring Avian Productivity and Survivorship (MAPS) stations in the Pacific Northwest. (MAPS was created by The Institute for Bird Populations of Point Reyes Station, California, for the purpose of monitoring the population dynamics of North American land bird species. There are many opportunities for birders to contribute to research in bird population dynamics by volunteering to work at MAPS stations.) With their banding data, the authors calculated the ratio of the numbers of young birds to adults. This ratio defined their *reproductive index*, which is used to measure the reproductive success of the neotropical migrants. When all 16 species were averaged, the authors found highly significant linear correlations between the reproductive index and an index that measures

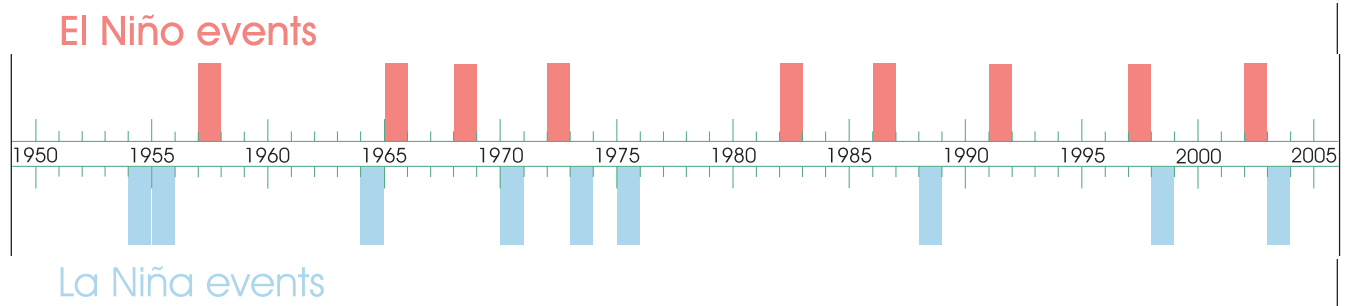


Fig. 2. Recent El Niño and La Niña events. The vertical lines denote the summer season. Typical ENSO events begin in the summer season of one year and end during the spring season of the following year. Figure prepared by Virginia Maynard.

ENSO. Their results suggest that after El Niño (or La Niña) events, neotropical migrant species have increased (or decreased) reproductive success. The authors suggest that this relationship may be related in part to changes in the prey biomass in western Mexico, which is likely to increase during the wetter El Niño years and decrease during the drier La Niña years. They also speculate that these changes in the prey biomass may influence the physical condition of neotropical migrants at the time they arrive on their breeding grounds. Furthermore, their examination of the strength and direction of the wind showed that during El Niño events the winds are more southerly at the altitude at which the neotropical migrants fly. As the authors point out, these enhanced southerly winds during El Niño events may aid the northward migration, which will also cause the birds to be in better physical condition when they arrive on their breeding grounds.

Composite Analysis

There is a popular and simple research technique that is used by atmospheric scientists and that could likely be adopted for examining ENSO / bird population relationships. This technique is known as composite analysis and is used to investigate the properties of numerous atmospheric variables, such as wind, temperature, precipitation, and ozone. When using composite analysis for ENSO research, atmospheric scientists select all of those years for which either an El Niño or La Niña event has taken place and then take an average of the variable under investigation. For example, if one is interested in the temperature field associated with El Niño, one would take an average of

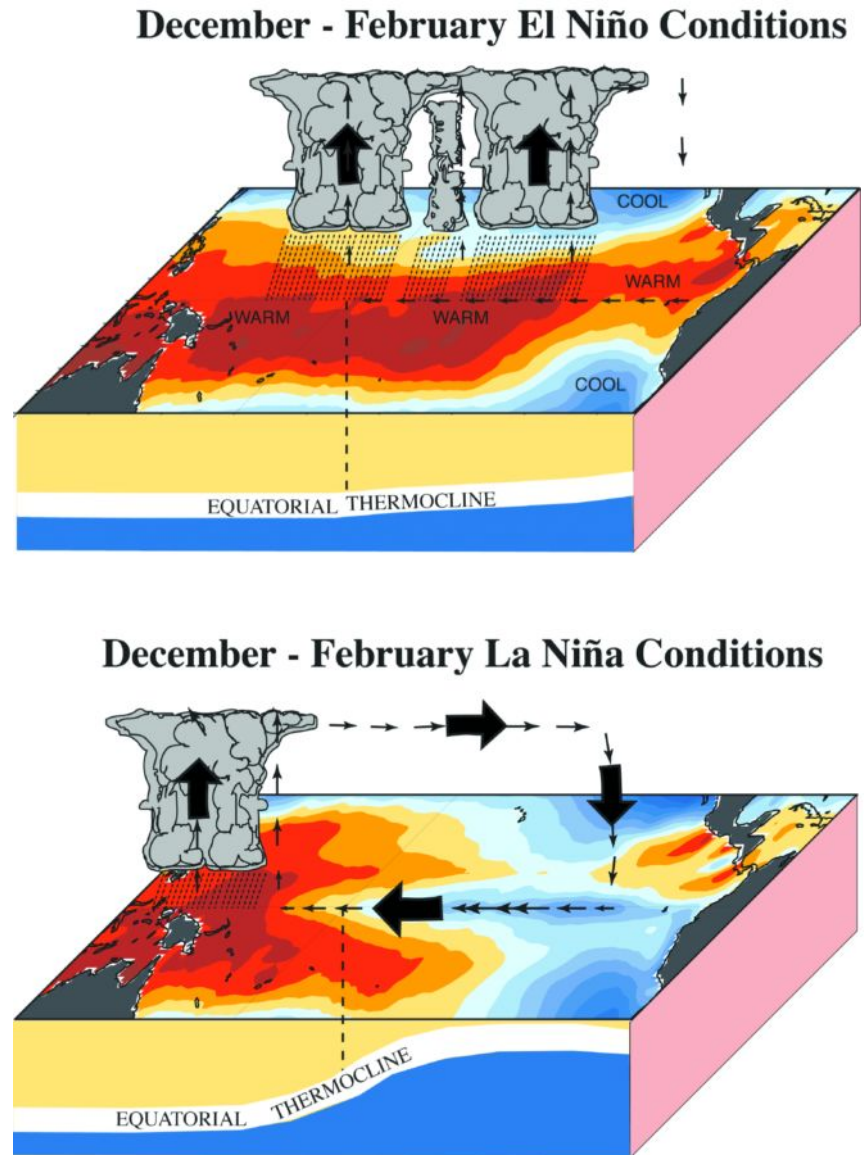


Fig. 3. Thunderstorm location, SST, and vertical winds during typical El Niño (top) and La Niña (bottom) events. Image provided as a public service by © the National Oceanic and Atmospheric Administration.

the temperature field for all El Niño events. This approach will yield a map, or a spatial pattern, of the El Niño temperature field. These calculations need to include a careful analysis of statistical significance, because one can make physically meaningful claims about averages only over many El Niño or La Niña events, not about a single event.

This technique is illustrated by the

following example. Suppose we wished to investigate whether there is a relationship between the winter irruption of Snowy Owls and La Niña (from Fig. 4, we can see that during La Niña there is more snow and cold weather over the western part of the Snowy Owl's winter range). For this investigation, we could calculate the composite Snowy Owl population with either Christmas Bird Count or

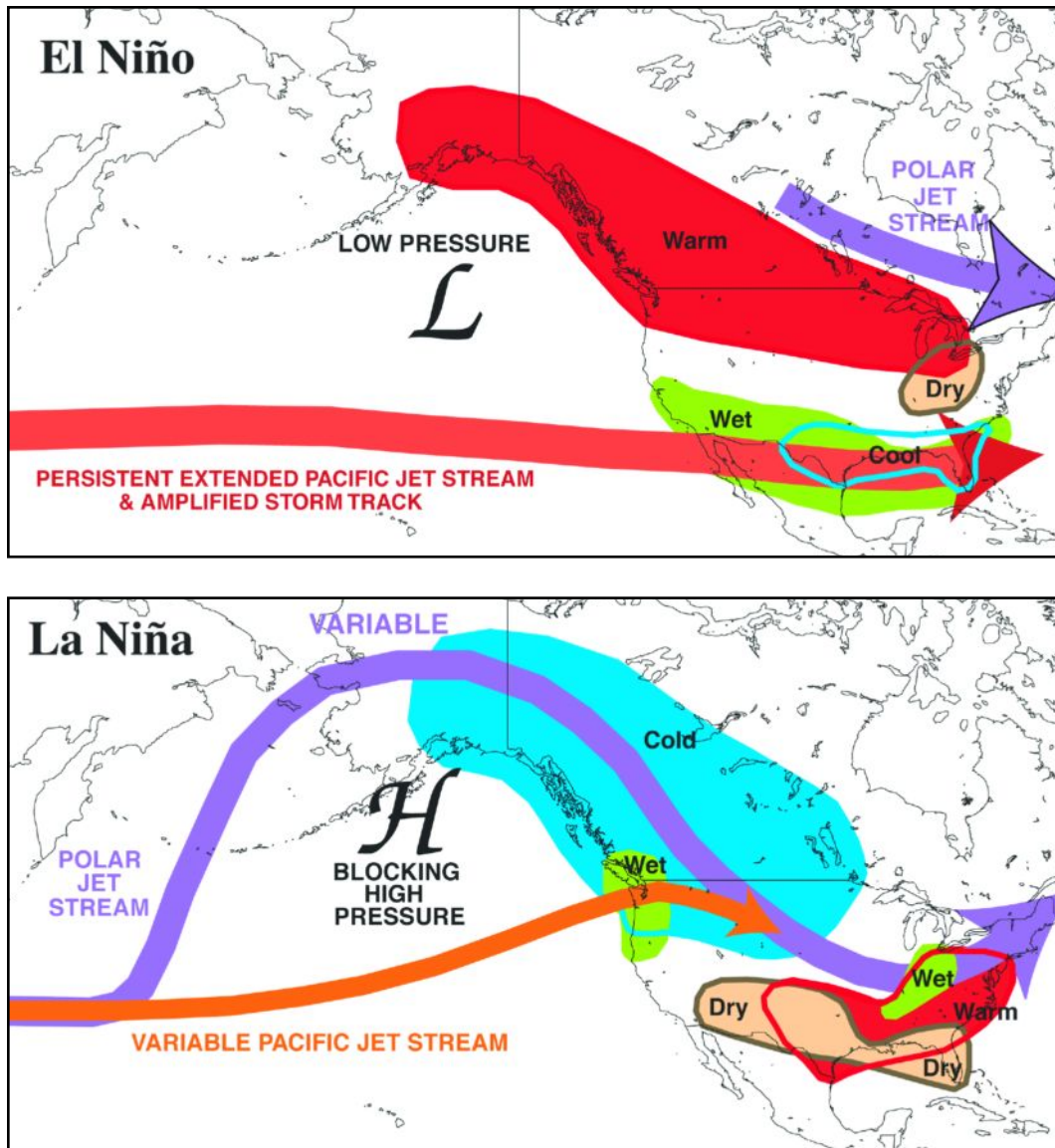


Fig. 4. Temperature anomalies and wind during typical El Niño and La Niña events, for the months of January through March. Image provided as a public service by © the National Oceanic and Atmospheric Administration.

Winter Bird Population Survey data. This analysis would result in a map of the Snowy Owl population as it is associated with La Niña. Calculations of statistical significance would then be performed to evaluate the extent to which we could claim that there is a relationship between La Niña and Snowy Owl irruptions.

A perusal of *North American Birds* (and its predecessors, *American Birds* and *Field Notes*) for several El

Niño and La Niña events suggests to me that there may be numerous other interesting ENSO / bird population relationships. For example, in southern Florida, it is my impression that there tends to be an increase in waxwings, robins, and northern finches during El Niño and a decrease in the same species during La Niña. Furthermore, in Texas and California, it seems that during El Niño events waterfowl tend to be

dispersed over wide areas, and during La Niña events the waterfowl are concentrated in fewer bodies of water. Presumably this is because of the increase in rainfall in those states during El Niño and the corresponding decrease in rainfall during La Niña. However, it is also apparent from *North American Birds* and its predecessors that there is much case-to-case variability in bird populations from one El Niño or La Niña event to the next.

The strength of the composite technique is that it allows one to find statistically significant patterns of bird populations that are related to ENSO. However, this composite analysis should not be used to make causal claims of how ENSO alters bird populations. To address causal relationships, it is necessary to use more sophisticated techniques that include additional observations and datasets, such as those used in the three papers described in the previous section.

Conclusions

ENSO has a very large impact on the climate of North America. Not surprisingly, recent research has shown that ENSO also has potentially important influences on the

population dynamics of North American land birds. Presumably, future research will reveal a whole host of additional relationships between North American land bird populations and ENSO.

Among the atmospheric and oceanic phenomena that fluctuate with time periods greater than one year and less than ten years, ENSO is the most dominant. However, there are other phenomena that make a large contribution to variability on these time scales. These include the North Atlantic Oscillation and Pacific / North American "teleconnection" patterns (Wallace and Gutzler 1981, Barnston and Livezey 1987, Feldstein 2000). In their study of the impact of ENSO on North American land birds, Nott *et al.* (2002) also show that the North Atlantic Oscillation has an important impact on the reproductive success of land bird species that breed in the Pacific Northwest and winter throughout the western U.S. It is likely that future research will find many other interesting relationships between land bird populations and these two teleconnection patterns.

Acknowledgments

I would like to thank Sukyoung Lee, Bernd Haupt, and Peter Gent for their helpful comments on this article. I would also like to thank David DeSante and Philip Nott for the useful ENSO / bird information that they provided.

Literature Cited

- Barnston, A.G., and R.E. Livezey. 1987. Classification, seasonality, and persistence of low-frequency atmospheric circulation patterns. *Monthly Weather Review* 115:1083–1126.
- Branstator, G. 1985a. Analysis of

SOUTH LOUISIANA SPRING BIRDING!

Join us for trips to cypress swamps, beaches, fields, forests, pine woods ...
BirdFest promises great birding around every corner!

Get more information and updates from:
WWW. NORTHLAKENATURE. ORG
 or call:
The Northlake Nature Center, 985-626-1238
 or
the St. Tammany Parish Tourist and Convention Commission, 1-800-634-9443



Serious Binoculars for Serious Observing.

Regal LS Series binoculars are designed with high-performance phase coated optics for brilliant views with rich contrast. These spectacular binoculars enhance the enjoyment of birding or any outdoor pursuit. Ideal for the active outdoors individual, the Regal LS Series binoculars offer a roof prism design, extreme near

#72012 focus, full multi-coatings, waterproof, fog-proof, and feature rubber covering, pop-up eye cups, long eye-relief, click-stop diopter adjustment. The Regal LS Series binoculars come with a soft case and neck strap as well as Celestron's Lifetime No Fault Warranty. For more information or the location of your nearest Authorized Celestron Dealer, please visit us at www.celestron.com.



Regal LS

Life Up Close™



Item No.	Item Name	Field of View	Eye Relief	Near Focus	Weight
72001	8x25 Regal LS	5.2° — 273'	19mm	6 ft.	16 oz.
72003	10x25 Regal LS	5.0° — 263'	17mm	6 ft.	16 oz.
72010	8x42 Regal LS	6.5° — 341'	20mm	6 ft.	25 oz.
72012	10x42 Regal LS	6.0° — 315'	16mm	6 ft.	25 oz.
72015	10x50 Regal LS	5.0° — 263'	20mm	9 ft.	29 oz.



Without Phase Coating



With Phase Coating

With phase coatings applied, roof prism binoculars are equal in quality to porro prism binoculars – again assuming all other things are equal. There is a lot of variance in quality of phase coatings on the market. The Regal LS binoculars use multi-layers of proprietary materials and are applied uniformly and with the proper density to take full advantage of this complex design to correct the phase shift.



Celestron
 2835 Columbia Street • Torrance, CA 90503 USA
 Tel: 310.328.9560 • Fax: 310.212.5835
www.celestron.com

© 2003 Celestron. Product design and technical specifications are subject to change without notice.

Birding



Far South & Far North

Antarctic and the Southern Ocean from New Zealand

Exclusive Charter: January 30 – February 29, 2004
Cost: Cabins from \$11,200, plus airfare to Invercargill

New Zealand's Endemic Landbirds

February 25 – March 9, 2004
Cost: \$3,390, plus airfare to Invercargill

Alaska's Copper River Delta & Prince William Sound

April 30 – May 12, 2004
Cost: \$3,450, plus airfare to Cordova

Cheesemans' Ecology Safaris

Non-smoking tours to spectacular wildlife areas
20800 Kittredge Road, Saratoga, CA 95070
800-527-5330 www.cheesemans.com

**CHANGING
MIGRATION
PATTERNS
SINCE 1964.**

A landmark and sanctuary
for migrating birds.

A spectacular 17.6-mile
drive for motorists.

And one of the Seven Engi-
neering Wonders of the
Modern World.

For a free brochure and East Coast map, or to
obtain a birding permit, call (757) 331-2960 or
mail to Chesapeake Bay Bridge-Tunnel, Dept.
B-1003, Cape Charles, VA 23310.

www.cbbt.com
(757) 331-2960

NAME _____

ADDRESS _____

CITY _____ STATE _____ ZIP _____

- general circulation model sea-surface temperature anomaly simulations using a linear model. Part I. Forced solution. *Journal of the Atmospheric Sciences* 42:2225–2241.
- Branstator, G. 1985b. Analysis of general circulation model sea-surface temperature anomaly simulations using a linear model. Part II. Eigenanalysis. *Journal of the Atmospheric Sciences* 42:2242–2254.
- Feldstein, S.B. 2000. The timescale, power spectra, and climate noise properties of teleconnection patterns. *Journal of Climate* 13:4430–4440.
- Harding, A.M.A., J.F. Piatt, and K.C. Hamer. 2003. Breeding ecology of Horned Puffins (*Fratrula corniculata*) in Alaska: Annual variation and effects of El Niño. *Canadian Journal of Zoology* 81:1004–1013.
- Held, I.M., and I-S. Kang. 1987. Barotropic models of the extratropical response to El Niño. *Journal of the Atmospheric Sciences* 44:3576–3586.
- Hoskins, B.J., and D. Karoly. 1981. The steady linear response of a spherical atmosphere to thermal and orographic forcing. *Journal of the Atmospheric Sciences* 38:1179–1196.
- Kok, C.J., and J.D. Opsteegh. 1985. On the possible causes of anomalies in seasonal mean circulation pattern during the 1982/83 El Niño event. *Journal of the Atmospheric Sciences* 42:677–694.
- Larkin, N.K., and D.E. Harrison. 2002. ENSO warm (El Niño) and cold (La Niña) event life cycles: Ocean surface anomaly patterns, their symmetries, asymmetries, and implications. *Journal of Climate* 15:195–213.
- Morrison, S.A., and D.T. Bolger. 2002. Variation in a sparrow's reproductive success with rainfall: Food and predator-mediated processes. *Oecologia* 133:315–324.
- Nott, M.P., D.F. DeSante, R.B. Siegel, and P. Pyle. 2002. Influences of the El Niño / Southern Oscillation and the North Atlantic Oscillation on avian productivity in forests of the Pacific Northwest of North America. *Global Ecology* 11:333–342.
- Sardeshmukh, P.D., and B.J. Hoskins. 1988. The generation of global rotational flow by steady idealized tropical divergence. *Journal of the Atmospheric Sciences* 45:1228–1251.
- Sillet, T.S., R.T. Holmes, and T.W. Sherry. 2000. Impacts of a global climate cycle on population dynamics of a migratory songbird. *Science* 288:2040–2042.
- Simmons, A.J., J.M. Wallace, and G. Branstator. 1983. Barotropic wave propagation and instability, and atmospheric teleconnection patterns. *Journal of the Atmospheric Sciences* 40:1363–1392.
- Valle, C.A., and M.C. Coulter. 1987. Present status of the flightless cormorant, Galápagos penguin, and greater flamingo populations in the Galápagos Islands, Ecuador, after the 1982–83 El Niño. *Condor* 89:276–281.
- Walker, G.T., and E.W. Bliss. 1932. *World Weather V. Memoirs of the Royal Meteorological Society* 4:53–84.
- Wallace, J.M., and D.S. Gutzler. 1981. Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Monthly Weather Review* 109:784–812.
- Wilson, U.W. 1991. Responses of three seabirds species to El Niño events and other warm episodes on the Washington coast, 1979–1990. *Condor* 93:838–858.