The Influence of El Niño on the Spring Fallout of Asian Bird Species at Attu Island

Sultan Hameed*

School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, New York

Henry H. Norwood

Wayland, Massachusetts

Michael Flanagan

School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, New York

Steven Feldstein

Earth and Environmental Systems Institute, The Pennsylvania State University, University Park, Pennsylvania

Chien-hsiung Yang

Voluntary Emeritus Corps, U.S. Air Force Research Laboratory, Hanscom AFB, Bedford, Massachusetts

Received 16 June 2008; accepted 6 April 2009

* Corresponding author address: Sultan Hameed, School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY 11794-5000.
E-mail address: shameed@notes.cc.sunysb.edu

DOI: 10.1175/2009EI272.1
ABSTRACT: Several studies have documented the effect of the recent secular climate warming on the distributions and geographical ranges of birds. Here the authors report the strong impact of a recurring climatic pattern in the equatorial Pacific, the El Niño–Southern Oscillation (ENSO) cycle of warm (El Niño) and cold (La Niña) events, on spring migrants along the Far Eastern flyway in northeast Asia. In El Niño years, an unusually large number of birds that use the flyway are observed at Attu Island, westernmost of the Aleutian Islands, nearly 960 km away from the Asian coast. This study is based on a 20-yr dataset documenting the year-to-year variation of Asian birds arriving on Attu in the spring season and uses a three-phased analytical methodology to examine climate impacts on bird movements and populations.

The authors offer evidence that birds are displaced toward the Attu area in strong eastward-moving storms. They also present results from a reverse trajectory model that was used to simulate trajectories that a sample of Attu arrivals likely followed in reaching the island. In a statistical analysis, it is shown that 79% of the variation of the Asian birds is explained by a single climate variable: sea surface temperature in the eastern equatorial Pacific in the previous fall. It is the rise in sea surface temperature in this region, more than 8000 km from Attu, that characterizes the onset of an El Niño episode.

Examining those years for which there was a strong ENSO signal in the fall, it is found that the following May is characterized by anomalously strong westerly winds in the northwest Pacific, conditions that are appropriate for large Asian bird fallouts at Attu. Because of the time lag between the fall sea surface temperatures in the El Niño region and the spring Asian bird count at Attu, and the strong correlation between these two quantities, the number of Asian birds arriving at Attu in spring is predictable in the previous autumn. Such predictions are presented for several years.

KEYWORDS: Bird migration; ENSO; Aleutian birds; Attu

1. Attu Island and avian research

Attu Island is the most remote, most westward island in Alaska’s Aleutian chain. Lying at 53°N, 173°E, the island is situated with Anchorage, Alaska, 1920 km to the northeast and the city of Petropavlovsk on the lower Kamchatka Peninsula of Russia nearly 960 km to the west. The island is 67 km long and 26 km across at its widest point and includes approximately 400 km² of land area dominated by high mountains and largely inaccessible wilderness area. The only roads and habitation are in the southeast corner of the island where there is a small coast guard station and runway and a rudimentary road system left over from an abandoned military base.

Attu Island has three major claims to fame: 1) its generally miserable weather, 2) the bloody battle fought by U.S. troops in 1943 to recapture the island in World War II, and 3) the remarkably rich mix of Eurasian bird species that can be found on the island during spring (and fall) migration. Relatively little was known about Attu’s avian population until the mid-1960s when systematic inventorifying of Alaska’s natural resources was undertaken in preparation for the creation of a series of new national parks and wildlife refuges throughout the state. Based on information from these early studies, Lawrence Balch (subsequently president of the American Birding Association) visited Attu in 1977 with two friends to cover the spring migration. The trip proved so successful that he began helping others to visit the island and in 1979 began running organized birding trips to the island. By
1980 the group size had grown to 50–80 participants (the maximum that could be handled at the rudimentary facilities available on the island) and remained at those levels throughout the following 20 years.

Field observations during this period focused on an approximately 64 km² area in the southeastern corner of the island known as Massacre Valley. The area is occupied by a Loran C Coast Guard station and a former military airbase and is bounded on the east and south by the Pacific Ocean and on the north and west by ridges and mountains backed up by the Bering Sea. The former military base included two main runways oriented north–south and east–west along with a series of taxiways and paved maintenance and parking areas. During the 1940s and 1950s several hundred support buildings were built in the area but most of these have either collapsed or been torn down, leaving little more than the extensive but badly eroded network of roads to mark where the buildings had been.

In very large measure this system of roads and runways proved to be the key to success to bird observation activities at Attu. Massacre Valley offered a wide range of habitats including extensive salt and freshwater marshes, streams and lakes, thick chest-high brush, and in protected areas dense thickets, but the combined vegetation, water, and omnipresent mud made off-road bushwhacking generally difficult. In the upland areas along the ridges and mountains, the off-road terrain was reasonably dry but tended to be relatively steep, rocky, and sometimes unstable. To add to the risks of off-road travel, a number of off-road areas both in the valley and at higher elevations had been declared off-limits because of possible live ammunition and/or other hazardous materials left over from the 1940s and 1950s.

Under these circumstances the compact network of roads and runways provided a permanently fixed infrastructure for facilitating consistent and systematic observer coverage of the area both on a day-by-day and year-by-year basis. Each day during the annual count period participants split up into four to six teams with each team assigned to cover a predetermined section of the road/runway network and associated areas. The basic function of each team was to seek out, identify, and count all but the most common species found in its assigned sector with particular emphasis on Asian species, since these were the species of most interest to many of the Attu observers. Each team leader was given a citizens band (CB) radio to report the team’s observations back to base camp on a half-hour basis as well as to communicate with nearby teams about potentially redundant observations. Teams were generally in the field, on bicycle and/or foot, for eight hours or more per day. At the end of each day, the teams met to review the count data, identify and resolve any questionable observations and redundancies, and compile a total count for the entire count area of the numbers of individuals of each species seen that day.

2. Creation of an Asian species database and a new AIDP set of statistics

During the early and mid-1980s it became increasingly evident to Attu observers that observations of species more normally found in Asia tended to be much more volatile from one year to the next than observations of species more commonly found in North America. Observers also noted that the appearance of large numbers of Asian species coincided closely with the arrival of major storms (see Tove 1988). And in 1992 a group of National Oceanic and Atmospheric Administration (NOAA)
climatologists at Boulder, Colorado, when shown a graph of annual total counts of Asian species, were immediately struck by the similarity of the pattern of the chart with graphs of the El Niño–Southern Oscillation (ENSO) index and offered to provide daily satellite wind field maps back to 1980 so that spring storm tracks in the northwest Pacific could be mapped and analyzed in El Niño and La Niña years.

Also noteworthy to some was an apparent long-term decline (an average of 4% yr$^{-1}$) in numbers of Asian species recorded at Attu between 1980 and 1992 that raised further questions about possible external environmental factors that might be at work. Birders along the Asian coast confirmed that they, too, had witnessed similar declines in their areas and suggested five possible explanations: 1) milder winters (4 of the 10 warmest winters in China in the previous 100 years had occurred between 1980 and 1990), 2) wetland destruction, 3) rapidly expanding “slash and burn” of tropical and subtropical forests in Southeast Asia, 4) major increases in the use of pesticides throughout the region, and 5) widespread hunting and trapping of birds for food and pets.

In response to these emerging issues, one of the authors set up a separate Asian species database in the latter part of 1992 to explore possible statistical relationships between these and other independent variables that might be influencing Asian species observations on Attu. Two broad criteria were established for inclusion of a species in the sample. First, the species had to breed predominantly in Asia. Second, it could not commonly breed on or around Attu or the neighboring islands. Table 1 contains a list of the species included in the Asian species sample for purposes of this study.

The Asian species database included daily observations for all species listed in Table 1 and were based on annual observation spreadsheets provided by L. Balch. The observation data in the Asian species database were the same as those in the total Attu observation database with two exceptions. First, the first 3 years of data (1977–79) in the Attu database were excluded from the Asian species database since procedures for observations were in the process of development during those 3 years. Second, two new annual datasets were introduced: 1) the total of all Asian individuals per day (total AIPD) reported for all Asian species for all the days in the count period and 2) the average number of Asian individuals per day (average AIPD) in which the total AIPD is divided by the total number of days in the annual count period. The average AIPD is important for statistical analysis purposes since it adjusts or normalizes each year’s total AIPD for the number of days that the main observer force was on Attu that year. The annual count periods varied in length from 18 to 30 days.

For the 20-yr period from 1980 through 2000, excluding 1995 when the Attu trip was aborted, daily counts of Asian individuals totaled 20,064 birds or an average of slightly more than 1000 total AIPDs per year but with annual variations ranging from a low of 164 in 1996 to 8873 in 1998 (see Figure 1). As discussed further in footnote 1, this sample was more than amble to meet the statistical requirements of this study.1

---

1 Some may question the reliability of the Attu Asian species database on the grounds that some of the sightings of rarer Asian species have not been fully documented. This line of reasoning ignores that 1) those Asian species in the database that were rarely seen on Attu represent a miniscule part of the AIPD database and 2) the study analyses only require a reasonable estimate of the total numbers of Asian birds observed on the island each year. To test the level of accuracy required for this study, a sensitivity analysis was conducted to determine at what point changes in the AIPD database affected the analytical outcomes. The analysis found that the error in the AIPD values would have to be greater than 30% in order to change the conclusions of this study.
The variations in the average AIPD data were equally striking. For example, as indicated in Figure 1, the annual fluctuations in the average AIPD ranged from a 20-yr low of 6.8 in 1996 to a 20-yr high 2 years later (1998) of 328.6, some 47 times greater than 1996. Over the years veteran observers at Attu could basically agree, given the sightings of certain “focus” species, which years were “great years,” “good years,” and “poor years,” but only with the AIPD statistics was it possible to fully grasp the magnitude of the annual swings in the numbers of Asian birds over the 20-yr period.

3. A three-phase research program

Over the next several years we pursued a three-phased research program. Phase 1 was essentially statistical in nature and involved correlating the average AIPD dataset against a wide range of El Niño and other climate-related indices and selecting the variables that correlated most strongly with the average AIPD. Phase 2 explored the relationship long recognized by Attu observers that large Asian species fallouts tended to coincide with large storms. Phase 3 then assessed possible dynamic cause-and-effect relationships between the average AIPD dataset, storms, and the ENSO indices.

3.1. Phase 1: Statistical analysis

For the 20-yr period from 1980 through 2000 and excluding 1995 when no Attu sighting data were collected, the average AIPD dataset was regressed and correlated with the monthly Southern Oscillation index (SOI) and various sea surface temperature (SST) indices as well as a wide range of other related atmospheric teleconnection indices. [Teleconnection indices measure changes in spatial patterns in the atmosphere that link remote locations across the globe. The dominant teleconnection patterns in the Northern Hemisphere are the North Atlantic Oscillation (NAO) and the Pacific–North American (PNA) pattern. The NAO, which spans the mid- and high-latitude North Atlantic, has a dipole spatial structure, and the PNA, which extends across the northeast Pacific and North America, takes on a wave train pattern.] Three sets of teleconnection indices proved particularly useful: 1) the SOI, 2) the atmospheric North Pacific Oscillation index (NPO), and 3) the SST-based Niño-3 index. The three indices differ significantly in their geographic locations. The SOI is based on the difference between sea level pressures at Tahiti and Darwin, Australia; the NPO is based on the difference in either sea level pressure or 700-hPa geopotential height between the Aleutians and Hawaii; and the Niño-3 index is based on the SST in the tropical Pacific between 5°N–5°S and 150°–90°W.

These indices also differed in the particular months that had the highest correlation with the average AIPD. For the first two indices, the April and May values for the same year as the Attu Asian bird sightings correlated most strongly with the average AIPD dataset with correlations declining for the previous winter and fall months. For the Niño-3 index, on the other hand, the opposite was true, with Niño-3 index values from the prior fall correlating most strongly with the following May/June
Table 1. Species included in the Asian species sample in this study.

<table>
<thead>
<tr>
<th>Asian species common name</th>
<th>Scientific name</th>
<th>No. of years seen</th>
<th>Sum of daily counts</th>
<th>Avg No. individuals seen per day</th>
<th>Asian species common name</th>
<th>Scientific name</th>
<th>No. of years seen</th>
<th>Sum of daily counts</th>
<th>Avg No. individuals seen per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bean goose</td>
<td>Anser fabalis</td>
<td>11</td>
<td>108</td>
<td>2.2</td>
<td>White-throated needletail</td>
<td>Hirundapus caudacutus</td>
<td>1</td>
<td>4</td>
<td>1.3</td>
</tr>
<tr>
<td>Lesser white-fronted goose</td>
<td>Anser erythropus</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
<td>Fork-tailed swift</td>
<td>Apus pacificus</td>
<td>2</td>
<td>4</td>
<td>1.3</td>
</tr>
<tr>
<td>Whooper swan</td>
<td>Cygnus cygnus</td>
<td>4</td>
<td>59</td>
<td>1.8</td>
<td>Great spotted woodpecker</td>
<td>Dendrocopos major</td>
<td>1</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>Falcated duck</td>
<td>Anas falcata</td>
<td>7</td>
<td>81</td>
<td>1.7</td>
<td>Brown shrike</td>
<td>Lanius cristatus</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Spot-billed duck</td>
<td>Anas poecilorhyncha</td>
<td>2</td>
<td>6</td>
<td>1.0</td>
<td>Sky lark</td>
<td>Alauda arvensis</td>
<td>15</td>
<td>198</td>
<td>2.3</td>
</tr>
<tr>
<td>Garganey</td>
<td>Anas querquedula</td>
<td>5</td>
<td>63</td>
<td>1.8</td>
<td>Middendorff’s grasshopper-warbler</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common pochard</td>
<td>Aythya ferina</td>
<td>12</td>
<td>211</td>
<td>2.0</td>
<td>Lanceolated warbler</td>
<td>Locustella lanceolata</td>
<td>2</td>
<td>38</td>
<td>5.4</td>
</tr>
<tr>
<td>Smew</td>
<td>Mergellus albellus</td>
<td>15</td>
<td>205</td>
<td>2.4</td>
<td>Arctic warbler</td>
<td>Phylloscopus borealis</td>
<td>6</td>
<td>82</td>
<td>6.3</td>
</tr>
<tr>
<td>Yellow bittern</td>
<td>Melobrychus sinensis</td>
<td>1</td>
<td>5</td>
<td>1.0</td>
<td>Narcissus flycatcher</td>
<td>Ficedula nucalisina</td>
<td>2</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>White-tailed eagle</td>
<td>Haliaeetus albicilla</td>
<td>16</td>
<td>67</td>
<td>1.2</td>
<td>Taiga flycatcher</td>
<td>Ficedula albicilla</td>
<td>7</td>
<td>38</td>
<td>2.5</td>
</tr>
<tr>
<td>Steller’s sea-eagle</td>
<td>Haliaeetus pelagicus</td>
<td>1</td>
<td>5</td>
<td>1.0</td>
<td>Dark-sided flycatcher</td>
<td>Muscicapa sibirica</td>
<td>3</td>
<td>13</td>
<td>2.2</td>
</tr>
<tr>
<td>Eurasian kestrel</td>
<td>Falco tinnunculus</td>
<td>2</td>
<td>3</td>
<td>1.0</td>
<td>Gray-streaked flycatcher</td>
<td>Muscicapa griseiicta</td>
<td>10</td>
<td>111</td>
<td>3.7</td>
</tr>
<tr>
<td>Eurasian hobby</td>
<td>Falco subbuteo</td>
<td>2</td>
<td>3</td>
<td>1.0</td>
<td>Asian brown flycatcher</td>
<td>Muscicapa daurrica</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Lesser sand plover</td>
<td>Charadrius mongolus</td>
<td>19</td>
<td>294</td>
<td>2.6</td>
<td>Siberian nuthroat</td>
<td>Luscinia calliope</td>
<td>17</td>
<td>418</td>
<td>3.9</td>
</tr>
<tr>
<td>Common ringed plover</td>
<td>Charadrius hiaticula</td>
<td>1</td>
<td>6</td>
<td>1.0</td>
<td>Rufous-tailed robin</td>
<td>Luscinia sibilans</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Little ringed plover</td>
<td>Charadrius dubius</td>
<td>1</td>
<td>7</td>
<td>1.0</td>
<td>Bluethroat</td>
<td>Luscinia sveca</td>
<td>3</td>
<td>9</td>
<td>1.8</td>
</tr>
<tr>
<td>Terek sandpiper</td>
<td>Xenus cinereus</td>
<td>6</td>
<td>119</td>
<td>3.5</td>
<td>Siberian blue robin</td>
<td>Luscinia cyane</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Common sandpiper</td>
<td>Actitis hypoleucus</td>
<td>20</td>
<td>420</td>
<td>3.4</td>
<td>Red-flanked blue tail</td>
<td>Tarsiger cyanurus</td>
<td>5</td>
<td>13</td>
<td>1.1</td>
</tr>
<tr>
<td>Green sandpiper</td>
<td>Tringa ochropus</td>
<td>2</td>
<td>3</td>
<td>1.0</td>
<td>Eyebrowed thrush</td>
<td>Turdus obscurus</td>
<td>18</td>
<td>721</td>
<td>6.8</td>
</tr>
</tbody>
</table>
Table 1. (Continued)

<table>
<thead>
<tr>
<th>Asian species common name</th>
<th>Scientific name</th>
<th>No. of years seen</th>
<th>Sum of daily counts</th>
<th>Avg No. individuals seen per day</th>
<th>Asian species common name</th>
<th>Scientific name</th>
<th>No. of years seen</th>
<th>Sum of daily counts</th>
<th>Avg No. individuals seen per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray-tailed tattler</td>
<td><em>Tringa brevipes</em></td>
<td>14</td>
<td>250</td>
<td>4.4</td>
<td>Dusky thrush</td>
<td><em>Turdus naumanni</em></td>
<td>7</td>
<td>17</td>
<td>1.1</td>
</tr>
<tr>
<td>Spotted redshank</td>
<td><em>Tringa erythropus</em></td>
<td>7</td>
<td>32</td>
<td>1.9</td>
<td>Eastern yellow wagtail</td>
<td><em>Motacilla tschutschensis</em></td>
<td>20</td>
<td>824</td>
<td>3.7</td>
</tr>
<tr>
<td>Common greenshank</td>
<td><em>Tringa nebularia</em></td>
<td>16</td>
<td>150</td>
<td>1.6</td>
<td>Gray wagtail</td>
<td><em>Motacilla cinerea</em></td>
<td>13</td>
<td>59</td>
<td>1.2</td>
</tr>
<tr>
<td>Wood sandpiper</td>
<td><em>Tringa glareola</em></td>
<td>20</td>
<td>6151</td>
<td>19.2</td>
<td>White wagtail</td>
<td><em>Motacilla alba</em></td>
<td>18</td>
<td>295</td>
<td>2.0</td>
</tr>
<tr>
<td>Far Eastern curlew</td>
<td><em>Numenius madagascariensis</em></td>
<td>10</td>
<td>37</td>
<td>1.0</td>
<td>Olive-backed pipit</td>
<td><em>Anthus hodgsoni</em></td>
<td>18</td>
<td>782</td>
<td>6.8</td>
</tr>
<tr>
<td>Black-tailed godwit</td>
<td><em>Limosa limosa</em></td>
<td>13</td>
<td>140</td>
<td>2.8</td>
<td>Pechora pipit</td>
<td><em>Anthus gustavi</em></td>
<td>4</td>
<td>29</td>
<td>1.8</td>
</tr>
<tr>
<td>Great knot</td>
<td><em>Calidris tenuirostris</em></td>
<td>2</td>
<td>3</td>
<td>1.0</td>
<td>Red-throated pipit</td>
<td><em>Anthus cervinus</em></td>
<td>17</td>
<td>249</td>
<td>2.6</td>
</tr>
<tr>
<td>Red-necked stint</td>
<td><em>Calidris ruficollis</em></td>
<td>16</td>
<td>404</td>
<td>5.0</td>
<td>Rustic bunting</td>
<td><em>Emberiza rustica</em></td>
<td>19</td>
<td>1842</td>
<td>12.2</td>
</tr>
<tr>
<td>Little stint</td>
<td><em>Calidris minuta</em></td>
<td>1</td>
<td>3</td>
<td>1.0</td>
<td>Yellow-throated bunting</td>
<td><em>Emberiza elegans</em></td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Temminck’s stint</td>
<td><em>Calidris temminckii</em></td>
<td>6</td>
<td>279</td>
<td>8.2</td>
<td>Yellow-breasted bunting</td>
<td><em>Emberiza aureola</em></td>
<td>2</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>Long-toed stint</td>
<td><em>Calidris subminuta</em></td>
<td>20</td>
<td>1149</td>
<td>6.3</td>
<td>Gray bunting</td>
<td><em>Emberiza variabilis</em></td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Spoon-billed sandpiper</td>
<td><em>Eurynorhynchus pygmeus</em></td>
<td>1</td>
<td>9</td>
<td>1.8</td>
<td>Reed bunting</td>
<td><em>Emberiza schoeniclus</em></td>
<td>3</td>
<td>8</td>
<td>1.0</td>
</tr>
<tr>
<td>Pin-tailed snipe</td>
<td><em>Gallinago stenura</em></td>
<td>3</td>
<td>5</td>
<td>1.0</td>
<td>Pallas’s bunting</td>
<td><em>Emberiza pallasi</em></td>
<td>1</td>
<td>8</td>
<td>1.0</td>
</tr>
<tr>
<td>Oriental pratincole</td>
<td><em>Glaeroxida maldivarum</em></td>
<td>1</td>
<td>2</td>
<td>1.0</td>
<td>Brambling</td>
<td><em>Fringilla montifringilla</em></td>
<td>20</td>
<td>3644</td>
<td>15.5</td>
</tr>
<tr>
<td>Black-tailed gull</td>
<td><em>Larus crassirostris</em></td>
<td>2</td>
<td>2</td>
<td>1.0</td>
<td>Common rosefinch</td>
<td><em>Carpodacus erythrinus</em></td>
<td>6</td>
<td>30</td>
<td>1.9</td>
</tr>
<tr>
<td>White-winged tern</td>
<td><em>Chlidonias leucopterus</em></td>
<td>1</td>
<td>2</td>
<td>1.0</td>
<td>Eurasian siskin</td>
<td><em>Carduelis spinus</em></td>
<td>1</td>
<td>4</td>
<td>1.3</td>
</tr>
<tr>
<td>Oriental turtle dove</td>
<td><em>Sturnella luteola</em></td>
<td>2</td>
<td>17</td>
<td>1.0</td>
<td>Oriental greenfinch</td>
<td><em>Carduelis sinica</em></td>
<td>8</td>
<td>38</td>
<td>1.7</td>
</tr>
<tr>
<td>Common cuckoo</td>
<td><em>Cuculus canorus</em></td>
<td>10</td>
<td>46</td>
<td>1.6</td>
<td>Eurasian bullfinch</td>
<td><em>Pyrrhula pyrrhula</em></td>
<td>2</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>Oriental cuckoo</td>
<td><em>Cuculus saturatus</em></td>
<td>3</td>
<td>8</td>
<td>1.0</td>
<td>Hawfinch</td>
<td><em>Coccothraustes cocothraustes</em></td>
<td>17</td>
<td>214</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Total AIPD</strong></td>
<td></td>
<td>20</td>
<td>064</td>
<td></td>
<td></td>
<td><strong>Total Asian species</strong></td>
<td>76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
average AIPD values with correlations declining in the ensuing winter and early spring months. Figure 2 illustrates the correlation coefficients for the May average AIPD versus the monthly Niño-3 values from the previous June to the following May. The average AIPD–Niño-3 correlations were particularly intriguing in that they suggested a sequential and/or predictive relationship.

A key issue in the statistical analyses was how to deal with the exceptionally high fallout of Asian birds at Attu in 1998. The average AIPD in 1998 was 328.6 or 6 times the next highest value of 55.3 recorded in 1983. To address this problem with the Niño-3 index data, the average AIPD data was log transformed and the resulting time series then regressed with the September Niño-3 index to obtain

\[
\log_{10}(\text{AIPD}) = -4.88 + 0.25(\text{NINO3})_9, \tag{1}
\]

where the independent variable on the right side is the value of the Niño-3 index during the previous September. Please note that the sea surface temperature values reported by the Climate Prediction Center were used in Equation (1) and not their anomalies. The predictions of this regression were then antilog transformed to obtain the estimated average AIPD. The correlation between the observed average AIPD and those from the regression model is 0.89, that is, the September Niño-3 explains 79% of the variance in average AIPD. The observed average AIPD is compared with the values from the regression in Figure 3.
For the regression calculation we have 20 years of data. However, the effective number of degrees of freedom can be less if the data series are autocorrelated. According to Angell and Korshover (1981) the effective number of degrees of freedom can be estimated by the formula

$$n' = \frac{n}{1 + 2r_1r_1' + 2r_2r_2' + \cdots},$$  \hspace{1cm} (2)$$

where $r_i$ is the autocorrelation of the first series at lag $i$ and $r_i'$ is the same for the other series. When we use this formula for (Niño-3)$_9$ and log(AIPD) we find $n' = 16.2$. With 16 degrees of freedom the correlation of 0.89 is statistically significant at better than 0.001 level.

Another commonly used indicator of ENSO conditions in terms of sea surface temperatures is the Niño-3.4 index, which is the observed temperature for 5°N–5°S, 170°–120°W. We carried out a regression analysis analogous to (1) using Niño-3.4 as the independent variable and found

$$\log_{10} (\text{AIPD}) = -6.01 + 0.28(\text{NINO3.4})_9,$$  \hspace{1cm} (3)$$

where the independent variable on the right side is the value of the Niño-3.4 index during the previous September. The predictions of this regression were then antilog transformed to obtain the estimated average AIPD. The correlation between the
observed average AIPD and those from the regression model is 0.78; that is, the September Niño-3.4 explains 61% of the variance in average AIPD. This comparison shows that the Attu bird fallout is very sensitive to the ocean temperatures of both of these regions of the equatorial Pacific. It is also noteworthy that the temporal variation of the correlation between AIPD and Niño-3.4 is parallel to that shown in Figure 1 for Niño-3.

We also examined the sensitivity of the above Niño-3 correlation to the very large average AIPD value in 1998. This was performed with the following procedure. First, the observed AIPD was replaced by smaller AIPD values. Then, the linear regression calculation was redone. Finally, the new regressed AIPDs were correlated with the observed AIPD values. The 1998 AIPD values selected for this sensitivity analysis were 55.0 (a severe underestimate of the observed AIPD value) through various increments of 55.0, that is, 1.0 × 55, 1.5 × 55, 2.0 × 55, 3.0 × 55, etc. The resulting correlations had values of 0.60, 0.75, 0.82, 0.87, etc. Each of these correlations is statistically significant beyond the $p < 0.01$ threshold. However, these results do show a rather large sensitivity in the regression to the 1998 AIPD value. This degree of uncertainty in the linear regression can also be evaluated by calculating the standard error of the intercept and the slope. The values obtained for this calculation were 0.062 for the slope and 1.54 for the intercept. The large spread is because there are only 20 data points and therefore the sensitivity to 1998 AIPD value is large. Nevertheless, as indicated by the above calculations, the relationship between the AIPD and ENSO is robust.

The 9-month lag between the September Niño-3 index value and the fallout of Asian species at Attu and the large correlation between the two suggest that the number of Asian birds arriving at Attu is predictable. This was confirmed by a
series of simulated annual predictions starting in 1987. To make the prediction for 1987, the average AIPD series for 1980–86 was regressed against the September Niño-3 index for 1979–85 (see Figure 3). The coefficients of this regression were then used with the September 1986 Niño-3 SST to make the prediction for the average AIPD for 1987. The procedure was then moved forward 1 year; that is, a regression was obtained for the average AIPD for 1980–87 with the 1979–86 Niño-3 index, and its coefficients were used to make a prediction for 1988, and so on. The correlation between the observed and predicted bird count for 1987–2000 is 0.80, which for \( n = 13 \) is significant at the 0.01 level.

### 3.2. Phase 2: Storm-track analysis

As noted earlier, observers at Attu have long recognized that large fallouts of Asian species tended to occur with the passage of strong storms. To explore the storm-track–Attu fallout relationship, the top single-day counts of Asian individuals between 1980 and 2000 were identified. Since such single-day high counts typically tend to cluster around 3 or more consecutive days, for analysis purposes, these days were grouped into 4-day “events” with the first day designated as the “lag 0 day.” If two events were separated by less than 4 days, the second event was discarded.

The 16 highest events, in terms of single-day counts, were then identified and a set of composite wind vector (speed and direction) charts at the 850-hPa level (~1.6 km in elevation) were generated. For this analysis, daily National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data were used. The lag 0 date of each event was used to calculate the composite wind vectors.\(^2\) The use of the lag 0 day was based on the assumption that this day would be close to the time that the storm first arrived at Attu. In subsequent days when large numbers of Asian birds were observed, these were assumed for analysis purposes to be lingerers in the wake of the storm. Composite wind vector charts were also prepared for the two consecutive days prior to the lag 0 day. These days are referred to as the lag −2 and lag −1 days.

The composite 850-hPa wind vectors are illustrated in Figure 4. The location of Attu is indicated by the letter “A” in all three frames of Figure 4. We show only those vectors for which at least one component is statistically significant beyond the \( p < 0.05 \) level. As can be seen, for all three lags, most of the statistically significant wind vectors are located either nearby or upstream of Attu. Since the magnitude of most wind vectors is in excess of 10 m s\(^{-1}\), these findings give quantitative support for the observation of visiting birders that most Asian bird fallouts at Attu coincide with the occurrence of powerful storms.

Figure 4a shows that at lag −2 days there are strong southwesterly winds that extend from central Japan directly across the northwest Pacific toward Attu. These southwesterly winds have long been recognized by observers as a portent of large

---

fallouts to come at Attu. One day later (Figure 4b), a cyclonic (counterclockwise) circulation can be seen developing upstream of Attu. The winds extend from Hokkaido, Japan; the Sea of Okhotsk; and the Kuril Islands eastward toward Attu. Figure 4c shows that, by lag 0 days, the cyclonic circulation has further intensified and is located directly over Attu. These results indicate that Asian bird fallouts over Attu are preceded by storms that develop off the east coast of Asia and propagate eastward toward Attu while simultaneously intensifying. The above results are also consistent with the view that Asian birds seen on Attu were misoriented and were simply flying in a direction parallel to the local ambient wind vector (Mlodinow et al. 1999).

Since the largest number of Asian birds on Attu did not always occur on the lag 0 day but rather sometimes 1 or 2 days later, a second composite wind vector calculation was performed based on the peak single-day Asian individual count for each event. This analysis (not shown) revealed a wind vector pattern similar to that
shown in Figure 4c, except for the cyclone being displaced eastward by about 10° longitude. This again supports the conclusion that large fallouts of Asian birds occur when an eastward-propagating storm is in the vicinity of Attu. Composite analysis offers a powerful visual analytical tool for both birders and ornithologists to test hypotheses as to how various climate and weather conditions may (or may not) affect bird behavior over time. NOAA Earth Systems Research Laboratory’s Physical Sciences Division provides composite analysis tools and supporting climate data online.

3.3. Phase 3: Dynamics of the relationship between El Niño, storm tracks, and average AIPD

We next examine the physical linkages between the Niño-3 index, storm tracks in the northwest Pacific, and the annual average AIPD index. To break this issue into two more manageable questions, we ask 1) what processes account for the increased frequency of storms in the Attu area during years when the average AIPD index is high, and 2) what is the physical relationship between the Niño-3 index and the Asian bird fallouts?

In addressing the first question, research was conducted into the possible relationship between storms associated with large fallouts of Asian birds and the location of the jet stream in the upper troposphere. This effort was motivated by the theoretical relationship between the track taken by storms and the largest values of the local atmospheric refractive index (e.g., Hoskins and Ambrizzi 1993) in the upper troposphere. The refractive index is a rather complex quantity, depending upon the potential vorticity gradient (Holton 1992) and the phase speed of the storm system, among other variables. To a large extent, however, the maximum refractive index value tends to coincide with location of the upper-tropospheric jet stream. Therefore, according to this theory, storms will follow a path that is close to that of the jet stream. However, this theory is rather idealized and it is best to view the relationship between storm track and the jet stream as probabilistic, with the most frequent storm track being collocated with the jet stream.


A plot of the composite 300-hPa wind field is shown in Figure 5a. Note that Attu Island is the small dot located at 53°N, 173°E. The vectors in Figure 5a denote the wind direction, and the color indicates the wind speed. As can be seen, the axis (centerline of highest wind speed) of the Pacific jet does not pass over Attu. Rather, the axis is approximately 11° of latitude to the south of Attu. Therefore, according to the above theory, during those years when there are large Asian bird fallouts, the majority of storms will pass to the south of Attu.

We next examine whether there is an increase in the number of storms and hence the probability of at least one significant storm hitting Attu in each of the 12 years in question. The anomalous 300-mb wind vector map in Figure 5b addresses the frequency issue. Figure 5b utilizes the same input data as Figure 5a, but wind vector values have been converted to reflect the difference between the 12-yr composite
Figure 5. (a) May composite wind vectors for the 12 high-count years. (b) As in (a), but for composite anomalous wind vectors.
value and a broader baseline of years, in this case, 1968–96. Positive vector values in Figure 5b indicate that the 12-yr values are higher by the amounts shown than the 1968–96 time-averaged May values, and negative values indicate the opposite.

In Figure 5b, the anomaly values are small everywhere in the North Pacific, except for a narrow zonal band that extends from Hokkaido to the central Aleutian Islands. Such a band of strong anomalous winds well to the north of the time-mean jet is a strong indicator that storm distribution will move northward and, in the case of the band in Figure 5b, would have led to an increase in the frequency of storms in the area around Attu during the 12 high-average-AIPD years.

The second question posed for research was whether there was a physical linkage between the Niño-3 index and Asian bird fallouts, and, if so, what was its nature. As a first step, all El Niño and La Niña events that occurred between 1955 and 2003 (specific years are shown in Figures 6a,b) and reached their peak during the previous fall and winter were identified. This was followed by a calculation of the composite 300-hPa wind field for both El Niño and La Niña years. For this purpose, an El Niño (La Niña) event was defined to have occurred if the October–February mean Niño-3.4 index was greater than (lesser than) 1.0°C relative to its 1971–2000 time mean. It is during these months that the Niño-3.4 index tends to reach its peak value.3 The Niño-3.4 index values are obtained from the NOAA/Climate Prediction Center (www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

In Figure 6a, the May El Niño composite shows a zonal band of anomalous westerlies across the North Pacific between 45° and 55°N that is very similar to the May zonal band in Figure 5b that is based on the 12 years that had at least one major Asian bird fallout at Attu. In contrast, the May La Niña composite in Figure 6b shows anomalous wind vectors that are mostly confined to the Gulf of Alaska, far to the east of Attu. These results suggest that winds associated with El Niño, but not La Niña, are positioned to impact storm tracks in the Attu area.

Further evidence of the physical linkage between the September Niño-3 signal and the fallout of Asian species at Attu can be found in the temporal evolution of anomalous tropical Pacific sea surface temperatures during El Niño events. For both El Niño and La Niña events, Larkin and Harrison (Larkin and Harrison 2002) describe the following picture. At the beginning of an ENSO event, the earliest SST anomaly occurs in the eastern tropical Pacific during the summer. By the time that the El Niño and La Niña events reach their peak, during late fall, the SST anomalies have expanded westward, encompassing both the central and eastern tropical Pacific. As the El Niño and La Niña events decay during the spring of the next year, the SST

---

3 The Niño-3.4 index, rather than the Niño-3 index, was used here because of the nature of the time evolution of SST anomalies during El Niño and La Niña events. The first SST anomalies appear in the eastern tropical Pacific during the summer and early fall, that is, where the Niño-3 index is largest. Therefore, during summer and early fall, the Niño-3 index is a better index at indicating the presence of an El Niño or La Niña event. By late fall and into the winter, the SST anomalies have expanded westward. At these times, the Niño-3 and Niño-3.4 indices are about equal at indicating the occurrence of an El Niño or La Niña event. Then, during the spring, the SST anomalies in the eastern tropical Pacific have declined substantially, leaving only SST anomalies in the central tropical Pacific. Therefore, during the spring, the Niño-3.4 index is better at indicating the occurrence of the El Niño or La Niña event. Since the focus here is on Attu bird fallouts during the spring, it is best to use the Niño-3.4 index for identifying El Niño and La Niña events. However, from the perspective of long time predictability, it is best to look at the Niño-3 index, since the first SST anomalies appear in the eastern tropical Pacific. Therefore, a switch from the Niño-3 to Niño-3.4 index makes sense based on the time evolution of the SST anomalies for El Niño and La Niña.
Figure 6. (a) May composite anomalous wind vectors for the 10 El Niño years. (b) As in (a), but for the 9 La Niña years.
anomalies in the both the eastern and central tropical Pacific weaken. However, since the weakening of the eastern tropical Pacific SST anomaly is more rapid, the spring SST pattern primarily consists of a moderate SST anomaly confined mostly to the central tropical Pacific. The absence of an eastern tropical Pacific SST anomaly is reflected in the weak correlation between the Niño-3 and the average AIPD indices during the spring. These remnants of the ENSO events in the central tropical Pacific are indicated by spring (averaged over the months of April, May, and June) Niño-3.4 index values of 0.42 for El Niño and −0.77 for La Niña events.

The above sequence of events suggest that the reason why the Niño-3 and average AIPD indices correlate so strongly in the fall and winter but considerably less so in the spring is because SSTs and Niño-3 index values are on the rise in the fall and winter but trail off significantly in the spring as the eastern tropical Pacific SST significantly weakens. On the other hand, because moderate SST anomalies remain in the central tropical Pacific throughout the spring, ENSO can still impact the midlatitude wind field during May. As the midlatitude atmosphere typically takes about 2 weeks to respond to tropical SST anomalies (Barsugli et al. 1999; Feldstein 2000), our results suggest that during El Niño events it is the central tropical Pacific SST anomalies in May that drive the Pacific jet poleward, which in turn redirects more storm systems toward Attu.

4. The powerful El Niño event of 1997/98 and development of the reverse trajectory model

By most measures, the El Niño episode that began in the latter half of 1997 and carried over to mid-1998 was the most powerful event of the last century. Consistent with our findings of the previous section, the 1998 El Niño event coincided with a series of major storms that buffeted Attu during May and June of 1998. Unquestionably, the most massive of these were two closely linked storms that hit the island over the 5-day period between 15 and 19 May. The first storm originated 696 km east-northeast of Tokyo, Japan, and rapidly intensified as it moved northeast toward Attu. The second storm originated just west of the central Kamchatka Peninsula in the Sea of Okhotsk and moved southeast around the rugged Kamchatka mountains to the Pacific and then northeast toward Attu. The next day the two storms merged into a megastorm near the Pribilof Islands. During the three days between 15 and 17 May, the average 850-hPa zonal winds from the Asian mainland to Attu and farther eastward were as much as 3 times the 1980–2004 average, with some winds in the area reaching as high as 60 m s⁻¹.

These two storms coincided with 1-day counts for a number of Asian species that were far beyond any ever recorded on Attu Island either before or since. The counts of five species in particular stood out. On 17 May, a total of 180 eyebrowed thrushes, 225 olive-backed pipits, 193 rustic buntings, and 366 bramblings were found, and on the next day 700 wood sandpipers were counted.

To address the question of how these large numbers arrived on Attu, we developed a reverse trajectory model.⁴ The model is based upon the supposition that any displacement a bird undergoes in a given period results from the sum of the wind velocity and the bird’s velocity relative to that of the surrounding air during

---

⁴ The concept of the reverse trajectory model had some interesting parallels with earlier work described by Tove (Tove 1988).
the period. Given the arrival time at the final destination, the model calculates the previous displacement of the bird by evaluating the velocities of both the wind and the bird relative to the surrounding air during the preceding time. To evaluate the motion of the air, we employ the meteorological data made available in the NCEP–NCAR reanalysis (hereafter, simply, the reanalysis) that provides global coverage of the atmospheric data at a 2.5° interval in both latitude and longitude on each of the 17 pressure levels between 1000 and 100 hPa, 4 times daily. The choice was made based on the comprehensiveness, accuracy, uniformity of coverage, and accessibility of the reanalysis data. In view of the resolution of the reanalysis data, the reverse trajectory model employs bilinear interpolation in space and linear interpolation in time and uses a 1-h time step in retrogression.

It is in defining the bird’s motion relative to the surrounding air that the model encounters the toughest challenge. Although much has been studied and written on bird migration, relatively little is available for answering such specific questions as the speed and altitude of birds (Alerstam 1993). Having designed the model to separate the two motions, we are able to run the model with different choices of values for these attributes and different specifications on how birds respond to the surrounding air and compare the resulting simulations for their plausibility. For example, a typical specification for a model run might be as follows: 1) The breeding ground of the bird is located at 60°N, 120°E; 2) the bird flies on the 850-hPa isobaric surface; 3) when there is no wind, the bird flies along the great circle at a speed of 10 m s\(^{-1}\) (will be later referred to as “active navigation”); 4) when the wind speed is less than 10 m s\(^{-1}\), the bird flies toward the breeding ground on the great circle at a speed of 8 m s\(^{-1}\) if the wind component along the great circle is directed toward the breeding ground but at a flight speed of 11 m s\(^{-1}\) if the wind component along the great circle is away from the breeding ground (“active navigation” mode); 5) when the wind speed is 10 m s\(^{-1}\) or more, the bird flies in the same direction as the wind with a speed of 5 m s\(^{-1}\) (later referred to as “passive downwind drift”); and 6) the bird arrives at Attu on one of the four times when the reanalysis data are available.\(^5\)

We believe that many of the simulated trajectories produced with the model are sufficiently realistic to be presented in this report. At the same time, given the uncertainties in the threshold values, it is probably best to regard the model as a tool for exploring the possible range of trajectories that the birds may have taken to reach Attu. In the case of the massive fallout of Asian species at Attu on 17–18 May 1998, we ran several sets of sensitivity analyses to determine how differing assumptions about the flying speed, altitude, and navigation attributes affected trajectory outcomes. Without question, the two most intriguing of these analyses involved 1) wind speed threshold values that triggered switches between active navigation and passive downwind drift and 2) varying assumptions regarding flight elevations.

The model provides for two basic modes of migration flight: 1) active navigation and 2) passive downwind drift. During the active navigation mode the model bird is assumed to fly at its normal average rate of speed in the direction of its breeding

\(^5\) The provisions in 4) and 5) are based on the supposition that the bird is innately responsive only to the magnitude of the wind speed in the direction of the breeding ground along the great circle. The bird thus flies with less speed in a tailwind situation and saves energy but with more flight speed in a headwind situation in order not to be overwhelmed by the headwind. When the wind does become too strong, the bird ceases to navigate and drifts passively with the wind.
grounds. In the passive downwind drift mode the model bird, when faced with excessive winds, is assumed to seek safety either by landing or, if over water, by drifting with the prevailing wind while maintaining sufficient flight speed to stay aloft until an acceptable landing place is found. The triggering point at which a bird moves back and forth between these two modes is what we refer to as the wind speed threshold value. A 10 m s\(^{-1}\) threshold value means that the bird is assumed to remain in active navigation mode up to a wind speed of 10 m s\(^{-1}\) and above that to shift to the passive downwind drift mode.

The alternate wind speed threshold values used for sensitivity analysis purposes were 5, 10, 15, and 20 m s\(^{-1}\). In both the 5 and 10 m s\(^{-1}\) runs, the prevailing winds overwhelmed the model bird’s ability to fly toward its breeding grounds and the bird used the “downwind drift” mode throughout its journey simply to survive. As a result, the trajectories in both cases were essentially downwind (west-southwest to east-northeast) from the Kurils to Attu. At the other end of the speed spectrum, the 15 and 20 m s\(^{-1}\) wind speed thresholds kept the model birds in active navigation mode for a substantially longer period of time and as a result the reverse trajectory model projected that it would have been necessary for the 15 and 20 m s\(^{-1}\) model birds to have started their flight some 3200 km east of Formosa in the Pacific Ocean and flown north in order to reach Attu on 17 May 1998 when the birds were observed.\(^6\)

Taken together, the four wind speed threshold sensitivity analyses demonstrate that 1) the active navigation mode is not a viable option in a period of high winds and 2) downwind drift is likely an important and frequently used alternative in high wind situations.

Our second set of sensitivity analyses focused on alternate assumptions about the elevations at which the birds flew while flying at speeds of 5 or 10 m s\(^{-1}\). Four elevation possibilities were considered: 600, 700, 850, and 1000 hPa. Results of these analyses showed that on the 2 days in question (17 and 18 May) wind speeds and directions were very similar at the 600-, 700-, and 850-hPa levels in the area between the west coast of Asia and Attu. At 600–850 (1000) hPa, wind speeds averaged 16 (12) m s\(^{-1}\). More importantly from the standpoint of trajectory location, the winds at 850 hPa were out of the west-southwest and as a result the birds would have had to originate their flights in the central and northern Kuril Islands in order to reach Attu when they did. If, on the other hand, the birds flew at 1000 hPa (sea level), the west-northwest–east-southeast winds prevailing at that level would have required that the trajectories begin along the east coast of the south-central Kamchatka Peninsula.

The model calculated that the total in-flight distances along the various Kurils–Attu trajectories ranged from 1372 to 1984 km, while the total in-flight distances from Kamchatka to Attu were considerably shorter at 931 to 952 km. Great circle distances were also calculated between the origin and destination points of each trajectory. These great circle distances ranged from 1294 to 1848 km for the

\[^6\] The south–north trajectory projection is perhaps best understood by first considering what might happen to a model bird in the last hour before it lands at Attu. Assume that 1) strong west-southwest winds are pushing the model bird east-northeast at 16 m s\(^{-1}\) and 2) the model bird has a wind speed threshold of 20 m s\(^{-1}\) and is actively navigating northwest toward its breeding grounds in Siberia at its normal flying speed of 10 m s\(^{-1}\). The combined effect of the wind and the bird’s navigation efforts is to produce a northerly trajectory. Accordingly, the model determines that the bird must be south of Attu at the beginning of the last hour in order to reach the island at the end of the hour. And so on for earlier hours.
Kurils–Attu trajectories and 811 to 875 km in the case of the Kamchatka–Attu trajectories.

Total simulated flight times from the Kurils to Attu ranged from 11 to 24 h, and from Kamchatka to Attu, 7 to 12 h. The differences in flight times were largely due to both the relative lengths of the trajectories and differing assumptions about the flying speed (10 versus 20 m s\(^{-1}\)) at which the bird flew.

Do the shorter flight times and distances from Kamchatka to Attu indicate that most Asian species at Attu likely came via the Kamchatka Peninsula? Not necessarily. Consider the eyebrowed thrush as an example. The principal breeding grounds of this thrush are northwest of the Sea of Okhotsk with a small, sparse breeding population on Kamchatka. According to Massey et al. (1986), the eyebrowed thrush is “rare in spring” in Japan. So where did the 180 thrushes come from? Is it likely, for example, that they flew across the Sea of Okhotsk and over the rugged mountain range that runs down the spine of Kamchatka? Or is it more likely that the thrushes were swept up earlier by the same very powerful southwest winds on the west side of the Seas of Japan and/or Okhotsk and/or Hokkaido or Sakhalin Islands as they migrated northward along their accustomed route on the west side of the two seas?

In search of answers to these questions, the model was used to extend the previous trajectories farther westward to the west side of the Seas of Japan and Okhotsk. The 850-hPa trajectories that passed over the Kurils, when modeled westward, passed over southern Sakhalin Island and the Amur River Delta. The length of the trajectories from Sakhalin to Attu ranged from 3522 to 3757 km with estimated flight times to Attu ranging from 29 to 41 h. The 1000-hPa trajectories that passed over the east coast of south-central Kamchatka, when modeled westward, passed over the Kamchatka mountain range and went north of the Sea of Okhotsk into central Siberia. The total trajectory distance from 143°E longitude to Attu ranged from 2874 to 3171 km with total flight times ranging from 25 to 38 h. These nonstop flight times would appear to be well within the physical capabilities of many avian migrants, particularly if given the downwind drift option.

While the results of our model runs do not provide precise answers as to where and when the thrushes or other species had been, we believe that they do provide likely routes and timing for their journey, when viewed collectively within the bounds of variation in the parameters of the model.

5. Concluding remarks

Some may well argue that the few hundred additional Asian birds observed at Attu in El Niño years were essentially isolated events on an isolated island and of little or no consequence in the broader scheme of things. The point easily missed is that the Attu research was not just about the fallout of Asian species at Attu but was focused on how a global and enormously complex climate phenomenon like El Niño can drastically affect bird populations and movements across very large geographic areas. The Attu database happened to provide an appropriate vehicle for gauging and evaluating those impacts.

For this study, we have been following the assumption of constancy. That is, we have assumed that the year-to-year fluctuation in the Attu bird count is due to climate variability operating upon a constant total population of birds, rather than
interannual variability in the total population of birds migrating northward along the East Asian flyway. Notwithstanding this limitation, this issue of constancy can be partially addressed by examining whether the linear trend in the Attu bird count is statistically significant. Such a calculation is based upon the assumption that any long-term trend in the Attu bird count is reflected in the total bird population. When the AIPD is linearly correlated with the year, a value of 0.21 is found, which is well below the $p < 0.05$ threshold for a zero null hypothesis. We also examined the sensitivity of the linear trend to the AIPD value for 1998, the year with the strongest El Niño of the twentieth century, and an Attu bird count 6 times larger than that of the year with the second highest count. For this set of calculations, the 1998 AIPD value was systematically increased in increments of 55.0, the second highest AIPD value. For AIPD values of $1.0 \times 55.0$, $1.5 \times 55.0$, $2.0 \times 55.0$, etc., the resulting correlations were $-0.30$, $-0.15$, $-0.04$, etc. None of these correlations exceed the $p < 0.05$ threshold. These findings suggest that for the 20-yr time period of our study there is no statistically significant linear trend in the total bird population.

It is also important to keep in mind that those few hundred additional sightings in El Niño years were undoubtedly only a very small sample of the numbers of birds affected by the El Niño episodes in question. As noted earlier, the Attu observational area was approximately 64 km$^2$ or some 16% of Attu’s approximately 410 km$^2$ total. How many more Asian birds landed in these more remote areas or on adjacent islands? And potentially far more significant, how many more birds were swept up in the broad swath of El Niño–amplified winds and storms that cut through the Seas of Japan and Okhotsk, only to die at sea while looking for landfall somewhere in the 1.4 million km$^2$ area between the Kurils and the Aleutians? However estimated, the numbers of birds displaced by El Niño were likely very large indeed.

The methodology of this study is certainly applicable to other locations. Over the past 5 years we have explored the extent to which the NAO may impact the wintering populations of various bird species in New England as reflected in a 30-yr sample of the Concord (Massachusetts) Christmas bird count (CCC). As at Attu, the CCC avian–climate relationships are complex, but the large correlations (in some cases higher than at Attu) for some individual species clearly indicate that the NAO has a substantial impact, direct and indirect, on the population levels of wintering species in the area. Interestingly, the largest correlations do not involve December and January climate variables but rather climate variables from the prior breeding season or fall migration period. The next phases in the analysis will be to define the role that climate plays and the specific cause-and-effect mechanisms that are likely at work. And here as at Attu, the key to success will lie in a strong interdisciplinary effort by climatologists, ornithologists, and birders committed to a common set of goals.

Acknowledgments. We thank Lawrence Balch for his years of effort in initiating and leading the many birding trips to Attu. Without his effort, and that of numerous other dedicated birders, the Asian species observational data for this study would not have been available for this study. We would also like to thank NOAA/ESRL, Physical Sciences Division, Boulder, Colorado, for providing the climate mapping capabilities and data through their Web site at http://www.cdc.noaa.gov/ that made this study possible. Also we
extend our thanks to John Heckscher of the U.S. Air Force Research Laboratory for his assistance in downloading and adapting the NASA 1980–91 satellite wind field data for our study. And finally, we thank John and Karen Shrader, Ted Floyd, Paul Lehman, and Wayne Petersen who devoted many hours of their valuable time and experience.

References